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VAM2D – Variably Saturated Analysis Model in Two Dimensions

Version 5.0 With Hysteresis and Chained Decay Transport

Documentation and User's Guide

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ABSTRACT

This report documents a two-dimensional finite element model, VAM2D, developed to simulate water flow and solute transport in variably saturated porous media. Both flow and transport simulation can be handled concurrently or sequentially. The formulation of the governing equations and the numerical procedures used in the code are presented. The flow equation is approximated using the Galerkin finite element method. Nonlinear soil moisture characteristics and atmospheric boundary conditions (e.g., infiltration and evaporation), are treated using Picard and Newton-Raphson iterations. Hysteresis effects and anisotropy in unsaturated hydraulic conductivity can be taken into account if needed. The contaminant transport simulation can account for advection, hydrodynamic dispersion, linear equilibrium sorption, and first-order degradation. Transport of a single component or a multi-component decay chain can be handled. The transport equation is approximated using an upstream weighted residual method. Several test problems are presented to verify the code and demonstrate its utility. These problems range from simple one-dimensional to complex two-dimensional and axisymmetric problems.

This document has been produced as a user's manual. It contains detailed information on the code structure along with instructions for input data preparation and sample input and printed output for selected test problems. Also included are instructions for job set up and restarting procedures.

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EXECUTIVE SUMMARY

Proper disposal of low-level radioactive waste (LLW) in the United States has been a problem with increasingly difficult technical and social challenges for several years. Under the 1980 Low-Level Waste Policy Act and Amendments, individual states, as well as groups of states, have been seeking to establish new disposal sites. Any new site to be established must meet applicable federal and state regulatory criteria to become licensed, such as 10 CFR Part 61 under the authority of Nuclear Regulatory Commission.

10 CFR Part 61.5 contains criteria covering many technical requirements for low-level waste siting. The first and most prominent hydrogeologic criterion states "the disposal site shall be capable of being characterized, <u>modeled</u>, analyzed, and monitored." The regulations also indicate that disposal zones should be well above the water-table fluctuation zone, unless very restrictive conditions are met which would allow disposal below the water table. One of the principal reasons that modeling is required, is to demonstrate that radionuclide migration away from the disposed waste, either in liquid or gaseous state, will meet regulatory concentration limits at the boundary of the site or points of exposure.

Current regulations require site performance criteria to be satisfied for a period of at least 500 years. Most operatinging and planned LLW disposal facilities are situated in the unsaturated zone above the water table. Problems with existing LLW disposal facilities have often been associated with unfavorable hydrologic conditions at the site (Robertson, 1984). Consequently, a subsurface flow and radionuclide transport model, capable of simulating a wide range of conditions, is an essential tool for performance assessment of a planned LLW facility.

Several states (such as Pennsylvania, New York, Illinois, California, Texas, and North Carolina) recently initiated programs to select, characterize, license, and operate new disposal sites. Other state and federal agencies will probably begin seeking additional sites within the next few years. Although a variety of disposal methods are being considered, most are focused on disposal above the water table. Regardless of the location or disposal method chosen, most new sites will require modeling of water flow and solute transport through the unsaturated zone to the water table. However, our ability to model these processes in most environments is limited by capabilities of existing models. Existing models such as UNSAT2, TRACER3D, TRUST, SUTRA, TOUGH, FEMWATER/FEMWASTE, GS2/GS3, and SATURN all have rather narrow limits in numerical stability, robustness, user-friendliness, or in other characteristics which inhibit their applicability to many real-world conditions existent at potential LLW sites currently under consideration. Some of the conditions which have previously been unfeasible or extremely difficult to model include:

- fully three-dimensional heterogeneous flow and transport with highly variable hydraulic properties;
- strong hysteretic and/or anisotropic conditions;
- nonlinear sorption and multi-species chain decay;
- highly variable transient moisture conditions, ranging from extremely dry to very wet and/or highly heterogeneous hydraulic properties;
- dual porosity fractured/porous media; and
- unusual boundary conditions and disposal concepts such as engineered two- and three-dimensional wicking schemes, capillary barrier trench cap designs, deep-boring emplacement, and intermediate depth burial.

Conditions likely to be encountered at LLW disposal sites include dry conditions with very low rates of liquid movement. Especially for the shallow land burial scenario, evapotranspiration losses will have a large effect on the site hydrology. Under arid conditions, this process may represent a very large portion of the total water balance and must be adequately accounted for in a model. In addition to passive movement with the water phase, the migration of radionuclides will be affected by sorption reactions with the solid phase matrix and chained decay reactions. These processes should also be accounted for in a model.

There is a clear regulatory need for a more suitable low-level waste site hydrogeologic model, as well as a broader technical need in nuclear and hazardous waste management and in general hydrology. The VAM2D model described in this report is intended to be useful in the selection, characterization, and design stages of a waste disposal facility, for instance by allowing evaluation of the effectiveness of different cap designs. The model will further enable more accurate prediction of repository performance and compliance assessment. The model advances the state-of-the-art in unsaturated zone modeling by incorporating features that are not available in current models.

Like all other modeling codes, the VAM2D model described herein has its limitations, such as two dimensionality. This code represents only one stage of an evolving modeling program which is eventually intended to accommodate three-dimensional flow, vapor phase, and energy transport, fractures and macro pores, and other enhancements.

The special capabilities and advantages of the version presented in this document include the following:

- accounts for moisture uptake and retraction by plants in the root zone;
- simulates flow and transport in saturated as well as unsaturated zones;
- can solve flow and transport equations simultaneously or sequentially;
- accommodates a wide range of field conditions including highly non-linear moisture characteristics, anisotropy, heterogeneity, highly transient boundary conditions;
- can use highly efficient preconditioned conjugate gradient matrix solvers for problems with many nodes and unknowns and incorporate other numerical options and enhancements which increase code robustness and ability to correctly simulate a wide range of hydraulic conditions and transients;
- accounts for multiple-component and multiple-chain decay reactions and species;
- computes hysteretic effects on flow due to wetting and drying cycles;
- computes effects of variable anisotropic hydraulic conductivities on flow in stratified media;
- includes other, more standard features such as linear equilibrium sorption and dispersion; and
- interfaces with a PC-based, user-friendly pre-processor which greatly facilitates problem set-up, reduces data modification time and eliminates inadvertent input format errors.

The principal objective in developing this version of VAM2D was to create a very versatile code which can be reliably applied to a wide range of low-level radioactive waste site conditions (and related types of sites) that have hitherto been either unamenable to modeling or extremely difficult to model. A second objective was to develop a code that is relatively easy to use on microcomputers by a large number of potential users with appropriate technical background. Finally, it is intended that this code have wide spread usefulness in application to situations other than LLW sites (e.g., hazardous waste, mixed-waste, and municipal landfill and electric power generation waste sites).

PART I

THEORY, MATHEMATICAL MODEL, AND CODE DESIGN

1 INTRODUCTION

1.1 BACKGROUND AND PURPOSE OF THE CODE

VAM2D is a two-dimensional, finite element code developed to simulate moisture movement and solute transport in variably saturated porous media. The code is capable of simulating a wide range of conditions commonly encountered in the field. Simulations can be performed in a vertical cross-section, or an axisymmetric configuration. Both flow and transport simulations can be handled concurrently or sequentially. Material heterogeneities and anisotropy are handled by taking full advantage of the finite element approach. Efficient matrix computational and solution schemes are employed in conjunction with simple rectangular elements to analyze problems involving highly nonlinear soil moisture characteristics. Many types of boundary conditions can be accommodated: 1) water table conditions, 2) atmospheric conditions associated with seepage faces, evaporation and nonponding infiltration, 3) water uptake by plant roots, 4) vertical recharge of the water table, and 5) pumping and injection wells.

The model formulation used in VAM2D is a descendant of the formulation used in the SATURN code presented by Huyakorn, et al. (1984, 1985). HydroGeoLogic, Inc. has recently enhanced certain portions of the published algorithms and their coding to achieve greater flexibility, wider capability, and more robust numerical performances when dealing with some difficult cases. Where possible, the new VAM2D code has been rigorously checked against available analytical or semi-analytical solutions and similar numerical codes including UNSAT2, FEMWATER/FEMWASTE, SATURN, and VADOFT. A variety of field simulation problems described in the works of Huyakorn et al. (1984, 1985, 1987), Enfield et al. (1983), and Carsel et al. (1985) have been used to validate VAM2D and demonstrate is utility. Additional simulation problems are described in this report.

1.2 OVERVIEW OF CODE CAPABILITIES AND SALIENT FEATURES

Multidimensional modeling of water flow and waste migration in variably saturated subsurface systems can be a formidable task unless one is equipped with a proper code that accommodates various field conditions. Recognizing this point, VAM2D was developed to have not only essential modeling capabilities but also salient features that facilitate practical use. An overview of these aspects of the code is presented below.

1. VAM2D can perform transient analyses or single step steady-state analyses of both variably saturated water flow and solute transport problems. If the flow and transport problems are associated, a dual simulation can be made by solving the problems concurrently or sequentially in a single computer run.

2. The finite element formulation and nonlinear solution procedures in VAM2D are based on the state-of-the-art technology designed to accommodate a wide range of field conditions including highly nonlinear moisture characteristics, material heterogeneity and anisotropy, and rapidly fluctuating transient flow boundary conditions.

3. VAM2D uses highly efficient matrix computational and matrix solution techniques. The code is directly interfaceable with newly developed Preconditioned Conjugate Gradient matrix solvers designed to handle problems with large number of nodal unknowns (on the order of 1000 or more) efficiently. This feature makes the code attractive to use on a minicomputer or even a personal computer.

4. The flow simulator of VAM2D can handle various boundary conditions and physical processes including infiltration, evaporation, plant root uptake, well pumping and recharging, and varying water table conditions. Temporal variations of head and flux boundary conditions can be handled conveniently using either continuous piecewise linear representations or discontinuous (stepped) representations. Additionally, hysteretic moisture characteristics as well as variable anisotropy in the hydraulic conductivity of the unsaturated soil can also be accounted for if needed. Presently, the effects of these phenomena on moisture movement and solute transport in the field are not clearly understood. In view of this, the VAM2D code may be used as a modeling tool to supplement field investigation or other research study of complex flow and transport behavior in variably saturated media.

5. The transport simulator of VAM2D can handle both single-specie and chained decay transport problems. Its formulation is designed to have upstream weighting capability to circumvent numerical oscillations. The scheme can accommodate straight and branch chains as well as contaminant sources that exhibit chained decay reactions. Both pulse and step releases of contaminants from each source can be simulated. These capabilities make it advantageous to use VAM2D in the prediction of fate and transport of reactive chemicals and radioactive elements.

1.3 APPLICABILITY OF THE CODE

The VAM2D code has many practical applications. Typical examples include the following:

- Investigation of moisture movement and evapotranspiration in the unsaturated zone including plant water uptake in the root zone.

- Watershed studies - used to predict the response of unconfined watersheds to different schemes of drainage or to infiltration and evaporation. The code computes spatial and temporal variations in the pressure head, water saturation, and flow rate across specified flow boundaries.

- Assessment of well performance and pumping test analysis - used to analyze flow in the vicinity of pumped wells, to predict well performance, and to prepare type curves for evaluation of pumping test data.

- Mine dewatering investigations - used to predict the change in elevations of water table or phreatic surface in response to mine dewatering operations. These predictions can be obtained by performing areal or cross-sectional analyses of unconfined flow problems.

- Contaminant migration assessment - used to predict leakage rates and flow fields in unconfined aquifers underlying sewage ponds, surface impoundments, and landfills. VAM2D can simulate contaminant transport in variably or fully saturated porous media.

1.4 CODE USER REQUIREMENTS

In order to apply the VAM2D code effectively, the user will need:

- a thorough understanding of hydrogeological principles

- a basic understanding of finite element techniques

- an awareness of the code's capabilities and limitations

- familiarity with the editor, operating system, and file handling concepts of the computer system used.

It is also recommended that the user run some of the test problems provided to gain confidence and understanding in using the code.

1.5 COMPUTER EQUIPMENT REQUIREMENTS

VAM2D is written in ANSI Standard FORTRAN 77 and can be compiled on any standard micro, mini, or mainframe system. The source code was developed and tested on PRIME minicomputers using the FORTRAN 77 compiler developed by the University of Salford, United Kingdom. Installation of earlier versions of the code has also been made on VAX, micro-VAX and SUN computers with standard FORTRAN 77 compilers. With minor conversion (e.g., changing OPEN FILE statements), the source code can be made to compile and run on a PC 386 machine properly equipped with at least 2 megabytes of core memory, a protected mode FORTRAN 77 compiler, and a 80387 or Weitek math co-processor.

2 GOVERNING MATHEMATICAL MODELS

2.1 PROCESS AND GEOMETRY

VAM2D performs two-dimensional or axisymmetric finite element simulations of water flow and/or solute transport in variably saturated and fully saturated porous media. The code employs the state-of-the-art numerical technology to provide efficient steady-state and transient solutions of practical problems encountered in the investigation, mitigation and remediation of soil and groundwater contamination due to disposal of chemical and/or nuclear wastes. The steady-state analysis is performed by disregarding all storage terms of the governing equations thus avoiding the necessity of time marching. The transient analysis is performed by time marching until the prescribed number time steps is reached. For water flow simulations, VAM2D can handle a variety of boundary conditions including infiltration, evaporation, and plant root extraction. The code can also accommodate severely nonlinear soil moisture characteristics and hysteresis as well as anisotropy in variably saturated hydraulic conductivity. For solute transport simulations, VAM2D accounts for advection, hydrodynamic dispersion, equilibrium sorption, and first-order decay.

Transport of a single component or straight and branch decay chains of parent-daughter components can be handled.

The user is permitted to employ the following coordinates:

- two-dimensional Cartesian coordinates (x,y) with the (x-y) plane being vertical or horizontal
- axisymmetric cylindrical coordinates with (x,y) corresponding to radial and vertical coordinates (r,z)
- two-dimensional Cartesian coordinates (x,y) with the (x-y) plane being vertical but sloping.

2.2 GOVERNING AND SUPPLEMENTARY EQUATIONS FOR VARIABLY SATURATED FLOW

For variably saturated flow analysis, the VAM2D code uses pressure head as the dependent variable. The governing equation for water flow in a variably saturated soil is written as:

$$\frac{\partial}{\partial x_i}\left[\rho_w K_{ij} k_{rw}\left(\frac{\partial \psi}{\partial x_j} + e_j\right)\right] = \frac{\partial}{\partial t}\left(\rho_w \phi S_w\right) - \rho_w q \qquad (2.1)$$

where ρ_w is the density of water, ψ is the pressure head, K_{ij} is the saturated hydraulic conductivity tensor, k_{rw} is the relative permeability with respect to the water phase, x_i (i = 1, 2) are spatial coordinates, t is time, e_j is the unit vector assumed to be vertically upward, S_w is water phase saturation, ϕ is the effective porosity, and q is the volumetric flow rate via sources (or sinks) per unit volume of the porous medium.

For a slightly compressible fluid, equation (2.1) can be written in the form

$$\frac{\partial}{\partial x_i}\left[K_{ij} k_{rw}\left(\frac{\partial \psi}{\partial x_j} + e_j\right)\right] = \left(S_w S_s + \phi \frac{dS_w}{d\psi}\right)\frac{\partial \psi}{\partial t} - q \qquad (2.2)$$

or

$$\frac{\partial}{\partial x_i}\left[K_{ij} k_{rw}\left(\frac{\partial \psi}{\partial x_j} + e_j\right)\right] = \eta \frac{\partial \psi}{\partial t} - q \qquad (2.3)$$

where η is a coefficient defined as

$$\eta = S_w S_s + \phi \frac{dS_w}{d\psi} \qquad (2.4)$$

The coefficient S_s in equation (2.4) is known as specific storage and is defined as $S_s = \rho_w g(\phi\beta+\alpha)$, where g is the gravitational constant and α and β are coefficients of compressibility of the porous medium and water, respectively. The off-diagonal components of the saturated conductivity tensor, $K_{12} = K_{21}$, will be zero if the coordinate system coincides with the principal axes of anisotropy of the hydraulic conductivity. An example is the x_i-direction parallel to stratification and x_2 direction normal to stratification. Otherwise, these off-diagonal components will be non-zero.

The initial and boundary conditions of the variably saturated flow problem are

$$\psi(x_i, 0) = \psi_o(x_i) \tag{2.5}$$

$$\psi(x_i, t) = \tilde{\psi} \text{ on } B_1 \tag{2.6}$$

and

$$V_i n_i = -V_n \text{ on } B_2 \tag{2.7}$$

where ψ_o is the initial head value, B_1 is the portion of the flow boundary where ψ is prescribed as $\tilde{\psi}$, V_i is the Darcy velocity vector, B_2 is the portion of the flow boundary where the outward normal velocity is prescribed as $-V_n$, and n_i is the outward unit normal vector.

In order to solve the variably saturated flow problem, it is also necessary to specify the relationships of relative permeability versus water phase saturation, and pressure head versus water phase saturation. Two alternative function expressions are used to describe the relationship of relative permeability versus water saturation. These functions are given by (Brooks and Corey, 1966; van Genuchten, 1976):

$$k_{rw} = S_e^n \tag{2.8a}$$

and

$$k_{rw} = S_e^{1/2} \left[1 - (1 - S_e^{1/\gamma})^{\gamma}\right]^2 \tag{2.8b}$$

where n and γ are empirical parameters and S_e is the effective water saturation defined as $S_e = (S_w - S_{wr})/(1 - S_{wr})$ with S_{wr} being referred to as the residual water saturation.

The relationship of pressure head versus water saturation is described by the following function (van Genuchten, 1976; Mualem, 1976):

$$\frac{S_w - S_{wr}}{1 - S_{wr}} = \begin{cases} \dfrac{1}{[1 + (\alpha|\psi-\psi_a|)^{\beta}]^{\gamma}} & \text{for } \psi < \psi_a \\ 1 & \text{for } \psi \geq \psi_a \end{cases} \qquad (2.9)$$

where α and β are empirical parameters, ψ_a is the air entry pressure head value, and S_{wr} is the residual water phase saturation. The parameters β and γ are usually related by $\gamma = 1-1/\beta$.

Equation (2.3) is solved numerically using the Galerkin finite element method subject to the initial and boundary conditions given in (2.5) through (2.7). After the distributions of ψ and S_w have been determined, Darcy velocity components are calculated from

$$V_i = -K_{ij}k_{rw} \left(\frac{\partial\psi}{\partial x_j} + e_j\right) \qquad (2.10)$$

2.3 DESCRIPTION OF HYSTERESIS AND UNSATURATED ANISOTROPY

Although generally ignored in variably saturated simulation models, the saturation-pressure head relation of soils exhibits hysteresis. At a given pressure head, saturation will be higher when the soil is draining from saturation than it is when the soil is rewetting. As a consequence, hysteresis may have a significant effect on flow as well as contaminant transport in the unsaturated zone when the soil is alternately wetting and draining. An example of such a situation is a waste disposal bed which receives waste water at intervals in time.

Because of hysteresis, the $S_w(\psi)$ relation cannot be described by a single curve. Instead, a family of curves is required, bounded by a main drying curve and main wetting curve. The actual saturation at any point in the soil during unsaturated flow is a function, not only of pressure head, but also of the entire wetting-drying history of the soil. The approach used in VAM2D to simulate hysteresis is based on the use of Eq. (2.9) to describe the $S_w(\psi)$ relation, but modifying the equation to allow for different wetting and drying curves. This is achieved by retaining the form of (2.9) for both wetting and drying $S_w(\psi)$ curves but assigning different values of the parameters α, β and γ to wetting versus drying curves. For a hysteretic simulation, the VAM2D code computes the appropriate $S_w(\psi)$ relation for all intermediate scanning curves from the specified parameters for the two boundary curves using the procedure developed by Kool and Parker (1987) which is summarized in Section 3.2.5.

Many natural soils and other geologic media exhibit some degree of stratification leading to anisotropy of hydraulic conductivity, with higher conductivity in the direction parallel to stratification than perpendicular to stratification. This anisotropy is usually expressed as a ratio

$$r = \frac{K_{11}}{K_{22}} \tag{2.11}$$

where the index 1 indicates the direction parallel to stratification and 2 corresponds to the perpendicular direction. As expressed by (2.11), the anisotropy ratio is constant and independent of saturation. Recent research (e.g., Yeh et al., 1985; Mantoglou and Gelhar, 1987; McCord et al., 1988) suggests that in reality, the relative permeability k_{rw} may be subject to strong anisotropy. This research indicates that for unsaturated conditions, the hydraulic conductivity anisotropy is inversely related to the degree of water saturation. Assuming an exponential $k_{rw}(\psi)$ relation and using stochastic theory, Yeh et al. (1985) have developed the following expression for anisotropy as a function of pressure head for layered soils with a mean unit downward hydraulic gradient.

$$r(\psi) = \frac{(Kk_{rw})_{11}}{(Kk_{rw})_{22}} = \exp\left[\frac{\sigma_f^2 + \sigma_a^2\, \bar{\psi}^2}{1 + \mu\bar{a}\cos\omega}\right] \tag{2.12}$$

where σ_f^2 is the variance of the log saturated conductivity (lnK), a is the slope of the $\ln(k_{rw})$ versus ψ curve, $\bar{a}$ is the mean value of a, σ_a^2 is the variance of a, $\bar{\psi}$ is the mean value of ψ, μ is the spatial correlation length, and ω is the angle between the soil layer stratification and the horizontal.

Equation (2.12) indicates that anisotropy increases as an exponential function of the second power of pressure head. According to (2.11) anisotropy will also be more pronounced when the spatial variability of hydraulic conductivity increases and the correlation length, μ, decreases. The concept of variable anisotropy is based on mainly theoretical considerations and the predictive value of (2.12) has not been extensively tested. Nevertheless, McCord et al. (1988) have experimentally observed patterns of water and solute plume migration in a hill slope infiltration study that are similar to results obtained by computer simulation which incorporated (2.12) to model variable anisotropy. VAM2D has an option to use (2.12) to incorporate variable anisotropy in unsaturated flow modeling. Details of the implementation procedure are given in Section 3.2.5.

2.4 ATMOSPHERIC BOUNDARY CONDITIONS AND PLANT ROOT UPTAKE

Atmospheric boundaries may correspond to soil-air interfaces where evaporation or infiltration occurs. They may also correspond to seepage faces through which water seeps from the saturated portion of the flow domain.

Along infiltration and evaporation boundaries, conditions may change from the Dirichlet (prescribed head) to the Neuman (prescribed flux) type. In the absence of surface ponding, a numerical solution must be obtained by maximizing the absolute value of the flux (while maintaining the appropriate sign) subject to the following requirements (Hanks et al., 1969; Neuman et al., 1974):

$$|v_i \; n_i| \leq |E_s^*| \tag{2.13}$$

and

$$\psi_L \leq \psi \leq 0 \tag{2.14}$$

where E_s^* is the maximum potential surface flux under the prevailing atmospheric conditions, and ψ_L is the minimum pressure head allowed under the prevailing soil conditions.

For cases involving plant root uptake, the sink term in the governing equation (2.3) is represented by the following equation (Feddes et al., 1974):

$$q = K_{11} \; k_{rw} \; (\psi - \psi_r) b'$$

where ψ_r is the root pressure head, and b' is the root effectiveness function.

2.5 GOVERNING EQUATIONS AND INITIAL AND BOUNDARY CONDITIONS FOR THE SOLUTE TRANSPORT MODEL

2.5.1 Single-Specie Transport

The governing equation for two-dimensional transport of a non-conservative single component in a variably saturated soil takes the form

$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial c}{\partial x_j}\right) - \frac{\partial}{\partial x_i}(v_i c) = \frac{\partial}{\partial t}[\phi S_w c + \rho_s (1-\phi) c_s] - q c^* + \lambda [\phi S_w c + \rho_s (1-\phi) c_s] \qquad (2.15)$$

where D_{ij} is the apparent hydrodynamic dispersion tensor, c is solute concentration in the fluid, v_i is the Darcy velocity, ρ_s is the density of solid grains, c_s is the adsorbed concentration, λ is the first-order decay coefficient, and c^* is the solute concentration in the injected fluid.

Assuming that the relation between adsorbed and solution concentration is described by a linear equilibrium isotherm, Equation 2.15 can be expressed as

$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial c}{\partial x_j}\right) - \frac{\partial}{\partial x_i}(v_i c) = \frac{\partial}{\partial t}\left[\phi S_w \left(1 + \frac{\rho_s(1-\phi)k_d}{\phi S_w}\right) c\right] - qc^* + \lambda\phi S_w \left[1 + \frac{\rho_s(1-\phi)k_d}{\phi S_w}\right] c \qquad (2.16)$$

where k_d is the equilibrium constant.

Equation 2.16 reduces to

$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial c}{\partial x_j}\right) - \frac{\partial}{\partial x_i}(v_i c) = \frac{\partial}{\partial t}(\phi S_w R c) + \lambda\phi S_w R c - q c^* \qquad (2.17)$$

where R is the retardation factor defined as

$$R = 1 + \frac{\rho_s(1-\phi)k_d}{\phi S_w} = 1 + \frac{\rho_B k_d}{\phi S_w} \qquad (2.18)$$

with the bulk density ρ_B being defined as $(1-\phi)\rho_s$. Expanding the convective and mass accumulation terms of Equation 2.17 and using the continuity equation of fluid flow, one obtains

$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial c}{\partial x_j}\right) - v_i\frac{\partial c}{\partial x_i} = \phi S_w R\frac{\partial c}{\partial t} + c\frac{\partial}{\partial t}(\phi S_w) + c\frac{\partial}{\partial t}(\rho_B k_d)$$

$$- c\frac{\partial}{\partial t}(\phi S_w) + q(c-c^*) + \lambda\phi S_w Rc \qquad (2.19)$$

which, assuming that the time derivative of $(\rho_B k_d)$ is negligible, reduces to

$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial c}{\partial x_j}\right) - v_i\frac{\partial c}{\partial x_i} = \phi S_w R\left(\frac{\partial c}{\partial t} + \lambda c\right) + q(c-c^*) \qquad (2.20)$$

Note that the term $q(c-c^*)$ is zero in the case where q corresponds to the specific discharge of a pumped well, because $c \equiv c^*$. The hydrodynamic dispersion tensorial components are computed using the following constitutive relations (Scheidegger, 1961):

$$D_{11} = \frac{\alpha_L(V_1)^2}{|V|} + \frac{\alpha_T(V_2)^2}{|V|} + D^o \qquad (2.21a)$$

$$D_{22} = \frac{\alpha_L(V_2)^2}{|V|} + \frac{\alpha_T(V_1)^2}{|V|} + D^o \qquad (2.21b)$$

$$D_{12} = D_{21} = (\alpha_L-\alpha_T)\frac{V_1V_2}{|V|} \qquad (2.21c)$$

where α_L and α_T are longitudinal and transverse dispersivities, respectively, and D^o is the apparent molecular diffusion coefficient (D^o is defined as $\phi \tau D_m$, where D_m is the free-water molecular diffusion, and τ is tortuosity).

Equation 2.20 is the required form of the transport equation and will be approximated using the upstream weighted residual finite element technique of Huyakorn and Nilkuha (1979). The initial and boundary conditions associated with Equation 2.20 are as follows:

$$c(x_1, x_2, 0) = c_o \tag{2.22a}$$

$$c(x_1, x_2, t) = \tilde{c} \quad \text{on} \quad B_1' \tag{2.22b}$$

$$D_{ij} \frac{\partial c}{\partial x_j} n_i = q_c^D \quad \text{on} \quad B_2' \tag{2.22c}$$

$$D_{ij} \frac{\partial c}{\partial x_j} n_i - V_i n_i c = q_c^T \quad \text{on} \quad B_3' \tag{2.22d}$$

where B_1 is the portion of the boundary where concentration is prescribed as $\tilde{c}$, and B_2 and B_3 are portions of the boundary where the dispersive and the total solute mass fluxes are prescribed as q_c^D and q_c^T, respectively.

2.5.2 Chained-Decay Transport

Transport of a chain of decaying solute species is described by the following set of equations:

$$\frac{\partial}{\partial x_i} \left(D_{ij} \frac{\partial c_\ell}{\partial x_j}\right) - V_i \frac{\partial c_\ell}{\partial x_i} = \phi S_w R_\ell \left(\frac{\partial c_\ell}{\partial t} + \lambda_\ell c_\ell\right) + q(c_\ell - c_\ell^*) - \sum_{m=1}^{M} \phi S_w \xi_{\ell m} R_m \lambda_m c_m , \tag{2.23}$$

$$\ell = 1, \ldots, n_c$$

where subscript ℓ denotes component ℓ, n_c is the number of components in the chain, $\xi_{\ell m}$ is the mass fraction of (parent) components m transforming to (daughter) component ℓ, and M is the number of parents transforming to ℓ.

For radioactive decay, λ_ℓ is related to the half-life by the following equation:

$$\lambda_\ell = \frac{\ln 2}{t_{\frac{1}{2},\ell}} \tag{2.24}$$

Initial and boundary conditions associated with (2.23) may be expressed as

$$c_\ell(x_1, x_2, 0) = c_{\ell o} \tag{2.25}$$

$$c_\ell(x_1, x_2, t) = \tilde{c}_\ell \quad \text{on} \quad B_1' \tag{2.26a}$$

$$D_{ij} \frac{\partial c_\ell}{\partial x_j} n_i = q_{c\ell}^D \quad \text{on} \quad B_2' \tag{2.26b}$$

$$D_{ij} \frac{\partial c_\ell}{\partial x_j} n_i - V_i n_i c_\ell = q_{c\ell}^T \quad \text{on} \quad B_3' \tag{2.26c}$$

For a decaying source, the prescribed concentration $\tilde{c}_\ell$ (or prescribed contaminant flux $q_{c\ell}^T$) is time-dependent and governed by Bateman's equation:

$$\frac{d\tilde{c}_\ell}{dt} = -\lambda_\ell c_\ell + \sum_{m=1}^{M} \xi_{\ell m} \lambda_m \tilde{c}_m \tag{2.27}$$

subject to

$$\tilde{c}_\ell\ (t=0) = \tilde{c}_\ell^o \tag{2.28}$$

For a n_c-member chain, the general solution of (2.27) subject to (2.28) may be written in the form:

$$\tilde{c}_\ell = \tilde{c}^o_\ell e^{-\lambda_\ell t} + \xi_{\ell,\ell-1} \lambda_{\ell-1} \tilde{c}^o_{\ell-1} \sum_{m=\ell-1}^{\ell} \frac{e^{-\lambda_m t}}{\prod_{\substack{k=\ell-1 \\ k\neq m}}^{\ell} (\lambda_k-\lambda_m)}$$

$$+ \dots + \xi_{\ell,\ell-1}\lambda_{\ell-1} \xi_{\ell-1,\ell-2} \cdots \xi_{21}\lambda_1\tilde{c}^o_1$$

$$\cdot \sum_{m=1}^{\ell} \frac{e^{-\lambda_m t}}{\prod_{\substack{k=1 \\ k\neq m}}^{\ell} (\lambda_k-\lambda_m)} \qquad (2.29)$$

where ℓ ranges from 1 to n_c, and $\tilde{c}^o_\ell$ ($\ell=1,\dots,n_c$) are initial source concentrations of components 1 through n_c. Note that λ_ℓ ($\ell = 1,\dots,n_c$) are source decay coefficients. In the VAM2D code these source decay coefficients may be assumed to be the same as or different from the decay coefficients in the governing advective-dispersive transport equations (2.23).

Equation (2.29) assumes a step release of dissolved contaminants at the source (i.e., all of the waste material begins to dissolve at time t=0 and distribution is allowed to proceed continuously at a uniform rate). For the case of pulse or band release of leach duration T, the right hand side of (2.29) must be modified by multiplying by the following factor:

$$f = [U(t) - U(t-T)] \qquad (2.30)$$

where U(t-T) is the Heaviside unit function defined as

$$U(t-T) = \begin{cases} 1, & t \geq T \\ 0, & t < T \end{cases} \qquad (2.31)$$

2.6 ASSUMPTIONS

VAM2D (Version 5.0) contains both flow and solute transport models. Major assumptions of the flow model are as follows:

- Water is the only flowing fluid phase (i.e., the air phase is assumed to be static).
- Flow of the fluid phase is considered isothermal and governed by Darcy's law.
- The fluid considered is slightly compressible and homogeneous.
- The soil or rock medium may be represented by a single continuum porous medium.

Major assumptions of the solute transport model are as follows:

- Transport in the porous medium system is governed by Fick's law. The hydrodynamic dispersion coefficient is defined as the sum of the coefficients of mechanical dispersion and molecular diffusion. The medium dispersivity is assumed to correspond to that of an isotropic porous medium and hence related to two constants, α_L and α_T, which are the longitudinal and transverse dispersivities.
- Adsorption and decay of the solute may be described by a linear equilibrium isotherm and a first order decay constant.
- Chained decay reactions are regarded as irreversible.

2.7 LIMITATIONS

- In performing a variably saturated flow analysis, the code handles only single-phase flow (i.e., water) and ignores the flow of a second phase (i.e., air or other nonaqueous phase) which, in some instances, can be significant.
- Flow and transport in fractures are not taken into account.
- The code does not take into account kinetic sorption effects and/or reversible chemical reactions which, in some instances, can be important.

2.8 INPUT DATA

Input data for variably saturated flow simulations include the following:

(1) System Geometry

- Horizontal and vertical dimensions including layering and other heterogeneities (L)

(2) Porous Medium Properties

- Horizontal component of saturated hydraulic conductivity, K_h (LT^{-1})
- Vertical component of saturated hydraulic conductivity, K_v (LT^{-1})
- Cross component of saturated hydraulic conductivity, K_{hv}, if the coordinate system does not coincide with the principal axes of anisotropy (LT^{-1})
- Specific storage, S_s (L^{-1})
- Saturated water content, θ_s

(3) Constitutive Relationships for Variably Saturated Flow

- Parameter n of the Brooks-Corey relation (2.8a).
- Air-entry pressure head, ψ_a (L)
- Parameters α, β and γ of the van Genuchten relations (2.8b) and (2.9) (α has dimensions of L^{-1}).
- Parameters describing anisotropy of relative conductivity.

(4) Initial and Boundary Conditions

- Initial distribution of pressure head, ψ_o (L)
- Prescribed values of pressure head, $\tilde{\psi}$ (L)
- Prescribed values of nodal fluid flux, Q (Q has dimensions of L^2T^{-1} for a cross-sectional simulation and L^3T^{-1} for an axisymmetric simulation).

Input data for the transport model include the following:

(1) System Geometry

- Horizontal and vertical dimensions including layering and other heterogeneities (L)

(2) Porous Medium Properties

- Longitudinal dispersivity, α_L (L)
- Transverse dispersivity, α_T (L)
- Apparent molecular diffusion coefficient, D^o (L^2T^{-1})
- Effective porosity, ϕ
- Bulk density, ρ_B (ML^{-3})

(3) Properties of Solute Species

- Decay coefficient, λ (T^{-1})
- Distribution coefficient, k_d (L^3M^{-1})

(4) Darcy velocity components of the fluid phase considered, v_1 and v_2 (LT^{-1})

(5) Saturation of the fluid phase considered, S_w

(6) Initial and boundary conditions

- Initial distribution of concentration, c_o (ML^{-3})
- Prescribed values of concentration, c (ML^{-3})
- Prescribed values of solute flux, $\dot{m}$ ($\dot{m}$ has dimensions of $ML^{-1}T^{-1}$ and MT^{-1} for cross-sectional and axisymmetric analyses, respectively.

(7) Boundary geometry and fluid flux data at the boundary nodes

2.9 OUTPUT

The primary line printer output from the flow model of VAM2D includes nodal values (at user-selected time levels) of pressure head and element centroidal values of Darcy velocity components and water-phase saturation at various time levels. VAM2D allows the user to select its fluid volumetric balance calculation option. If this option is selected, a fluid volumetric balance budget will also be printed out at the end of each time step. This budget contains information about the net flow rate of fluid due to boundary fluxes and sources and sinks, the rate of fluid accumulation in the entire flow domain, the flow balance error, and the cumulative volumetric fluid storage up to the current time.

To enable the user to use results from the flow model to run the transport model, VAM2D also provides the main link of the two models by writing the linking information on FORTRAN Unit 9. This information includes computed element centroidal values of Darcy velocities and fluid saturation, nodal fluid storage terms, and boundary nodal flux values.

A restart option for the flow model is provided in the code. This is facilitated by writing the nodal values of pressure head computed at the final time step of the current run on FORTRAN Unit 8.

The primary line printer output of the transport model VAM2D includes nodal values (at user-selected time levels) of solute concentration. VAM2D also allows the user to select its solute mass balance calculation option. If this option is selected, a solute component mass balance budget will be printed at the end of each time step. This budget contains information about the total dispersive and advective fluxes, the net rate of material accumulation taking into account storage, adsorption and decay, the mass balance error, the cumulative mass of solute still remaining in the porous medium at the current time, and the cumulative mass decay up to the current time value.

A restart option for the transport model is also provided in the code. This is facilitated by writing the nodal values of concentration computed at the final time step of the current run on FORTRAN Unit 8.

The code is also capable of performing concurrent simulation or sequential simulations of flow and transport. In the concurrent simulation approach, the flow and transport equations are solved together in each time step. Thus there is no need to be concerned about creating velocity backup files for transport simulations. In the sequential simulation approach, the flow problem is solved for the entire time period of simulation. In order to solve the associated transport problem after running the flow problem, the user should select an option that directs the code to write values of element velocities and water saturation obtained by solving the flow problem onto FORTRAN Unit 9. The information written on Unit 9 should then be supplied to the code as supplementary input data for the transport calculation.

3 NUMERICAL SOLUTION TECHNIQUES

3.1 GENERAL

In this chapter, numerical techniques for approximating the variably saturated flow equation and the non-conservative solute transport equation are described. The flow equation is treated using the Galerkin finite element method. The non-linearity is treated using the Picard and Newton-Raphson iterative techniques.

The transport equation is treated using the upstream-weighted finite element method designed to circumvent numerical oscillations. For both flow and transport problems, spatial discretization is performed using simple rectangular elements. The elements may be oriented in an arbitrary manner in the flow domain. Element matrices are computed using highly efficient influence coefficient matrix formulas (Huyakorn et al., 1984, 1985). The systems of algebraic equations resulting from the finite element approximations of the flow and transport equations can be solved in a standard manner using direct (banded matrix) solvers for symmetric and asymmetric matrices, respectively. An alternative version of VAM2D that utilizes state-of-the-art Preconditioned Conjugate Gradient (PCG) algorithms (designed to handle a large number of nodal unknowns efficiently) has also been developed. An example demonstrating application of these PCG iterative matrix solvers is provided in Chapter 4.

3.2 NUMERICAL TECHNIQUES FOR VARIABLY SATURATED FLOW

3.2.1 Galerkin Formulation

Equation (2.3) is solved by the Galerkin finite element method. In the Galerkin procedure, the pressure head function is represented by a trial function of the form

$$\psi(x_i,t) = N_J(x_i)\ \psi_J(t) \qquad , J = 1,2,\ldots,n \qquad (3.1)$$

where $N_J(x_i)$ and $\psi_J(t)$ are basis functions and nodal values of pressure head at time t, respectively, n is the number of nodes in the finite element network, and repeated indices imply nodal summation. Applying the Galerkin criterion to (2.3) and transforming the second-order derivative term, one obtains

$$\int_R K_{IJ}\, k_{rw} \frac{\partial N_I}{\partial x_i} \frac{\partial N_J}{\partial x_j} \psi_J \, dR + \int_R K_{ij}\, k_{rw} \frac{\partial N_I}{\partial x_i} e_j \, dR$$

$$+ \int_R \eta\, N_I\, N_J \frac{d\psi_J}{dt} \, dR - \int_B K_{ij}\, k_{rw} \left(\frac{\partial \psi}{\partial x_j} + e_j\right) n_i dB$$

$$- \int_R N_I\, q \, dR = 0 \quad , \quad I = 1,2,\ldots,n \qquad (3.2)$$

where R is the solution domain with boundary B, and n is the number of nodes in the finite element network.

Equation (3.2) can be written more concisely as

$$A_{IJ}\, \psi_J + B_{IJ} \frac{d\psi_J}{dt} = F_{IJ} \quad , \quad I = 1,2,\ldots,n \qquad (3.3)$$

where

$$A_{IJ} = \sum_e \int_R K_{IJ}\, k_{rw} \frac{\partial N_I}{\partial x_i} \frac{\partial N_J}{\partial x_j} \, dR \qquad (3.4a)$$

$$B_{IJ} = \sum_e \int_{R^e} \eta\, N_I\, N_J \quad dR \qquad (3.4b)$$

$$F_I = \sum_e \left(\int_{R^e} - K_{IJ}\, k_{rw} \frac{\partial N_I}{\partial x_i} e_j \, dR\right) \qquad (3.4c)$$

$$+ \int_R N_I\, q \, dR + \sum_e \left(\int_{B^e} V_n\, N_I \, dB\right)$$

in which R^e is the element subdomain with boundary B^e, and V_n denotes the normal velocity at the boundary. The sign convention for V_n is the same as for q. That is, V_n is positive for inward flow and negative for outward flow.

In VAM2D, linear rectangular elements are used. For such elements, the element matrices can be evaluated efficiently using influence coefficient formulas given in Huyakorn et al. (1984).

3.2.2 Picard and Newton-Raphson Schemes

Equation (3.3) represents a system of n nonlinear ordinary differential equations. Time integration of these equations is performed using implicit finite difference approximations. Two alternative nonlinear treatment procedures are provided in VAM2D. The first scheme is a Picard scheme that leads to a system of algebraic equations with symmetric coefficient matrix. The second scheme is a Newton-Raphson scheme that leads to a system of algebraic equations with asymmetric coefficient matrix. Both schemes are presented briefly in this section.

In the Picard scheme, equation (3.3) is approximated by the following equation:

$$\omega A_{IJ}^{k+\omega} \psi_J^{k+1} + (1-\omega) A_{IJ}^{k+\omega} \psi_J^{k} + \frac{B_{IJ}^{k+\omega}}{\Delta t_k} (\psi_J^{k+1} - \psi_J^{k}) = F_I^{k+\omega} \quad , \quad I = 1,2...,n \tag{3.5}$$

where ω is a time-weighting factor, superscripts k and k + 1 are used to denote the previous and current time level respectively, and $\Delta t_k = t_{k+1} - t_k$. To obtain an implicit time-stepping scheme, the value of ω must be equal to or greater than 0.5.

Equation (3.5) is now rearranged in the form

$$\left(\omega A_{IJ}^{k+\omega} + \frac{B_{IJ}^{k+\omega}}{\Delta t_k}\right) \psi_J^{k+1} = F_I^{k+\omega} + (\omega-1) A_{IJ}^{k+\omega} \psi_J^{k} + \frac{B_{IJ}^{k+\omega}}{\Delta t_k} \psi_J^{k} \tag{3.6}$$

which represents a symmetric matrix equation in view of the fact that both [A] and [B] are symmetric matrices. Nonlinear iterations are performed within each time step to achieve a stable numerical solution. For each iteration the most recent nodal values $\psi_J^{k+\omega}$, determined from $\psi_J^{k+\omega} = (1-\omega)\psi_J^k + \omega\psi_J^{k+1}$, are used to calculate coefficient matrices and the right-hand-side vector. A combination of central and backward difference time-stepping schemes may be used. For nodal points that are in the unsaturated zone, ω is equal to 0.5 for central difference time stepping. For nodal points in the saturated zone ω is set equal to 1 for backward difference time stepping. The use of backward difference time stepping combined with lumping (diagonalization) of storage matrix [B] proves to be advantageous for highly nonlinear situations where damping of oscillatory convergence behavior of the numerical solution is desirable.

In the Newton-Raphson scheme, equation (3.3) is replaced by the following integrated fully-implicit finite difference approximation:

$$G_I \equiv A_{IJ}\,\psi_J^{k+1} + B'_{IJ}\,(\psi_J^{k+1} - \psi_J^k)/\Delta t_k$$

$$+ E_I\,(S_{wJ}^{k+1} - S_{wJ}^k)/\Delta t = 0,\ I=1,2\ldots,n \qquad (3.7)$$

where G_I is the non-linear (vector array) function of the nodal head values, and B'_{IJ} and E_I are defined as

$$B'_{IJ} = \int_R S_s S_w N_I N_J dR \qquad (3.8a)$$

$$E_I = \int_R \phi N_I dR \qquad (3.8b)$$

Application of the Newton-Raphson procedure to (3.7) yields (see Huyakorn and Pinder, 1983):

$$G_I^{r+1} = G_I^r + \left(\frac{\partial G_I}{\partial \psi_J}\right)^r \Delta\psi_J^{r+1} = 0 \quad , \quad I-1,2,\ldots,n \qquad (3.9)$$

where r and r+1 denote previous and present iteration levels at the current time value, $\Delta\psi_J^{r+1}$ is an iteration displacement vector defined as

$$\Delta\psi_J^{r+1} = \psi_J^{r+1} - \psi_J^r \qquad (3.10)$$

and $(\partial G_I/\partial \psi_J)^r$ is the Jacobian of the Newton-Raphson iteration. Equation (3.8) can be written in the form

$$H_{IJ}^r \psi_J^{r+1} = H_{IJ}^r \psi_J^r - G_I^r \quad , \quad I=1,2,\ldots,n \qquad (3.11)$$

where $H_{IJ} = (\partial G_I/\partial \psi_J)^r$.

Owing to the fact that [H] is an asymmetric matrix, (3.11) thus represents an asymmetric matrix equation. As in the Picard scheme, it is necessary to perform nonlinear iterations within the time step to achieve a stable numerical solution. Iterations are performed until the successive change in pressure head values is within a prescribed tolerance. For each iteration, the Newton-Raphson scheme requires more than twice the computational effort compared with the Picard scheme. However, experience has indicated that the Newton-Raphson scheme with lumping of the storage matrix is more robust than the Picard scheme when dealing with highly nonlinear soil moisture characteristics.

In VAM2D, several convergence enhancement features have been implemented and used in conjunction with both the Picard and the Newton-Raphson techniques. The first of such features is the use of extrapolation formulas for estimating nodal values, ψ_J^{k+1}, thereby enhancing convergence of the iterative process. At the start of a new time level, an initial estimate of ψ_J^{k+1} is obtained from

$$\psi_J^{k+1} = \begin{cases} \psi_J^k & , \text{ if } k = 1 \\ \psi_J^k + (\psi_J^k - \psi_J^{k-1})\,\Delta t_k/2\Delta t_{k-1} & , \text{ if } k = 2 \\ \psi_J^k + (\psi_J^k - \psi_J^{k-1})\,\dfrac{\log(t_{k+1}/t_k)}{\log(t_k/t_{k-1})} & , \text{ if } k > 2 \end{cases} \qquad (3.12)$$

During subsequent iterations, improved estimates of ψ_J^{k+1} are obtained from

$$\psi_J^{k+1} = (1-\gamma)\ \psi_J^r + \gamma\ \psi_J^{r+1} \qquad (3.13)$$

where γ is an underrelaxation factor ($0 < \gamma < 1$), and ψ_J^r and ψ_J^{r+1} are the current and previous iterations of nodal values of pressure head at the current time level, $k + 1$, respectively.

Another salient feature is the use of an automatic underrelaxation procedure to cope with oscillatory convergence behavior of the numerical solution. Via this procedure, the value of the underrelaxation factor, γ, is computed as the iterations progress. The algorithm used to compute γ is adapted from Cooley (1983), and is given as

Step 1

$$s = \begin{cases} \dfrac{e_{r+1}}{e_r \gamma_{old}} & \text{if } r > 1 \\ 1 & \text{if } r = 1 \end{cases} \qquad (3.14)$$

Step 2

$$\gamma_{new} = \begin{cases} \dfrac{3 + s}{3 + |s|} & \text{if } s \geq -1 \\ \dfrac{1}{2|s|} & \text{if } s < -1 \end{cases} \qquad (3.15)$$

where r and $r + 1$ denote previous and current iteration levels, respectively, γ_{old} and γ_{new} are old and new values of the underrelaxation factor, and e is the absolute value of the largest difference between head values at two successive iteration levels ($e_r = \max_I |\psi_I^r - \psi_I^{r-1}|$).

The third convergence enhancement feature is the (optional) use of upstream weighting of relative permeability. This feature has been directly incorporated into the computation of element matrices for both the Picard and Newton-Raphson procedures. Via upstream weighting, the relative permeabilities for various elements are evaluated based on the flow direction.

The fourth feature is the (optional) use of various chord slope formulas for evaluating gradients of water saturation versus head ($dS_w/d\psi$) and relative permeability versus water saturation (dk_{rw}/dS_w).

In addition to the mentioned convergence features, VAM2D utilizes automatic time step reduction and marching procedure to handle convergence difficulties. Normally, for each specified (target) time step, the code will perform nonlinear iterations until the head values converge or until the maximum allowable number of iterations (NITMAX) prescribed by the user is reached. If NITMAX is reached, and the solution has not converged, the computational time step is then reduced to 1/2 of the original target time step, and the iteration procedure is allowed to recommence. Should convergence be achieved, the simulation will continue using the reduced value of computational time step until the end of the target time step. If convergence still fails to occur, the computational time step is reduced further (by another 1/2 (i.e., now 1/4 of the target time step)). The iteration procedure is continued until either convergence is reached or the maximum allowable successive reductions of time step size (IRESOL) prescribed by the user is reached. The code will be halted if IRESOL value is reached with a warning message to the user.

3.2.3 Treatment of Evaporation and Infiltration Boundary Conditions

An iterative procedure is used to handle evaporation and infiltration boundary conditions. This procedure is adapted from that used by Neuman et al. (1974). It is described as follows:

- During the first iteration in each time step, treat all surface nodes subjected to infiltration or evaporation as prescribed flux nodes. Assign to these nodes flux values that correspond to a certain fraction of $|E^*|$.

- Check whether computed pressure head values, ψ_I, satisfy the head value constraint ($\psi_L \leq \psi_I \leq 0$).

- For the nodes satisfying the head constraint, update the prescribed flux values by reassigning f_I^{r+1}, the fraction of the maximum potential infiltration (or evaporation) rate to be applied at iteration r+1. The value $f_I^{r+1} = f^*$ for $r = 0$, $f_I^{r+1} = f_I^r + (f^*)^{1/(r+1)} \leq 1$ for $r \geq 1$, where f* is a preset initial value of fraction of the maximum potential infiltration (or evaporation) rate assigned to the node. Note that $0 < f^* \leq 1$.

- For the nodes at which ψ_I does not satisfy the head constraint, alter the boundary conditions from prescribed flux to prescribed head. For the next iteration set the head values ψ_I to ψ_L for evaporation, and to zero for infiltration. Compute the flux values and check whether they satisfy the flux constraint. If, at any stage of the computation, the computed flux at node I exceeds the maximum potential flux, then in the next iteration apply the flux boundary condition to that node and set its nodal flux value equal to the maximum potential flux.

- Repeat the above iterative procedure until convergence is achieved at all nodes in the finite element network.

3.2.4 Treatment of Water Uptake by Plant Roots

Uptake of water by plant roots is handled by including a root extraction term q* as part of the sink term on the right-hand side of the flow equation (2.3). The root extraction term, q*, is represented (Feddes et al., 1974) as

$$q^* = Kk_{rw}(\psi - \psi_r)f_r \tag{3.16}$$

where K is the mean hydraulic conductivity defined as $K = (K_{11}+K_{22}+K_{33})/3$, ψ_r is the pressure head in the plant roots, and f_r is the root effectiveness function.

To simplify the coding, the root zone is discretized into columns of rectangular elements. All elements in the root zone are identified, and plant species numbers are also assigned to individual nodal columns. Note that only the nodes below the soil surface are counted as part of the root zone. The nodes at the soil surface are assumed to be contributing only to direct evaporation and not to root extraction. Data for each plant species must be supplied as input. These data include: wilting pressure head, ψ_w, potential transpiration rate, E_{pl}, and relationship of root effectiveness function versus depth.

Because the rate of water uptake by plant roots depends on atmospheric conditions and conditions underground, it cannot be predicted a priori. Thus iterations must be performed to maximize the total rate of transpiration per unit surface area, E_{pl}, so that the following constraints are satisfied:

$$|E_{pl}| \le |E^*_{pl}| \tag{3.17a}$$

and

$$\psi_r \geq \psi_w \tag{3.17b}$$

The constrained maximization is achieved using the procedure introduced by Neuman et al. (1974). For each time step, the calculation procedure for each individual nodal root-zone column is outlined as follows:

- Set ψ_r equal to ψ_w.
- Compute integrated nodal values of root extraction flux, Q_I, using current values of pressure head and relative permeability. For the nodes with $Q_I^* > 0$, set $Q_I^* = 0$.
- Compute E_{pl} for the nodal column:

$$E_{pl} = \frac{1}{A_c} \sum_{I=1}^{e} Q^* \tag{3.18}$$

where n_c is the number of effective nodes in the column, and A_c is the surface area of the column.

- If $|E_{pl}|$ is less than or equal to $|E_{pl}^*|$, use the computed values of Q_I^* in the solution of the system of finite element equations (3.6).
- If $|E_{pl}|$ is greater than $|E_{pl}^*|$, adjust computed values of Q_I^* by a factor of $|E_{pl}^*|/|E_{pl}|$ to make their sum equal to E_{pl}^*. Update the root pressure head by determining its new value from

$$E_{pl} = \frac{1}{A_c} \sum_{I=1}^{n_c} Q_I^* = \frac{1}{A_c} \sum_{I=1}^{n_c} \alpha_I \, (\psi_I - \psi_r) \tag{3.19}$$

where $\alpha_I = Kk_{rw}f_{rI}$.

- The above process is performed for each vertical nodal column within the root zone. After all components of Q_I^* have been determined, the system of finite element equations (3.6) is solved. Iterations are performed until convergence is obtained.

3.2.5 Treatment of Hysteresis and Anisotropy

To simulate the effect of hysteresis in soil moisture properties in a variably saturated flow simulation, VAM2D incorporates the procedure described by Kool and Parker (1987). This procedure requires that the boundary wetting and drying curves in the $S_w(\psi)$ relation are known. In VAM2D it is assumed that these boundary curves are described by expressions that have the same form as (2.9), but with different parameter values for wetting and drying boundaries. Using superscripts w and d to distinguish between wetting and drying, respectively, the boundary $S_w(\psi)$ curves are described by the following relationships

$$\frac{S_w^{w} - S_{wr}}{S_{ws} - S_{wr}} = \begin{cases} \dfrac{1}{[1 + (\alpha^{w}|\psi-\psi_a|)^{\beta^{w}}]^{\gamma^{w}}} & \psi < \psi_a \\ 1 & \psi \geq \psi_a \end{cases} \qquad (3.20)$$

$$\frac{S_w^{d} - S_{wr}}{1 - S_{wr}} = \begin{cases} \dfrac{1}{[1 + (\alpha^{d}|\psi-\psi_a|)^{\beta^{d}}]^{\gamma^{d}}} & \psi < \psi_a \\ 1 & \psi \geq \psi_a \end{cases} \qquad (3.21)$$

In equation (3.15) S_{ws} represents the maximum saturation value upon rewetting of an initially air-dry soil. If no air-entrapment occurs, $S_{ws} = 1.0$. However, if air-entrapment occurs, S_{ws} will be less than one. Parameters α, β and γ are the curve shape parameters, with different values for wetting and drying. Note that α^w cannot be less than α^d, i.e.

$$\alpha^w \geq \alpha^d$$

Often, the following simplifications can be used (Kool and Parker, 1987)

$$\beta^w = \beta^d = \beta$$

$$\gamma^w = \gamma^d = 1 - 1/\beta$$

With these simplifications, only five parameters are required to characterize the hysteretic saturation-pressure head relation. The parameters are the porosity, ϕ, residual saturation, S_{wr}, and shape parameters α^w, α^d and β. Lacking data, one may use $\alpha^w = 2\alpha^d$ as a first approximation (Kool and Parker, 1987). A typical hysteretic $S_w(\gamma)$ relation is shown in Figure 3.1. This figure illustrates the correspondence of the parameters in (3.15) and (3.16) to the boundary wetting and drying curves.

In a hysteretic flow simulation, VAM2D automatically computes scanning curves in the $S_w(\psi)$ relation to determine the appropriate saturation path for every element in the modeled domain when reversals from wetting to drying, or vice-versa occur. This is achieved by defining "pseudo" values of the residual and saturated S_w. In the simulation, these pseudo-values are substituted into Eqs. (3.20) and (3.21). This has the effect of scaling the boundary wetting and drying curves to make them pass through the reversal points. For a reversal from wetting to drying, the nominal value of 1.0 for S_w at saturation is replaced by

$$S'_{ss} = \frac{S_w^{rev} - S_{wr}\,[1 - S_e^d\,(\psi^{rev})]}{S_e^d\,(\psi^{rev})} \qquad (3.22)$$

where S_w^{rev} and ψ^{rev} are the saturation and pressure head at the reversal point, respectively and $S_e^d\,(\psi^{rev})$ is the effective drying saturation given by the left hand side of (3.21) for $\psi = \psi^{rev}$. Analogously, for a reversal from drying to wetting, a pseudo-value for S_{wr} is used, which is given by

$$S'_{wr} = \frac{S_w^{rev} - S_e^w\,(\psi^{rev})}{1 - S_e^w\,(\psi^{rev})} \qquad (3.23)$$

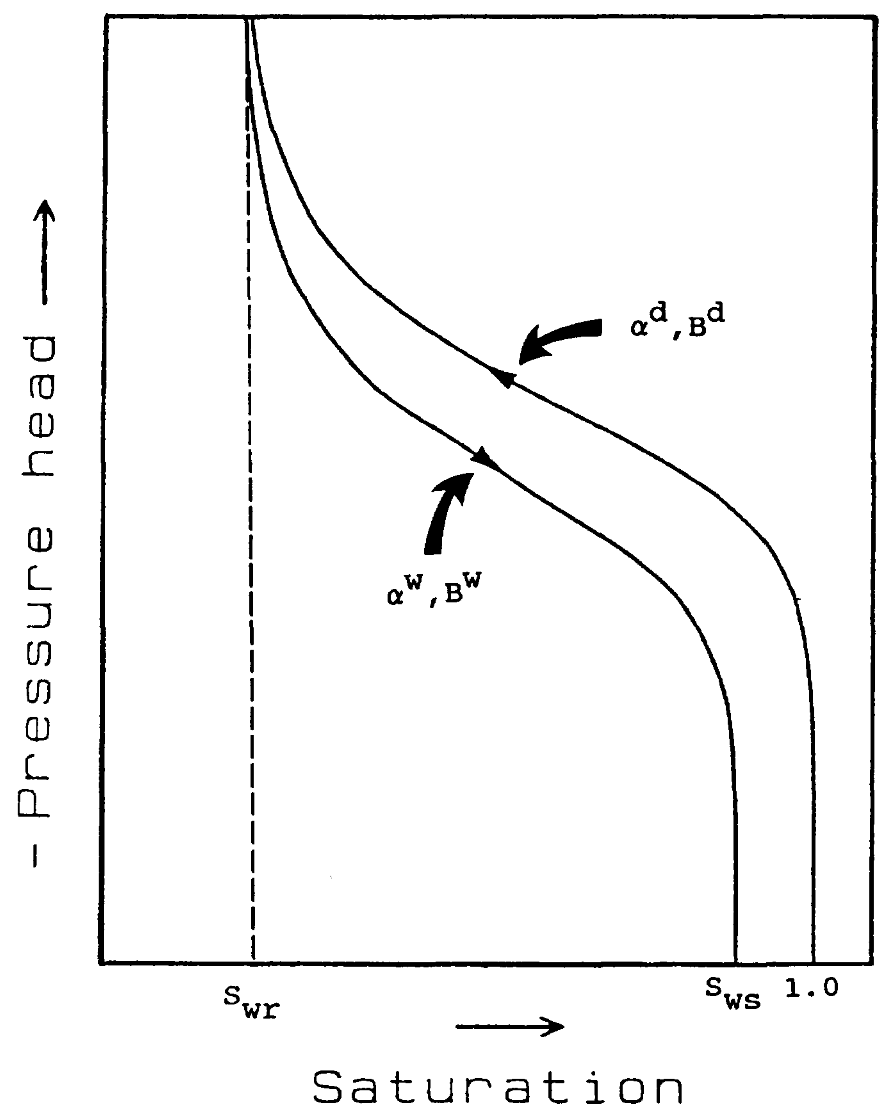


Figure 3.1. Example of hysteretic $S_w(\psi)$ relation showing the boundary wetting and drying curves.

where S_e^w is the effective wetting saturation corresponding to the left hand side of (3.20). The hysteresis subroutine in VAM2D checks whether each element is wetting or drying and computes the appropriate values of S'_{ss} and S'_{wr} for each element. This is achieved by means of an index variable, κ_i, which is set to κ_i = +1 if the i-th element is wetting and κ_i = -1 if the i-th element is drying. At the end of every time step a check is made for every element to determine whether a reversal in the saturation path has occurred. A reversal occurs if

$$\frac{\bar{\psi}_i^{t-\Delta t} - \bar{\psi}_i^{t}}{\kappa_i} > \delta_\psi \tag{3.24}$$

where δ_ψ is the pressure head iteration convergence tolerance, and $\bar{\psi}_i$ is the average nodal pressure head for the i-th element

$$\bar{\psi}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} \psi_{ij} \tag{3.25}$$

with n_i the number of nodes for the element. When a reversal occurs, the code determines the new scanning curve for the element which is subsequently used to calculate $S_w(\psi)$. An example of such scanning curves is shown in Figure 3.2. In this example the boundary hysteresis loop is closed at saturation, i.e., S_{ws} = 1.0. The figure shows a primary wetting scanning curve (1) and a secondary drying scanning curve (2). In order to completely specify the initial conditions for a hysteretic simulation, the user must specify not only the initial nodal values of ψ, but also the initial saturation values for each element, and whether the element is initially wetting or drying.

VAM2D can simulate the effect of saturation dependent anisotropy on unsaturated flow by using Eq. (2.12) to evaluate anisotropy as a function of pressure head. This requires input values of the variables σ_f^2, σ_α^2, μ and ω. The parameter $\bar{a}$ is evaluated by VAM2D as the derivative of the $\ln[k_{rw}(\psi)]$ relation. In order to obtain an operational algorithm, two criteria were used.

First, a maximum bound must be imposed on the anisotropy ratio. Inspection of (2.12) shows that otherwise the computed anisotropy ratio will become unrealistically large, even for moderate values of ψ. The upper bound, r_{max}, for $r(\psi)$ is a user-specified value in VAM2D. A value of $r_{max} = 10^7$ has been found

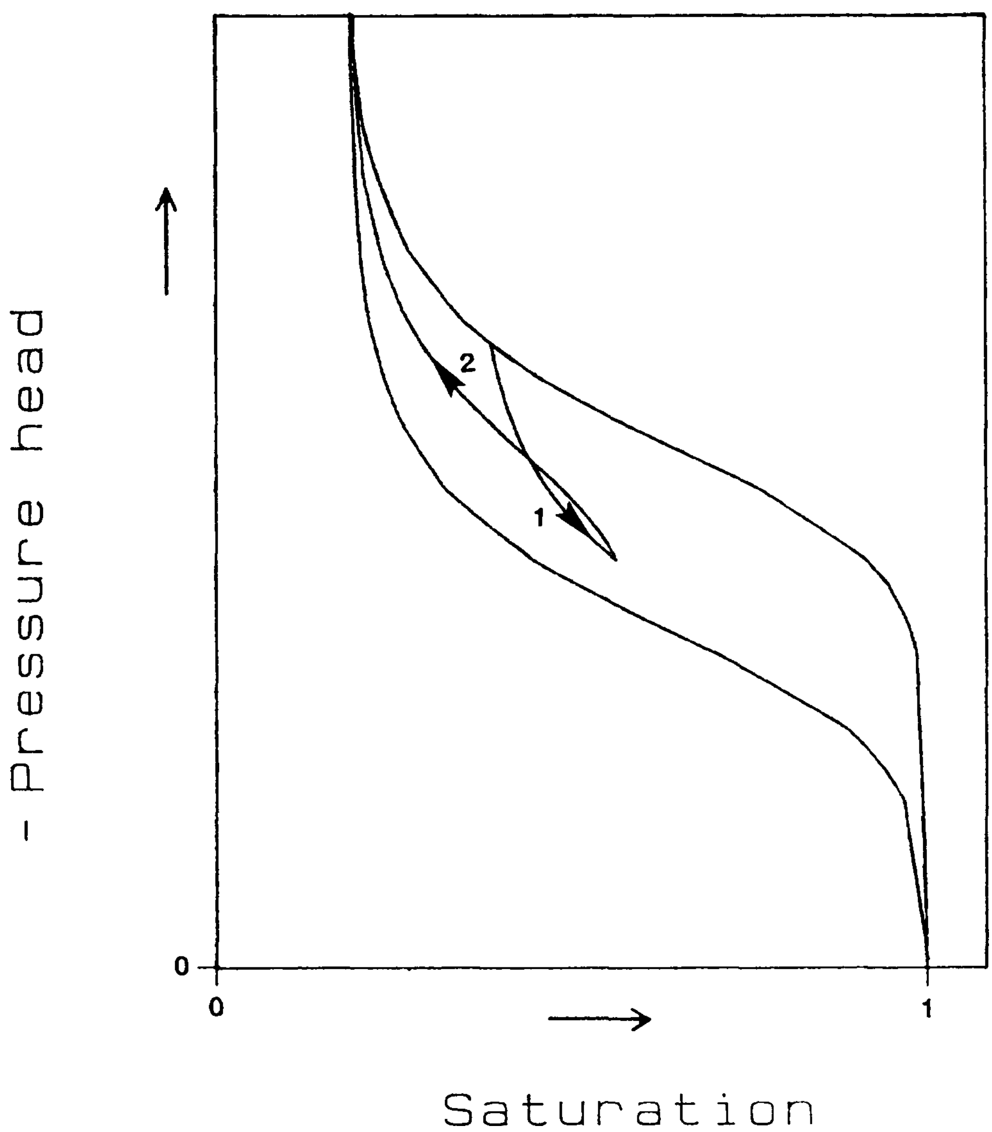


Figure 3.2. Typical scanning curves produced by the hysteresis model in VAM2D. Curve (1) denotes primary wetting scanning curve, curve (2) denotes secondary drying scanning curve.

to give satisfactory results. Secondly, Eq. (2.12) gives the conductivity ratio, but not the actual values of conductivity parallel and perpendicular to stratification. In order to obtain the desired, monotonically decreasing $k_{rw}(\psi)$ relations, VAM2D uses an empirical logarithmic interpolation procedure to ensure that both $(Kk_{rw})_{11}$ and $(Kk_{rw})_{22}$ decrease with decreasing pressure head and that the correct anisotropy ratio is maintained for any ψ value. An example anisotropic $k_{rw}(\psi)$ relation as modeled by VAM2D is shown in Figure 3.3. This figure shows relative conductivity as a function of soil water pressure head. The solid curve represents the isotropic case in which conductivity is given by (2.8) and (2.9). The dashed lines represent the anisotropic case with anisotropy ratio computed from (2.12). The following anisotropy parameters were used here: $\sigma_f^2 = 0.82$, $\sigma_\alpha^2 = 0.0005$, $\mu = 40$ cm and $\omega = 0.0$. The figure clearly illustrates the dramatic effect of anisotropy on relative conductivities.

3.2.6 Matrix Solution Techniques

The system of algebraic equations resulting from the finite element approximation of the flow equation needs to be solved using an efficient matrix solver to obtain cost-effective simulations of realistic field problems. Two versions of VAM2D have been created. The first version utilizes standard direct solvers designed for symmetric and asymmetric banded matrices. These solvers are reasonably efficient (in terms of computational time core storage) when the matrix bandwidth (MBW) and the number of equations (NP) are not large. Experience has indicated that if the number of equations is up to 1000 and the bandwidth is up to 70, the direct banded solvers can handle a typical transient simulation problem reasonably well on a minicomputer or a personal computer model 386 with a proper compiler and co-processor board. However, for situations where the number of equations and matrix bandwidth are large, it is desirable to resort to advanced Preconditioned Conjugate Gradient (PCG) iterative matrix solution algorithms. For this reason, the second (alternative) version of the VAM2D code was created. In this section, a brief description of the symmetric matrix PCG algorithm incorporated into the new version of VAM2D is presented. The asymmetric PCG algorithm will be described in Section 3.3.4.

The Preconditioned Conjugate Gradient (PCG) method (see Kershaw, 1978) has emerged as one of the most promising iterative methods for solving large sparse matrix equations generated by finite element (or finite difference) approximations of multi-dimensional field problems. There have been a number of recent papers describing successful conjunctive applications of PCG and finite element or finite difference method to groundwater flow problems. These include the publications by Gambolati (1980), Kuiper (1981, 1987), Gambolati et al. (1986), Kalf (1988), Meyer et al. (1989).

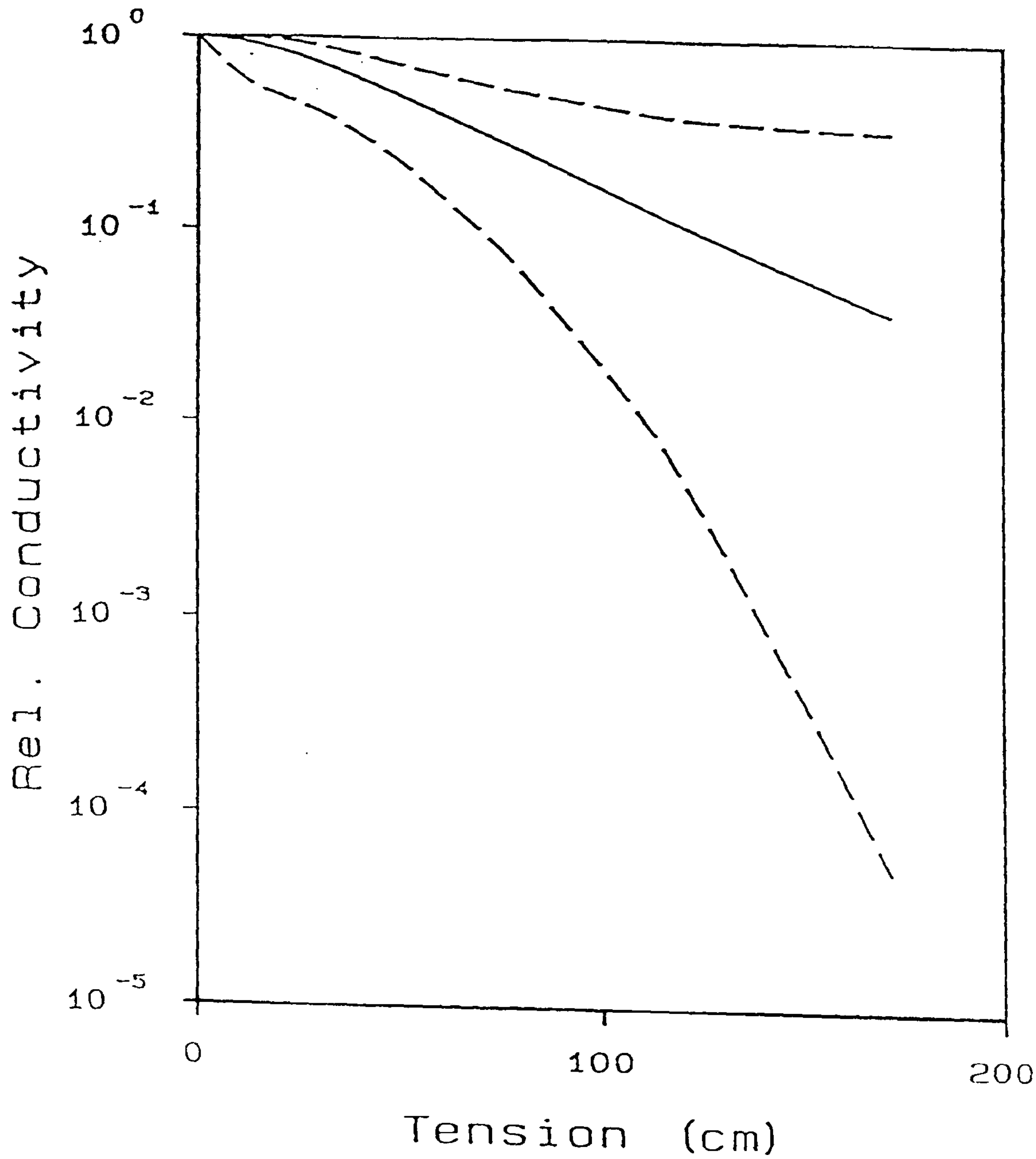


Figure 3.3. Example of anisotropic $k_{rw}(\psi)$ relation as modeled by VAM2D.

The symmetric PCG solver implemented into VAM2D is based on a two-step procedure of Kershaw (1978) and Anderson and Shestakov (1983). The first step involves preconditioning of the finite element coefficient matrix A of a general system Ax = y by computing an incomplete triangular Cholesky decomposition (LDL^T) of A. The second step involves Conjugate Gradient iterations on an initial guess x^o of the vector x. The CG recursive equations are as follows:

$$\text{Let} \quad K \equiv (LDL^T) \tag{3.26a}$$

$$r^o = y - Ax^o \tag{3.26b}$$

$$p^o = K^{-1} r^o \tag{3.26c}$$

$$q^o = Ap^o \tag{3.26d}$$

then for i = 0,1,2,....

$$\alpha_i = (r^i, K^{-1} r^i)/(p^i, q^i) \tag{3.26e}$$

$$x^{i+1} = x^i + \alpha_i p^i \tag{3.26f}$$

$$r^{i+1} = r^i - \alpha_i q^i \tag{3.26g}$$

$$\beta_i = (r^{i+1}, k^{-1} r^{i+1})/(r^i, K^{-1} r^i) \tag{3.26h}$$

$$p^{i+1} = K^{-1} r^{i+1} + \beta_i p^i \tag{3.26i}$$

$$q^{i+1} = Mp^{i+1} \tag{3.26j}$$

This scheme is repeated until the L_2 norm of the head error is less than a prescribed tolerance criterion.

3.3 NUMERICAL TECHNIQUE FOR SOLUTE TRANSPORT

3.3.1 Upstream Weighted Residual Formulation

For the contaminant transport simulation, VAM2D solves (2.17) for single specie transport or (2.23) for multi-component transport using an upstream weighted residual finite element method. To illustrate the application of the technique, consider equation (2.17) and a trial solution for concentration be written in the form:

$$c(x_i,t) = N_J(x_i)c_J(t) \tag{3.27}$$

where $N_J(x_i)$ and $c_J(t)$ are the basis functions and nodal values of concentration at time t, respectively.

In the upstream weighted residual technique, the weighted residual integral equation is obtained using asymmetric (upstream) weighting functions (see Huyakorn and Nilkuha, 1979) to weight the spatial derivative terms of the transport equation, and the standard basis functions to weight the remaining mass accumulation term. Application of this procedure to (2.17) yields

$$\int_R W_I \left[\frac{\partial}{\partial x_i} \left(D_{ij} \frac{\partial c}{\partial x_j} - v_i \frac{\partial c}{\partial x_i}\right) \right]$$

$$- \int_R N_I \left[\phi S_w \, R \left(\frac{\partial c}{\partial t} + \lambda c\right) + q(c-c^*) \right] dR = 0 \tag{3.28}$$

where W_I are the upstream weighting functions.

Using Green's theorem to remove the second derivative and substituting for c, one obtains

$$\int_R \left(D_{ij} \frac{\partial W_I}{\partial x_i} \frac{\partial N_J}{\partial x_j} + v_i \, W_I \frac{\partial N_J}{\partial x_i}\right) c_J \, dR$$

$$+ \int_R \phi S_w \; R \; N_I \; N_J \; (\frac{dc_J}{dt} + \lambda c_J) \; dR + \int N_I \; q \; (c^* - N_J c_J) \; dR$$

$$- \int_B W_I \; (D_{ij} \frac{\partial c}{\partial x_j}) \; n_i \; dB \;\; = \;\; 0 \qquad (3.29)$$

Equation 2.17 can be expressed in the form

$$(E_{IJ} + B^*_{IJ}) c_J + \tilde{B}_{IJ} \frac{dc_J}{dt} \;\; = \;\; \tilde{F}_I \qquad (3.30)$$

where

$$\tilde{F}_I \;\; = \;\; - \int_R N_I \; q \; (c^* - N_J c_J) \; dR + \int_B W_I \; (D_{ij} \frac{\partial c}{\partial x_j}) \; n_i \; dB$$

$$E_{ij} \;\; = \;\; \int_R (D_{ij} \frac{\partial W_I}{\partial x_i} \frac{\partial N_J}{\partial x_j} + v_i \; W_I \frac{\partial N_J}{\partial x_i}) \; dR$$

$$\tilde{B}_{IJ} \;\; = \;\; \int_R (\phi S_w R) \; N_I \; N_J \; dR$$

$$B^*_{IJ} \;\; = \;\; \int_R (\lambda \phi S_w R) \; N_I \; N_J \; dR$$

Once all of the element matrices have been computed and assembled into global matrices, the system of ordinary differential equations (3.30) can be integrated with respect to time. This leads to the following system of algebraic equations

$$(\omega (E_{IJ} + B^*_{IJ}) + \frac{\tilde{B}_{IJ}}{\Delta t_k}) \; c_J^{k+1} \;\; = \;\; (\omega - 1) \; (E_{IJ} + B^*_{IJ}) \; c_J^k + \frac{\tilde{B}_{IJ}}{\Delta t_k} \; c_J^k$$

$$+ \omega \tilde{F}_I^{k+1} + (1-\omega) \tilde{F}_I^k \qquad (3.31)$$

where ω is the time weighting factor.

Equation 3.31 can be rearranged in the form

$$G_{IJ} c_J^{k+1} = R_I^{k+1} \qquad (3.32)$$

where

$$R_I^{k+1} = (\omega-1) (E_{IJ} + B_{IJ}^*) c_J^k + \frac{\tilde{B}_{IJ}}{\Delta t_k} c$$

$$+ \omega \tilde{F}_I^{k+1} + (1-\omega) \tilde{F}_I^k \qquad (3.33a)$$

and

$$G_{IJ} = \omega(E_{IJ} + B_{IJ}^*) + \tilde{B}_{IJ}/\Delta t_k \qquad (3.33b)$$

To obtain a second-order accuracy in time approximation, ω is chosen to be 0.5 thus yielding the Crank-Nicolson time stepping scheme. Equation (3.32) represents a system of linear algebraic equations with an asymmetric banded coefficient matrix. Its solution is achieved by using either a direct solver or PCG iterative solver.

3.3.2 Treatment of Boundary Conditions for Single Component Transport

The first-type boundary condition (2.22b) is treated by setting current concentration values at the boundary nodes to the prescribed concentration $\tilde{c}$. Physically, the first-type boundary condition may apply to inflow boundary segments where the concentration of the incoming fluid is assumed to be approximately the same as the resident nodal concentration in the porous medium. Nodal points representing injection wells or contaminant sources may also be subject to the first type boundary condition if the stated equilibrium assumption is adopted.

The second-type boundary condition (2.22c) is treated by adding the integrated value of the prescribed dispersive flux to the right hand side of the discretized finite element equations. Physically, the second-type boundary condition may apply to impermeable boundary segments where the fluxes and normal concentration gradients are zero. It may also apply to certain contaminant sources placed in an undisturbed flow field wherein the mass of waste material is leaching at a prescribed rate, q_c^D.

The third-type boundary condition (2.22d) generally applies to inlet boundary segments and/or injection wells when the concentration of incoming or injected fluid c* may be unequal to the resident nodal concentration values. In this case, the integrated nodal values of the flux q_c^T are added to the right side of the finite element equations, and the integrated advective flux term corresponding to $v_i n_i c$ of (2.22d) is incorporated into the coefficient matrix. For the special case of pumping wells and outflow boundary, the outflow concentration c* usually takes the same value as the resident nodal concentration, c. The boundary condition (2.22d) then reduces to that of (2.22c) with zero dispersive flux. This corresponds to the natural boundary condition of the finite element formulation used in the code and no treatment is needed.

A temporal variation of the boundary condition at any given node may be accommodated in a convenient manner by using either a continuous piecewise linear approximation or discontinuous (stepped) approximation of the actual graph of concentration or solute flux versus time.

3.3.3 Treatment of Boundary Conditions for Chained Decay Transport

The three boundary conditions (2.22a) - (2.22c) for chained decay transport are treated in a similar manner to those of single-component transport. In the case of a decaying source, the prescribe source concentrations of solute mass fluxes released from the source are computed using the general analytical solution of the Bateman equation (2.29).

3.3.4 Matrix Solution Techniques

The system of algebraic equations resulting from the finite element approximation of the transport equation may be solved using either a direct solver or an iterative PCG solver for an asymmetric coefficient matrix. Since the banded solver is standard, it is not described here. The asymmetric PCG solver implemented into the alternative version of VAM2D is based on the work of Shestakov and Anderson (1983) and Koniges and Anderson (1987). Their schemes are referred to as ILUCG2 (Incomplete LU decomposition Conjugate Gradient in 2-D) and ILUBCG2 (Incomplete LU decomposition Bi-Conjugate Gradient in 2-D), respectively. Both schemes consist of two major steps. The first step is preconditioning, which involves an incomplete triangular (LU) decomposition of the coefficient matrix A of the system Ax = y. Once the LU decomposition is done, one then applies either Conjugate Gradient (CG) or Bi-Conjugate Gradient (BCG) iterative procedure to the equivalent matrix system:

$$L^{-1} AU^{-1} Ux = L^{-1}y.$$

The CG algorithm takes the following form:

$$r^o = y-Ax^o \tag{3.34a}$$

$$q^o = A^T (LL^T)^{-1} r^o \tag{3.34b}$$

$$p^o = (U^TU)^{-1}q^o \tag{3.34c}$$

then for i = 0,1,2,....

$$\alpha_i = (r^i, (LL^T)^{-1} r^i)/(p^i,q^i) \tag{3.34d}$$

$$x^{i+1} = x^i + \alpha p^i \tag{3.34e}$$

$$r^{i+1} = r^i - \alpha_i Ap^i \tag{3.34f}$$

$$\beta_i = (r^{i+1}, (LL^T)^{-1} r^{i+1})/(r^i, (LL^T)^{-1}, r^i) \tag{3.34g}$$

$$q^{i+1} = A^T(LL^T)^{-1} r^{i+1} + \beta_i q^i \tag{3.34h}$$

$$p^{i+1} = (U^TU)^{-1} q^{i+1} \tag{3.34i}$$

The above iterative CG procedure is repeated until the desired convergence is achieved.

The BCG algorithm takes the following form:

$$r^o = y-Ax^o \tag{3.35a}$$

$$\bar{r}^o = U^T L^{-1} r^o \quad (3.35b)$$

$$p^o = (LU)^{-1} r^o \quad (3.35c)$$

$$\bar{p}^o = (LL^T)^{-1} r^o \quad (3.35d)$$

then, for i = 0,1,2,...

$$\alpha_i = (r^i, (LU)^{-1} r^i)/(\bar{p}^i, Ap^i) \quad (3.35e)$$

$$x^{i+1} = x^i + \alpha p^i \quad (3.35f)$$

$$r^{i+1} = r^i - \alpha_i Ap^i \quad (3.35g)$$

$$\bar{r}^{i+1} = \bar{r}^i - \alpha_i A^T \bar{p}^i \quad (3.35h)$$

$$\beta_{i+1} = (\bar{r}^{i+1}, (LU)^{-1} r^{i+1})/(\bar{r}^i, (LU)^{-1} r^i) \quad (3.35i)$$

$$p^{i+1} = \beta_i p^i + (LU)^{-1} r^{i+1} \quad (3.35j)$$

$$\bar{p}^{i+1} = \beta_i \bar{p}^i + (LU)^{-T} \bar{r}^{i+1} \quad (3.35k)$$

The above iterative procedure is repeated until the desired convergence is achieved.

3.4 MASS BALANCE COMPUTATION PROCEDURE

As an option in the computer program, a mass balance calculation is provided at the end of each time step. For the flow equation, the mass balance over the whole solution region R is obtained by integrating Equation 2.1 and applying Green's theorem to the spatial derivative terms. Thus, one obtains

$$\int_B K_{ij} k_{rw} (\frac{\partial \psi}{\partial x_j} + e_j) \, dB - \int_R \eta \frac{\partial \psi}{\partial t} \, dR + \int_R q \, dR = 0 \quad (3.36)$$

where

$$\eta = S_w S_s + \phi \frac{dS_w}{d\psi} .$$

It should be noted that the first integral in Equation 3.36 represents the net fluid flow across the whole boundary, the second integral represents the rate of volumetric storage in region R, and the last integral represents the net rate of volume production due to point sources and sinks.

If the exact solution of the flow equation is substituted into Equation 3.36, the right hand side will be zero. However, if an approximate finite element solution ψ is substituted, the right hand side of (3.36) will be non-zero, and will correspond to an error in material balance, $\dot{\epsilon}_v$

$$\dot{\epsilon}_v = - \int_B v_i n_i \, dB - \int_R \eta \frac{\partial \psi}{\partial t} dR + \int_R q \, dR \tag{3.37}$$

where

$$q = \sum_{I'=1}^{n_w} Q_{I'} \, \delta(\underset{\sim}{x} - \underset{\sim}{x}_{I'})$$

$$v_i = -K_{ij} k_{rw} \left(\frac{\partial \psi}{\partial x_j} + e_j \right)$$

Next, we make use of the following properties of the basis functions:

$$\sum_{I^*=1}^{n_w} N_{I^*} (\underset{\sim}{x}^*) = 1 \quad \text{for all } \underset{\sim}{x}^* \text{ on B} \tag{3.38}$$

and

$$\sum_{I=1}^{n} N_I (x) = 1 \quad \text{for all x on R} \tag{3.39}$$

where n_B is the number of nodes on the boundary and n is the total number of nodes in the whole solution region.

Combined Equations 3.37-3.39 yields

$$\dot{\epsilon}_V = \sum_{I^*=1}^{n_B} - \int_B N_{I^*} v_i n_i dB - \sum_{I=1}^{n} \int_R (\eta \; N_I \; N_J \frac{d\psi_J}{dt}) \; dR + \sum_{I'=1}^{n_W} Q_{I'} \tag{3.40}$$

Equation 3.40 can be written in the form

$$\dot{\epsilon}_V = \sum_{I^*=1}^{n_B} -f^B_{I^*} - \sum_{I=1}^{n} f^S_I - \sum_{I'=1}^{n_W} f^W_{I'} \tag{3.41}$$

where

$$f^B_{I^*} = \int_B N_{I^*} \; v_i n_i \; dB$$

$$f^S_I = \int_R \eta \; N_I \; N_J \frac{d\psi_J}{dt} \; dR \quad , \quad f^W_{I'} = Q_{I'}$$

The storage and sink and source terms in Equation 3.41 are evaluated in a straightforward manner. The boundary integral terms, f^{B*}_I are evaluated by performing the back-substitution of the Galerkin finite element equations at various boundary nodes. The procedure avoids the problem of discontinuities in the velocity field at the boundary nodes. Such discontinuities arise if one employs Darcy's Law to compute velocities at boundary nodes of individual elements and uses these velocities to obtain f^{B*}_I.

After all the terms in 3.37 have been computed, the error in the rate of material balance, $\dot{\epsilon}_v$, can be determined. For each time level, the cumulative material balance error, $\epsilon_v^{t_{k+1}}$, is evaluated from

$$\epsilon_v^{t_{k+1}} = \sum_{\ell=1}^{k} \dot{\epsilon}_v \, \Delta t_\ell \qquad (3.42)$$

A normalized form of ϵ_v is also determined using the following equation:

$$|| \epsilon_V || = | \epsilon_V | / [\sum_{I*=1}^{n_B} | f_{I*} | + \sum_{I=1}^{n} | f_s^I | + \sum_{I'=1}^{n_w} | f_{I'}^w |] \qquad (3.43)$$

The solute mass balance calculation procedure is also performed in a similar manner to that already described for the fluid. First the integral form of the solute transport equation (2.15) is obtained

$$\int_B (D_{ij} \frac{\partial c}{\partial x_j} - v_i c) n_i \, dB - \int_R (\frac{\partial}{\partial t} (\phi S_w R c) + \phi \lambda S_w R c) \, dR + \sum_{I'=1}^{n_w} Q_{I'} c_{I'}^* = 0 \qquad (3.44)$$

This leads to the following expression for the rate of material balance error

$$\dot{\epsilon}_M = \sum_{I*=1}^{n_B} \int_B N_{I*} (D_{ij} \frac{\partial c}{\partial x_j} - v_i c) n_i \, dB - \sum_{I=1}^{n} \int_R \phi S_w R N_I N_J (\frac{dc_J}{dt} + \lambda c_J) \, dR + \sum_{I'=1}^{n_w} Q_{I'} c_{I'}^*$$

$$- \sum_{I=1}^{n} \int_R N_I N_L c_L \eta N_J \frac{d\psi_J}{dt} \, dR \tag{3.45}$$

which can be expressed in the form

$$\dot{\epsilon}_M = - \sum_{I^*=1}^{n_B} F^B_{I^*} - \sum_{I=1}^{n} f^s_I + \sum_{I'=1}^{n_W} F^W_{I'} \tag{3.46}$$

where

$$F^B_{I^*} = \int_B N_{I^*} \left(v_i \; c - D_{ij} \frac{\partial c}{\partial x_j}\right) n_i \; dB$$

$$F^s_I = \int_R \phi S_w \; R \; N_I \; N_J \left(\frac{dc_J}{dt} + \lambda c_J\right) dR + \sum_{I=1}^{n} \int_R N_L c_L \left(\eta N_I N_J \frac{d\psi_J}{dt}\right) dt$$

$$F^W_I = Q_{I'} \; c^*_{I'}$$

Except for the boundary integral term, all other terms in Equation 3.45 can be evaluated in the straightforward manner. The evaluation of the boundary material flux is more involved and requires further elaboration. In a case involving a third type boundary condition, the total material flux distribution is prescribed as

$$\left(v_i c - D_{ij} \frac{\partial c}{\partial x_j}\right) n_i = q^T_c \tag{3.47}$$

and thus, $F^B_{I^*}$ is given explicitly by

$$F^B_{I^*} = \int_B N_{I^*} \; q^T \; dB \tag{3.48}$$

In a case involving a second type boundary condition, the outward dispersive flux distribution is prescribed as

$$-D_{ij} \frac{\partial c}{\partial x_j} n_i = q_c^D \tag{3.49}$$

and the outward advective flux is obtainable from

$$v_i n_i c = q \, N_J \, c_J \tag{3.50}$$

where q is the outward normal fluid flux distribution. Equations 3.49 and 3.50 are combined with Equation 3.48 to yield

$$\begin{aligned} F_{I*}^B &= \int_B N_{I*} \, (q \, N_J \, c_J + q_c^D) \, dB \\ &\approx c_{I*} \int_B N_{I*} \, q \, dB + \int_B N_{I*} \, q_c^D \, dB \end{aligned} \tag{3.51}$$

where the summation convention is not applied to subscript I*, and the fluid integral corresponds to the nodal fluid flux at boundary node I*.

In a case involving a first type boundary condition, the dispersive boundary nodal flux is not known explicitly and should be computed by back-substitution of c into the original finite element approximation of the transport equation at node I*. Once the dispersive nodal flux Q_c^{DI*} has been computed the total boundary nodal flux is obtainable from

$$F_{I*}^B \approx c_{I*} \int_B N_{I*} \, q \, dB + Q_{cI*}^D \tag{3.52}$$

Finally, when all the various material flux terms have been computed, the error in the rate of material balance, ε_M, can be determined from Equation 3.46. In practice, the cumulative mass balance error at a current time level, $\epsilon_M^{t_{k+1}}$, should also be computed. It is given by

$$\epsilon_M^{t_{k+1}} = \sum_{\ell=1}^{k} (\dot{\epsilon}_M \, \Delta t_\ell) \tag{3.53}$$

Both $\epsilon_M^{t_{k+1}}$ and its normalized form $E_M^{t_{k+1}}$ are used as indicators of the global accuracy of the numerical solution of the transport equation. For convenience, we define $E_M^{t_{k+1}}$ as

$$E_M^{t_{k+1}} = \sum_{\ell=1}^{k} \{(\dot{\epsilon}_M \, \Delta t_\ell)/(\sum_{\ell=1}^{n} F_I^s)\} \tag{3.54}$$

4 EXAMPLE VERIFICATION AND APPLICATION PROBLEMS

4.1 GENERAL

Two sets of test problems were used for verification of numerical schemes and demonstration of major capabilities of the VAM2D code. Specific purposes of the example problems presented in this chapter are described below.

- Simulation of water flow under variably saturated (or saturated-unsaturated) conditions

- Simulation of single and multiple component transport

- Coupled simulation of flow and transport problems with various types of boundary conditions

- Simulation of a laboratory column experiment on hysteric flow

- Simulation of an intermediate-scale field experiment on solute transport in a Caisson

- Verification of the VAM2D code against analytical solutions and other finite element variably saturated flow and transport codes (UNSAT2, FEMWATER and FEMWASTE, and VADOFT)

- Demonstration of the ability of VAM2D to cope with highly nonlinear conditions

- Demonstration of computational efficiency of the Preconditioned Conjugate Gradient algorithms implemented into the VAM2D code.

The first problem set comprises seven transient and steady-state flow problems with different features of boundary conditions and varying degree of nonlinearity. These problems are as follows:

- Horizontal flow in a soil slab

- Transient evaporation and infiltration in a soil column

- Transient hysteretic flow in a soil column

- Transient two-dimensional flow in an unconfined aquifer adjacent to a landfill

- Transient two-dimensional flow in a root zone
- Steady-state two-dimensional flow beneath a landfill
- Transient vadose-zone infiltration under initially dry soil condition.

The second problem set comprises seven transient transport problems. Three of these problems are associated with three of the seven flow problems just mentioned. The transport problems considered are listed as follows:

- One-dimensional horizontal transport in a soil slab
- Two-dimensional transport in a soil slab
- One-dimensional transport of two three-member chains of radionuclides
- Two-dimensional transport in uniform groundwater flow
- Transient two-dimensional transport in a root zone
- Leachate migration from a sanitary landfill
- Simulation of a solute transport Caisson experiment.

A detailed description of all test problems, values of the physical parameters used in the simulation, and numerical result, are presented in the following sections.

4.2 VARIABLY SATURATED FLOW PROBLEMS

4.2.1 One-Dimensional Flow in a Horizontal Soil Slab

The purpose of this problem is to test the implementation of the Galerkin finite element formulation and the nonlinear iterative schemes for a case in which there is no gravity effect. The problem is depicted schematically in Figure 4.1. As illustrated, a slab of soil 20 cm long has an initial pressure head of -83.33 cm. Wetting occurs at the left boundary ($x = 0$) where the pressure head is increased to 0.0 and maintained constant. The pressure head at the right boundary ($x = 20$ cm) is kept constant at -83.33 cm. For convenience, the soil was assumed to be homogeneous and isotropic with a saturated hydraulic conductivity of 1 $cm{\cdot}d^{-1}$ and porosity of 0.45. The soil moisture characteristics used in the simulation are

$$k_{rw} = (S_w - S_{wr})/(1 - S_{wr})$$

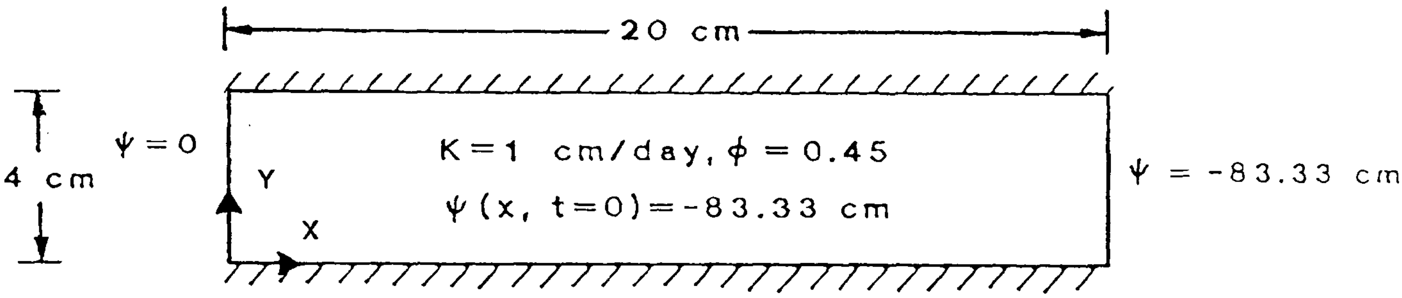


Figure 4.1. Geometry and boundary conditions used in the simulation of unsaturated flow in a soil slab.

and

$$\frac{1-S_w}{1-S_{wr}} = \frac{\psi-\psi_a}{-100-\psi_a}$$

where S_{wr} = 0.3333 and ψ_a = 0.0 cm. The selected relative permeability function corresponds to the Brooks-Corey equation with n = 1. The selected water saturation function corresponds to the van Genuchten equation with $\alpha = -0.01$ cm^{-1}, $\beta = 1$ and $\gamma = -1$.

Values of the saturated hydraulic conductivity and the porosity employed in the simulation are also depicted in Figure 4.1 together with simple linear relationships of k_{rw} versus S_w. Numerical solutions were obtained using equal mesh spacings, Δx = 1 cm, Δy = 4 cm and constant time increments, Δt = 0.01 days. Computed pressure head and water saturation profiles are plotted in Figures 4.2 and 4.3, respectively. In Figure 4.2, the pressure head profiles computed by VAM2D are compared with those computed by UNSAT2, the two-dimensional Galerkin finite element code, documented in Neuman et al. (1974) and Davis and Neuman (1983). It can be seen that there is good agreement between the two numerical solutions. For reference purposes, a tabulation of the values of inflow rate versus time obtained from VAM2D and UNSAT2 is provided in Table 4.1.

4.2.2 Transient Evaporation and Infiltration in a Soil Column

This problem concerns one-dimensional vertical flow in an unsaturated zone above a water table. It is selected to test the implementation of the Galerkin finite element formulation, the Picard iterative procedure, as well as the schemes for handling nonlinear atmospheric boundary conditions due to infiltration and evaporation. Two cases were simulated: case 1 involves infiltration and evaporation, and case 2 involves a no flow boundary condition on the top soil surface.

For case 1, the flow region representing a soil column is shown in Figure 4.3 together with the two-dimensional coordinate system used in the simulation. The soil properties are given in Table 4.2.

The flow region was discretized using a rectangular grid consisting of 40 elements and 82 nodes. A constant nodal spacing was used along each coordinate axis. The spacings in the x and y directions were Δx = 50 cm and Δy = 5 cm, respectively. Initially, the soil was assumed to be dry having a water phase saturation of 0.35. The bottom of the flow region

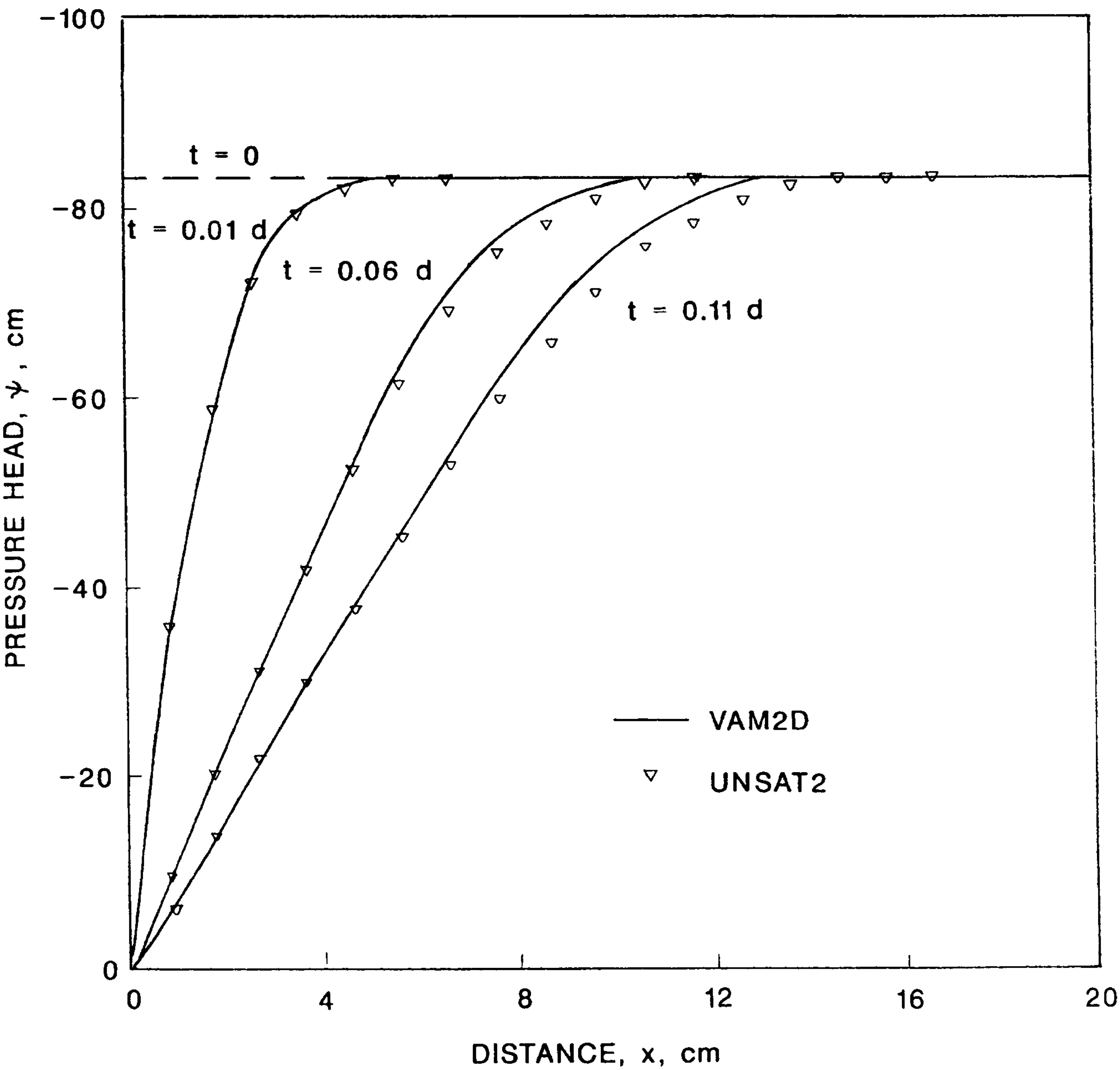


Figure 4.2. Pressure head distributions along the base and the top of the flow region.

Table 4.1. Net inflow rate versus time computed by VAM2D and UNSAT2 for test problem 4.2.1

Time (days)	Inflow rate (cm^3/day) VAM2D	UNSAT2
0.01	39.09	21.79
0.02	18.63	16.65
0.03	14.06	13.39
0.04	11.74	11.44
0.05	10.28	10.13
0.06	9.262	9.177
0.07	8.495	8.446
0.08	7.892	7.864
0.09	7.402	7.386
0.10	6.993	6.983
0.11	6.645	6.637
0.12	6.344	6.335
0.13	6.080	6.068
0.14	5.846	5.827
0.15	5.636	5.610

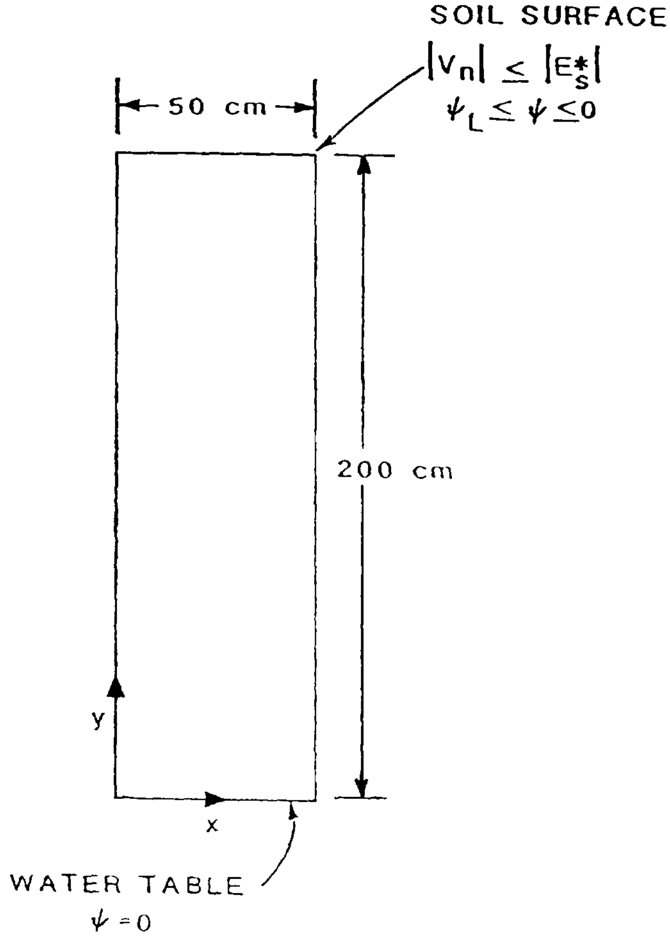


Figure 4.3. Geometry and boundary conditions used in the simulation of case 1 of the soil column problem.

Table 4.2. Soil Properties Used in the Simulation Case 1 of the Soil Column Problem.

Saturated hydraulic conductivity, K	10 $cm \cdot d^{-1}$
Porosity, ϕ	0.45
Residual water phase saturation, S_{wr}	0.333
Air entry value, ψ_a	0.0 cm
Maximum potential surface flux, $\lvert E_s^* \rvert$	5 $cm \cdot d^{-1}$
Minimum allowable pressure head at soil surface, ψ_L	-90 cm

Constitutive relations:

$$k_{rw} = (S_w - S_{wr})/(1 - S_{wr})$$

$$(\psi - \psi_a)/(\psi_r - \psi_a) = (1 - S_w)/(1 - S_{wr})$$

where ψ_r = -100 cm.

corresponds to the water table where a zero pressure head was prescribed. The soil surface was then subjected to infiltration (Case 1a) for the duration of 10 d. The maximum potential infiltration flux was prescribed as 5 $cm \cdot d^{-1}$. The simulation of the response to infiltration was performed for 18 time steps. The time stepping was started with an initial step of 0.1 d and was enlarged using a multiplier of 1.2 to a maximum value of 1 d. Computed pressure head distributions (Case 1a) are presented in Figure 4.4 for five time values. Also included in this figure are the numerical results from the UNSAT2 code, which illustrate reasonably good agreement between the numerical solutions from VAM2D and UNSAT2.

The soil surface was next subjected to evaporation (Case 1b). The potential evaporation flux was specified as 5 $cm \cdot d^{-1}$ for a second time period of 10 d. It took 22 time steps to cover the 10 d of evaporation. The time stepping was started with an initial step of 0.05 d and was enlarged using a multiplier of 1.2 to a maximum value of 1 d. Computed pressure head distributions (Case 1b) are presented in Figure 4.5 for typical time values. The numerical results from VAM2D are in excellent agreement with the results from UNSAT2.

Case 2 concerns one-dimensional vertical flow in an unsaturated zone above the water table. It is selected to test the implementation of the Galerkin finite element formulations, the Picard iterative scheme, as well as different schemes for handling mass lumping of the storage matrix. The problem is depicted schematically in Figure 4.6. A vertical column of soil 20 cm long was initially subjected to a hydrostatic presure head distribution. At later time values the pressure head at the lower end was maintained at zero value. A no-flow boundary condition was applied at the top end. Values of the saturated hydraulic conductivity and the porosity as well as the constitutive relationships were the same as those used in case 1. The simulation was performed for 15 time steps using a constant value of $\Delta t = 0.01$ d. Two schemes were used to obtain numerical solutions; mass lumping of the storage matrix (scheme 1) and no lumping (scheme 2). Results for t = 0, 0.01, 0.06, 0.11, and 0.15 d are plotted in Figures 4.7 and 4.8. The pressure head and saturation profiles computed by VAM2D and UNSAT2 are in good agreement. Note that the predicted position of water table and water saturation for scheme 1 is slightly ahead of scheme 2 for early time steps. This is probably due to the mass lumping of the element storage matrix.

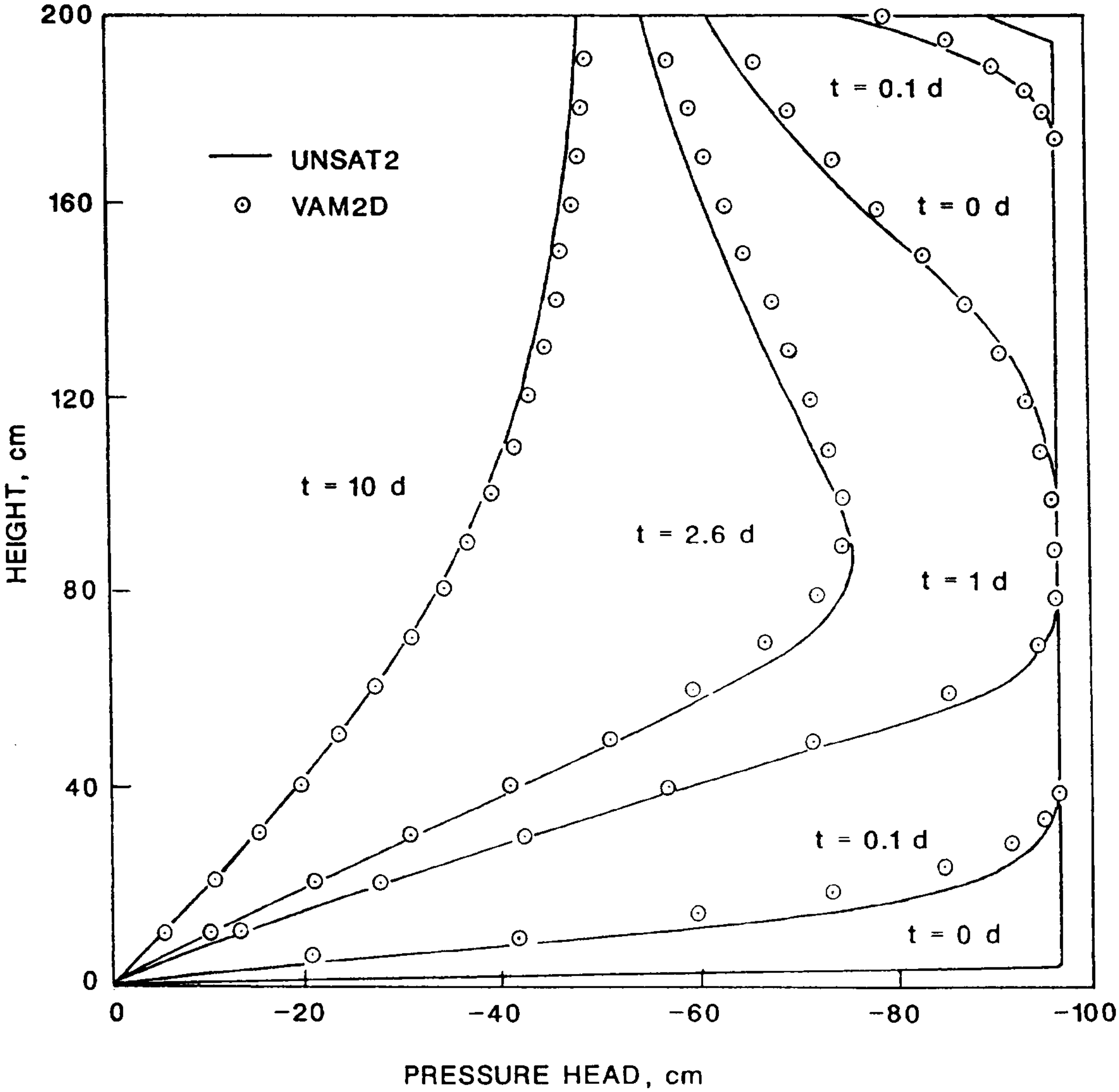


Figure 4.4. Pressure head distributions during infiltration for case 1a.

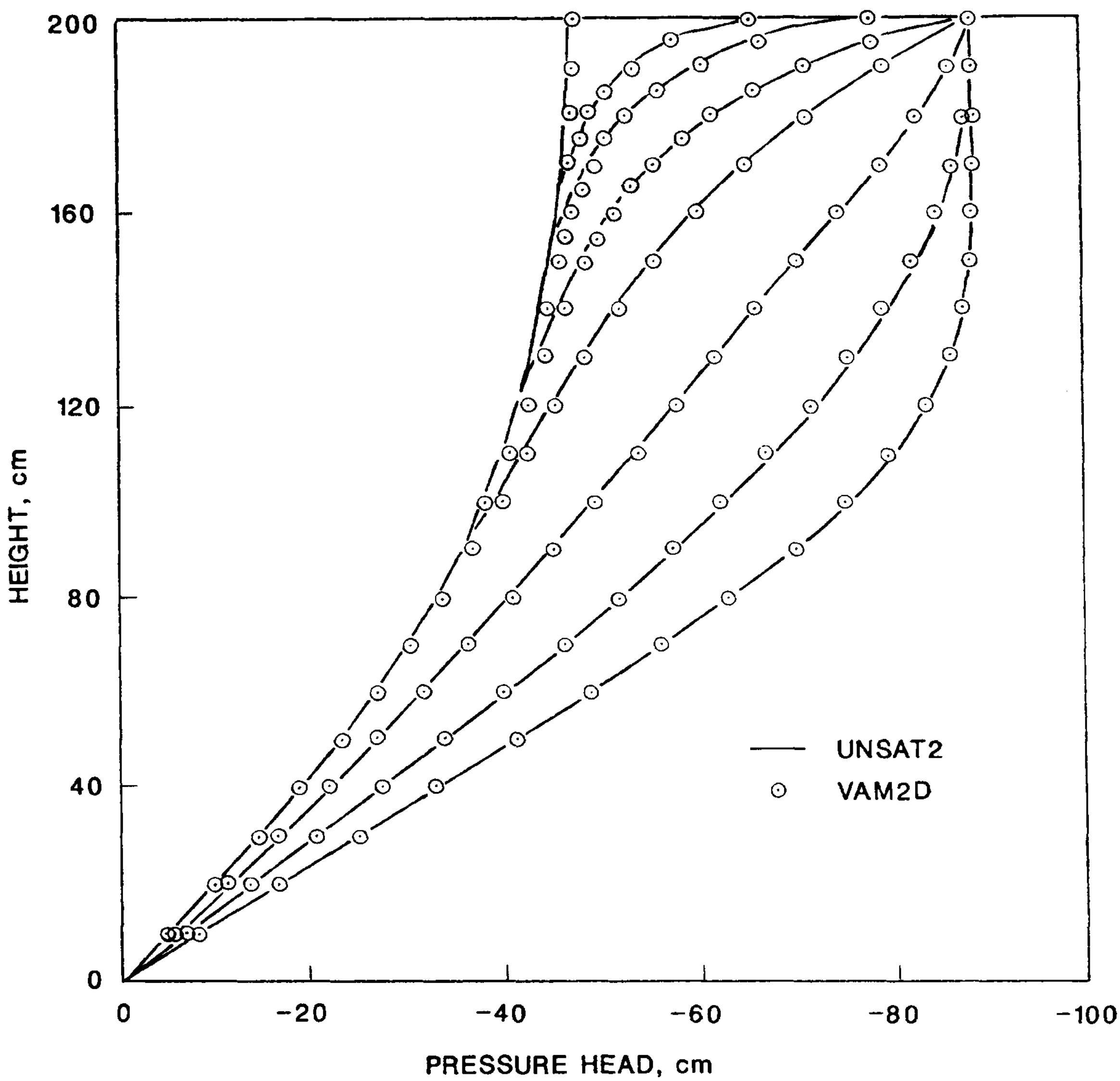


Figure 4.5 Pressure head distributions for the evaporation case 1b (time values from left to right = 0, 0.05, 0.11, 0.27, 0.65, 1.98, 4.37, and 10.0 d).

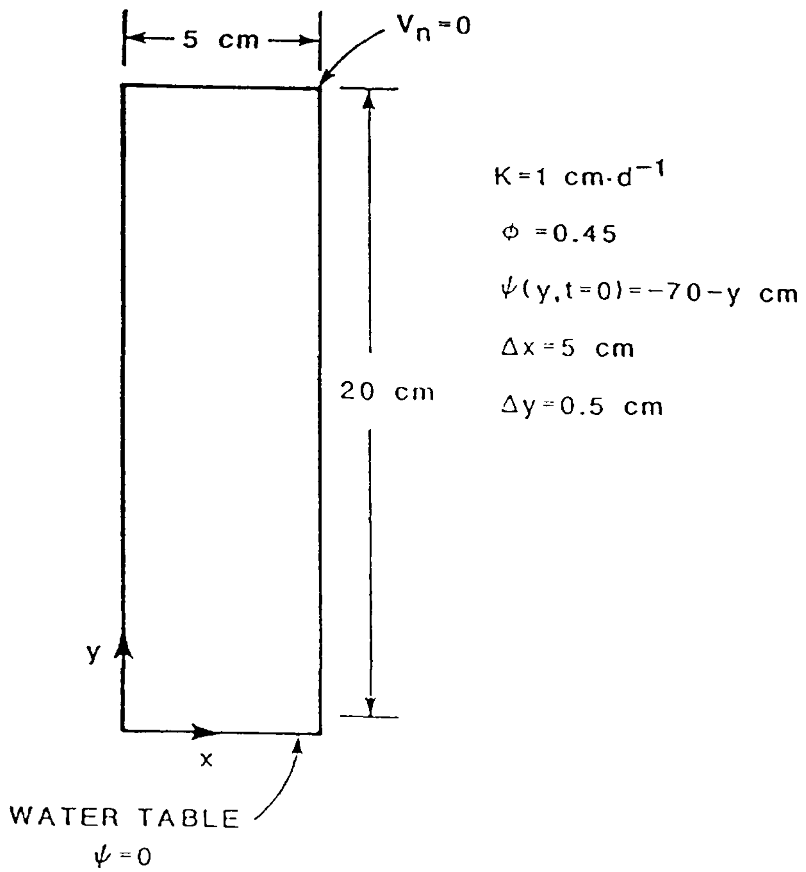


Figure 4.6. Geometry and boundary conditions used in the simulation of case 2.

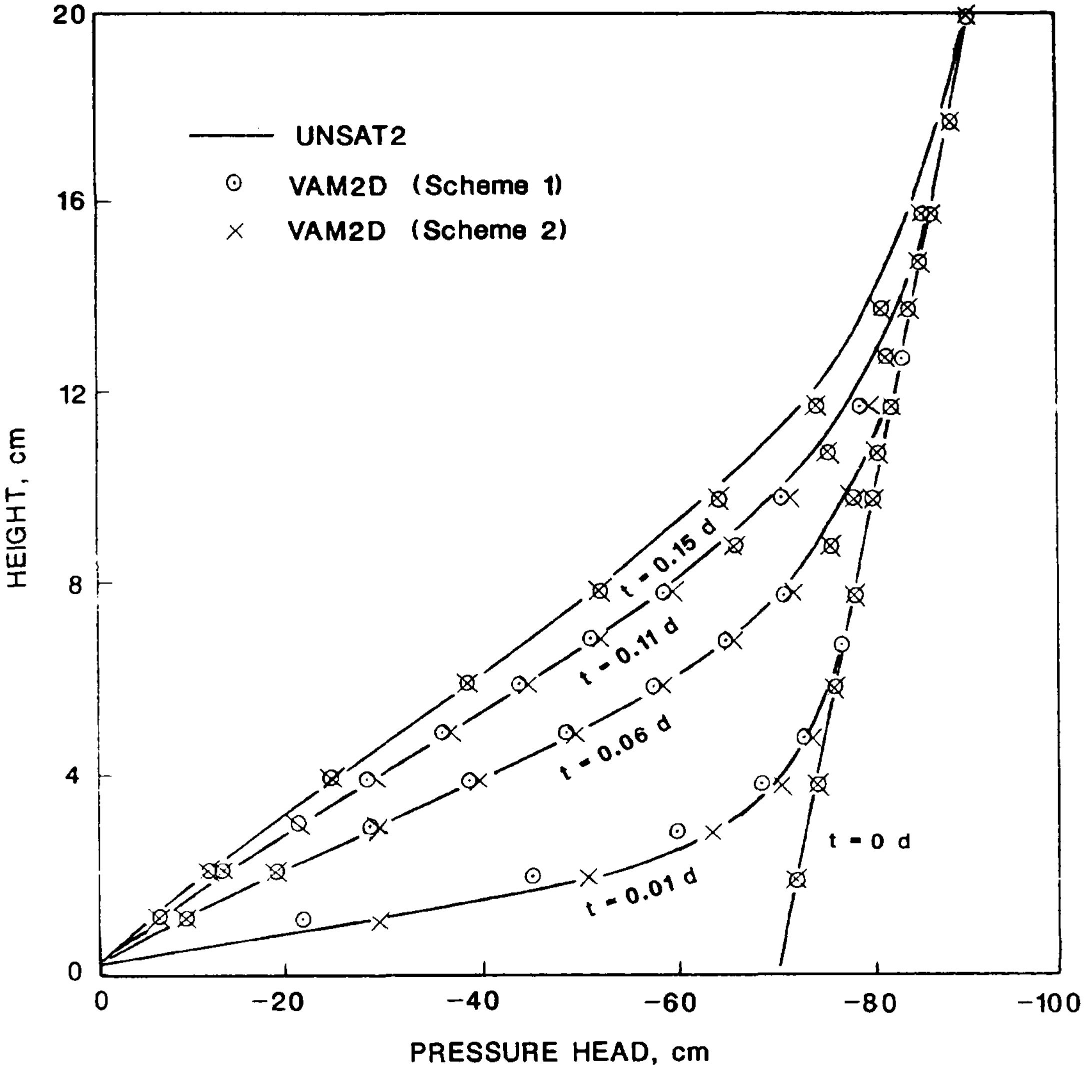


Figure 4.7. Pressure head distributions for case 2.

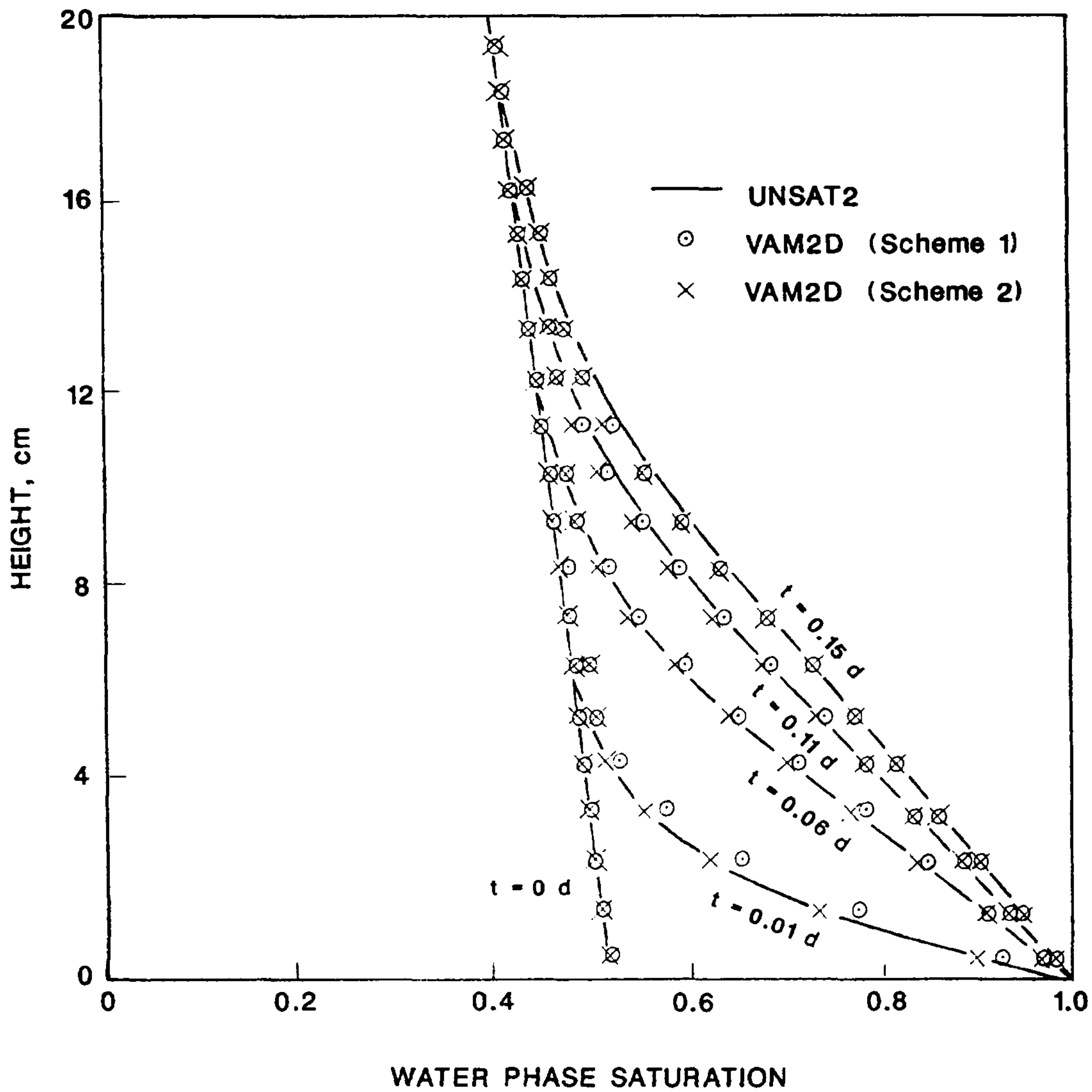


Figure 4.8. Water phase saturation profiles for case 2.

4.2.3 Transient Hysteretic Flow in a Soil Column

This problem involves transient, one-dimensional hysteretic flow in a vertical soil column subject to drainage and infiltration. The problem simulated is the slow-drainage rewet experiment described by Gillham et al. (1979). In this example the soil moisture relationship (Figure 4.9) exhibits considerable hysteresis. The data points in Figure 4.9 represent the experimental data, while the solid lines were obtained by performing a least-squares fit of van Genuchten equation to this data. The $K(S_w)$ relationship of the material (Dune Sand) is given by the following relationship

$$K = K_s (S_w)^n$$

Parameter values for the unsaturated flow constitutive relations are given in Table 4.3. The experimental configuration in the experiment of Gillham et al. consisted of an initially saturated, 60 cm tall column. The column was first drained and then rewetted by varying the pressure head at the base of the column. A plot of the controlled bottom boundary pressure head as a function of time is shown in Figure 4.10. The imposed variations in bottom boundary pressure head cause the column to drain (along the boundary drying curve), followed by rewetting (along primary wetting curves) after t = 60 minutes. The VAM2D simulation of this experiment is shown in Figure 4.11. The data points in this figure represent measured saturations at t = 68 min and t = 125 min. Saturation profiles predicted by VAM2D are represented by the solid lines. The dashed curve represents simulation results of Gillham et al. The measured data in Figure 4.11 can be seen to exhibit considerable scatter, especially in the upper part of the column. This was attributed by Gillham et al. to measurement error and lack of homogeneity of the sand material. The VAM2D simulation results and those of Gillham et al. are in generally good agreement with the measured results and with each other. Some deviations between the codes are apparent though. VAM2D predicts somewhat higher saturations between 10 and 20 cm elevation at t = 68 min, and there are also some differences between the two simulations at t = 125 min. These differences in saturation profiles are due mainly to differences in the way hysteresis is modeled in the two codes. At the first time value shown, t = 68 min, the part of the column below 27 cm elevation has started to rewet, while the upper part of the column is still draining. In the VAM2D simulation, the wetting-drying boundary at this time is predicted to be at 25 cm elevation. At t = 125 min, both the measured and simulated results indicate that the entire column is wetting. Allowing for the scatter in the experimental data, Figure 4.11 shows a quite good agreement between observed and simulated saturation profiles.

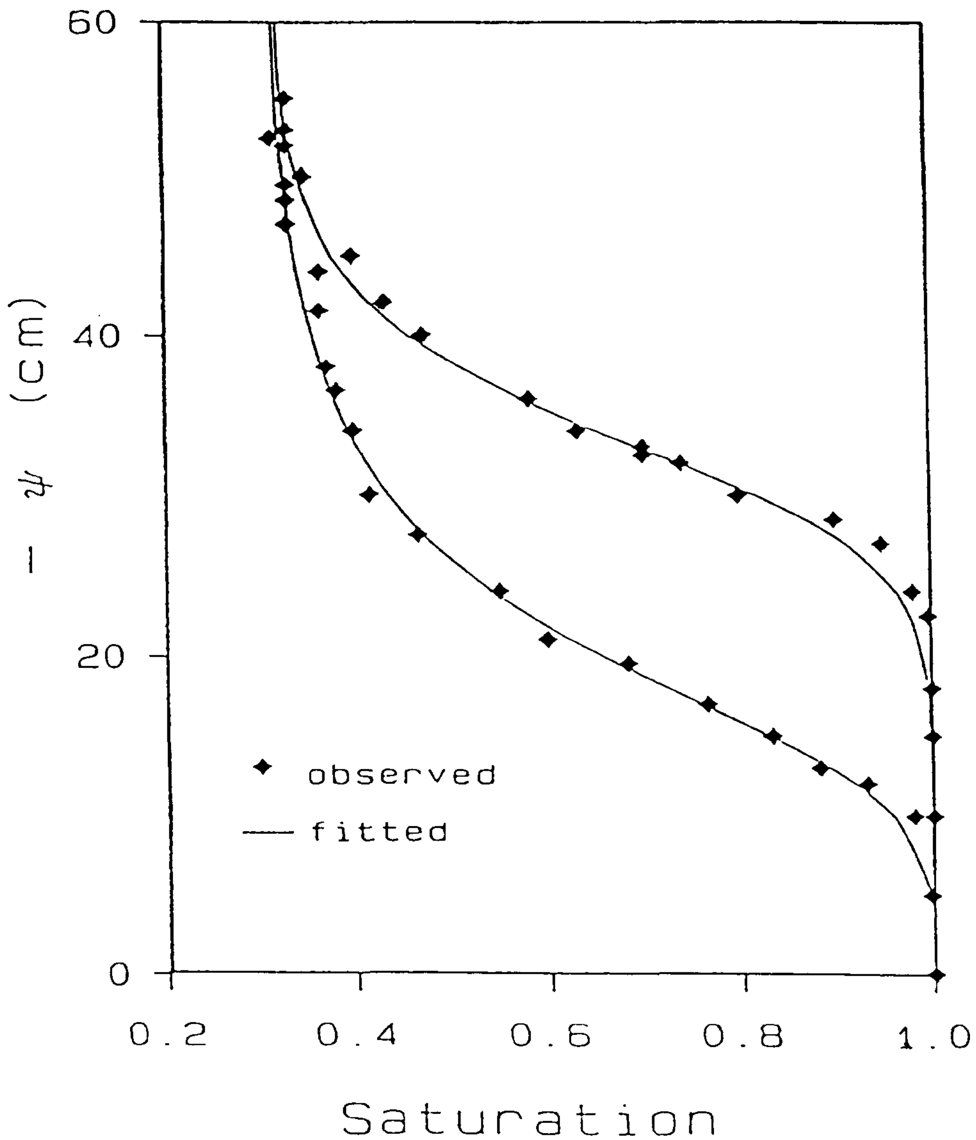


Figure 4.9. Boundary wetting and drying $S_w(\psi)$ curves of the Dune Sand used in problem 4.2.3. Data points represent measured data of Gillham et al. (1979). The curves represent fitted $S_w(\psi)$ functions.

Table 4.3. Parameters for unsaturated flow constitutive relations of Dune Sand.

Parameter	Value
Porosity, ϕ	0.301
Air entry pressure head, ψ_a	0.0
Wetting saturation, S_{ws}	1.0
Residual saturation, S_{wr}	0.332
Wetting curve parameter, α^w	0.0547 cm^{-1}
Wetting curve parameter, β^w	4.264
Wetting curve parameter, γ^w	0.765
Drying curve parameter, α^d	0.0302 cm^{-1}
Drying curve parameter, β^d	8.904
Drying curve parameter, γ^d	0.888
Saturated conductivity, K_s	23.56 cm/hr
Exponent, n	5.509

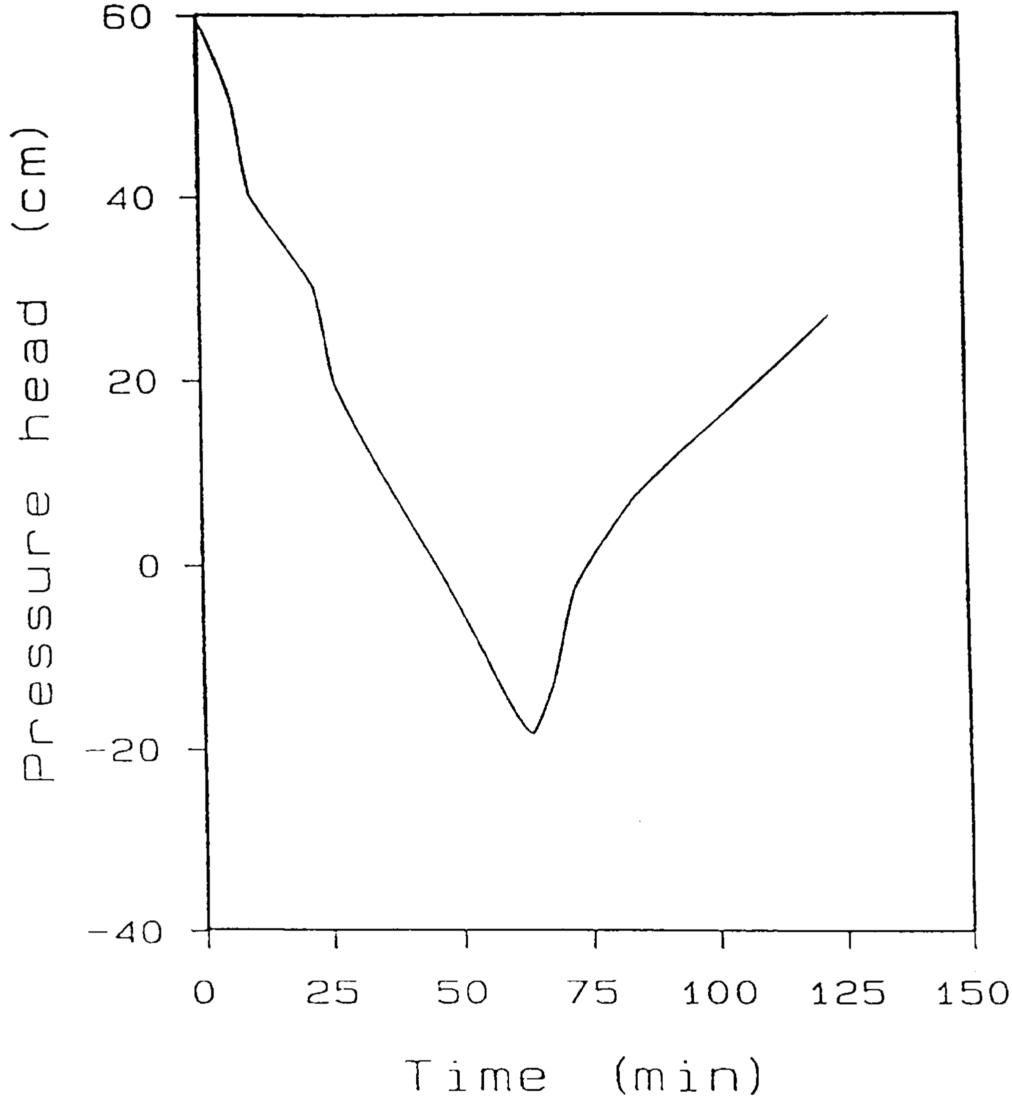


Figure 4.10. A plot of the controlled pressure head at the bottom of the soil column versus time for problem 4.2.3.

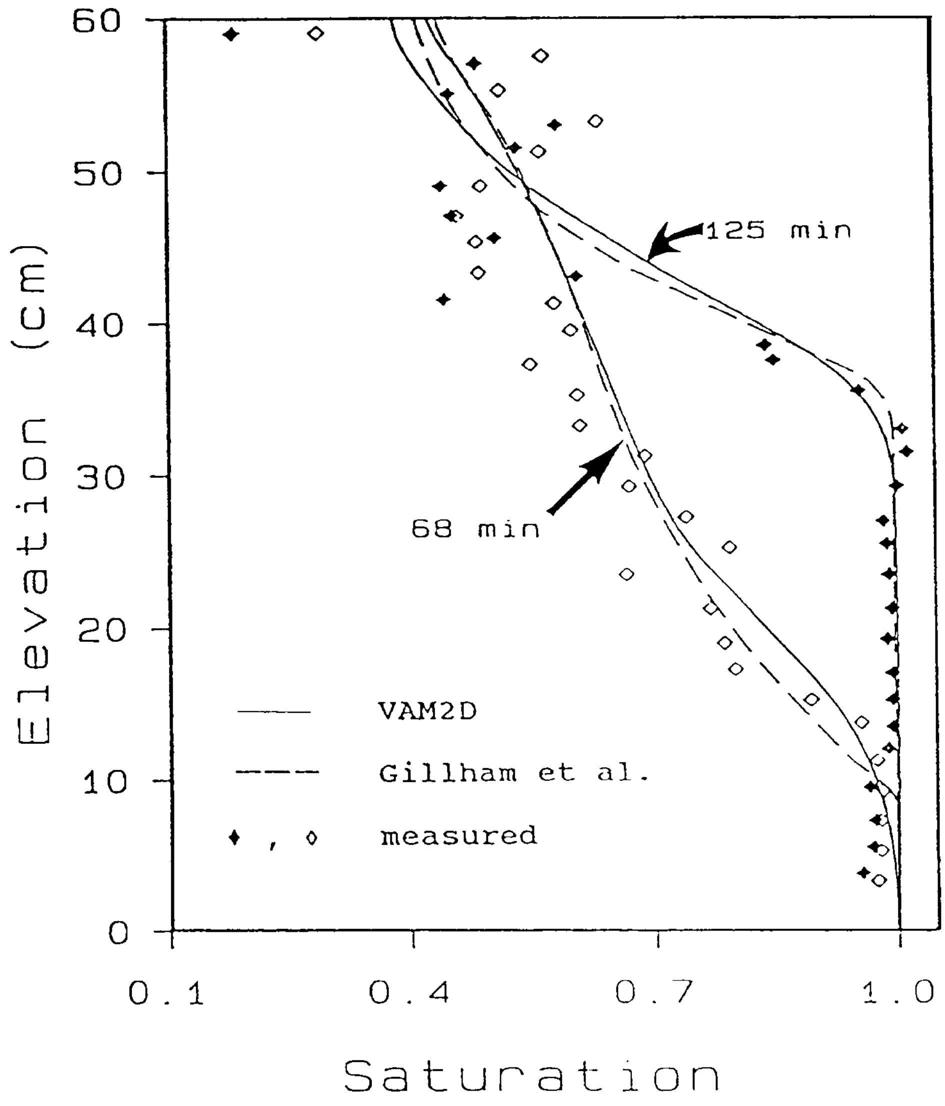


Figure 4.11. Comparison of measured and simulated saturation profiles at two time values.

4.2.4 Transient Two-Dimensional Flow in an Unconfined Aquifer Adjacent to a Landfill

In this example, a transient simulation of saturated-unsaturated flow in a complex groundwater system adjacent to a landfill site is presented. Data used in this simulation was assembled using some general information extracted from Silka et al. (1982). The cross section analyzed is depicted in Figure 4.12. Three distinct layers are considered. The top layer is made of a loam material, whereas the middle and the lower layers are made up of dissected clay and a mixture of clay and till, respectively. The landfill site corresponds to a canal which is presently backfilled with the loam and clay materials. There exists a semipermeable clay cap, extending over 125 m length from the center of the landfill, which corresponds to the right vertical boundary of the flow region. To control the water table position, a tile drain was placed at 100 m from the right vertical boundary. In addition, a pump was also placed in the basement of a building located at a distance of 207.5 m from the right vertical boundary of the landfill. This pump is normally put into operation whenever the water level in the basement lies above the bottom of the basement.

The initial condition for this problem corresponds to a static water level 32 m above the base of the clay and till layer. The boundary conditions are as shown in Figure 4.12. Note that the water level in the drain is fixed at 4 m below the base of the desiccated clay layer, and when the pump is in operation, the water level in the basement is fixed at 6 m from the top. Vertical recharge is applied to the top boundary at two different rates, as depicted in Figure 4.12.

The soil material properties used in the simulation are given in Table 4.4. The function of water saturation versus pressure head was taken from van Genuchten et al. (1977), whereas the function of relative permeability versus water saturation was taken from Brooks and Corey (1966) and Mualem (1976). Although the constitutive relations used in this example are not as highly nonlinear as those used in the two previous examples, the present simulation is probably as difficult as the previous simulations. This is because in the present case it is necessary to accommodate sudden and large changes of head values at the drain and the basement boundaries, as well as drastic changes of gradients of the nonlinear functions at certain saturated nodes which become unsaturated.

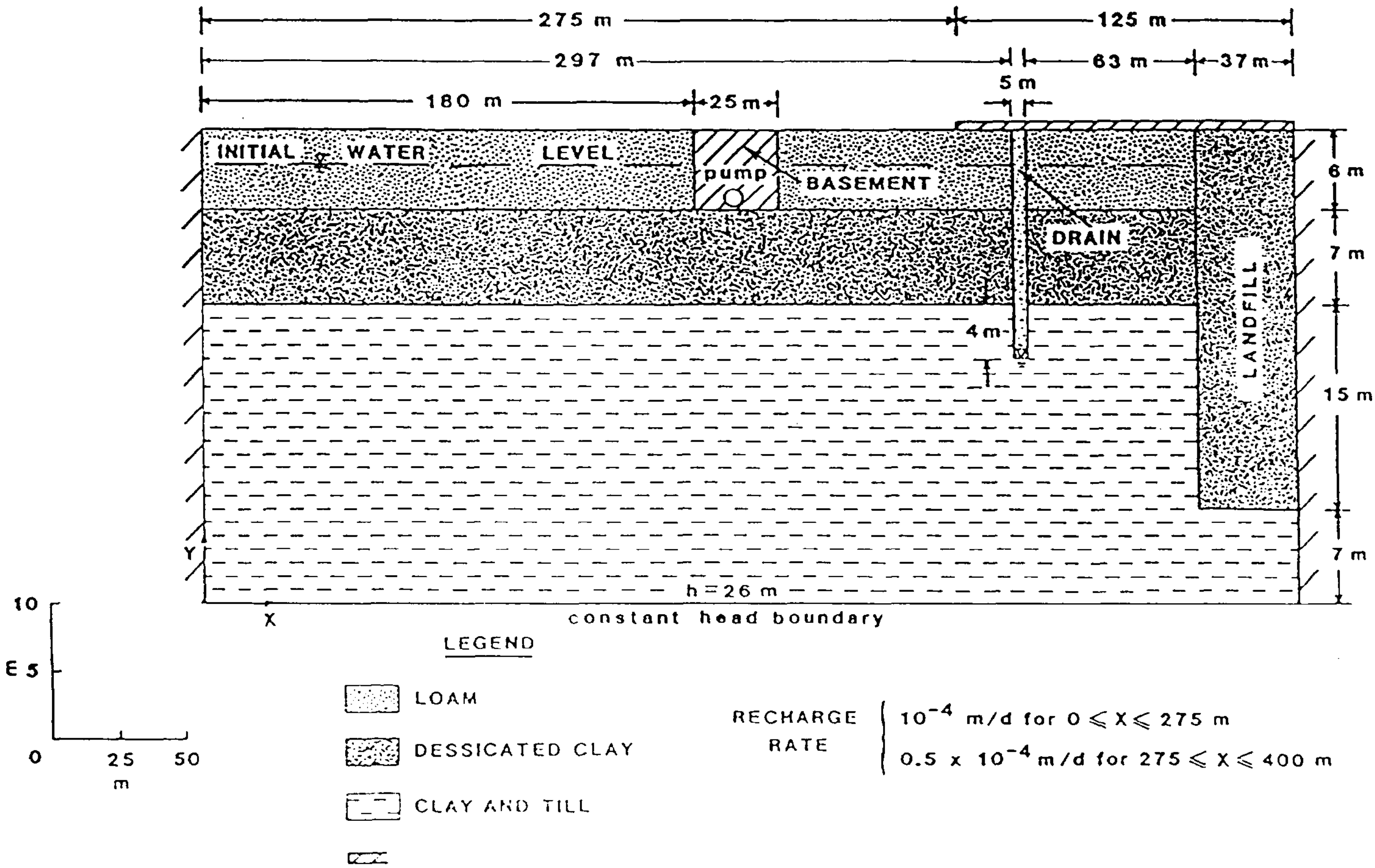


Figure 4.12. Schematic cross-section of the problem of transient flow in an unconfined groundwater system adjacent to a landfill.

Table 4.4. Material Properties for the Landfill Problem.

Material type	K, m/d	ϕ	S_s, m^{-1}
Loam	5×10^{-2}	0.45	10^{-3}
Desiccated clay	5×10^{-3}	0.60	2×10^{-3}
Clay and till	5×10^{-4}	0.60	2×10^{-3}

Material Type	S_{wr}	n	α, m^{-1}	β	γ
Loam	0.05	2	0.5	2	1.
Desiccated clay	0.20	2	0.282	1.5	1.
Clay and till	0.20	2	0.282	1.5	1.

Constitutive relations:

$$k_{rw} = S_e^n$$

$$S_e = 1/[1 + (\alpha \mid \psi \mid)^{\beta}]^{\gamma}$$

where $S_e = (S_w - S_{wr})/(1 - S_{wr})$.

Using the given physical parameter values and a moderately fine mesh consisting of 252 nodes and 225 elements (216 rectangles and nine triangles), the problem was solved for 40 time steps. The time step values were computed using the following algorithm: Δt_1 = d, Δt_k = 1.414, $\Delta t_{k-1} \leq$ 600 d, k = 2, ..., 40. The seepage face boundary condition at the drain was treated in a simple manner using a trial-and-error procedure similar to that given by Neuman et al. (1974). For most of the time the Picard algorithm took four or five iterations per time step, whereas the Newton-Raphson algorithm took three iterations to converge within a head tolerance of 10^{-4} m. Both nonlinear algorithms produced pressure head solutions which were very close to each other. To show the effects of drainage and pumping on the flow system, the hydraulic head profiles along y = 18.5 m and y = 29 m are plotted in Figures 4.13 and 4.14, respectively. Note that there is quite a significant difference between head values at the two elevations. This indicates significant vertical flow, particularly in the vicinity of the tile drain. Also evident is the influence of pumping at the basement. This causes the reversal of the hydraulic gradient in the horizontal plane, y = 18.5 m, and from the tile drain toward the basement.

Finally, a plot showing temporal variation of the drain flux is presented in Figure 4.15. Once again, it is apparent that the Picard and the Newton-Raphson algorithms produced virtually identical results. The drain flux curve approaches the steady state value asymptotically, which implies a long-time attainment of equilibrium between the withdrawal and the replenishment of water in the flow system.

4.2.5 Transient Two-Dimensional Flow in a Root Zone

This problem concerns transient flow in root zone subject to a prescribed amount of infiltration. The problem is depicted in Figure 4.16. The purpose is to demonstrate another application of VAM2D to a different type of field problem. The modeled root zone is 100 cm thick and comprised of three layers with contrasting hydraulic properties. Although this particular problem is only one-dimensional, it was analyzed using a rectangular grid consisting of 256 nodes (16 rows and 16 columns of nodes). The reason for this was the intention to test the efficiency of the preconditioned conjugate gradient matrix solvers using a typical two-dimensional grid. Both flow and transport problems were solved. In this section, only the flow simulation result is presented. VAM2D input and output files for this flow simulation are presented in Section 10.2. The transport simulation will be dealt with in Section 4.3.5. The

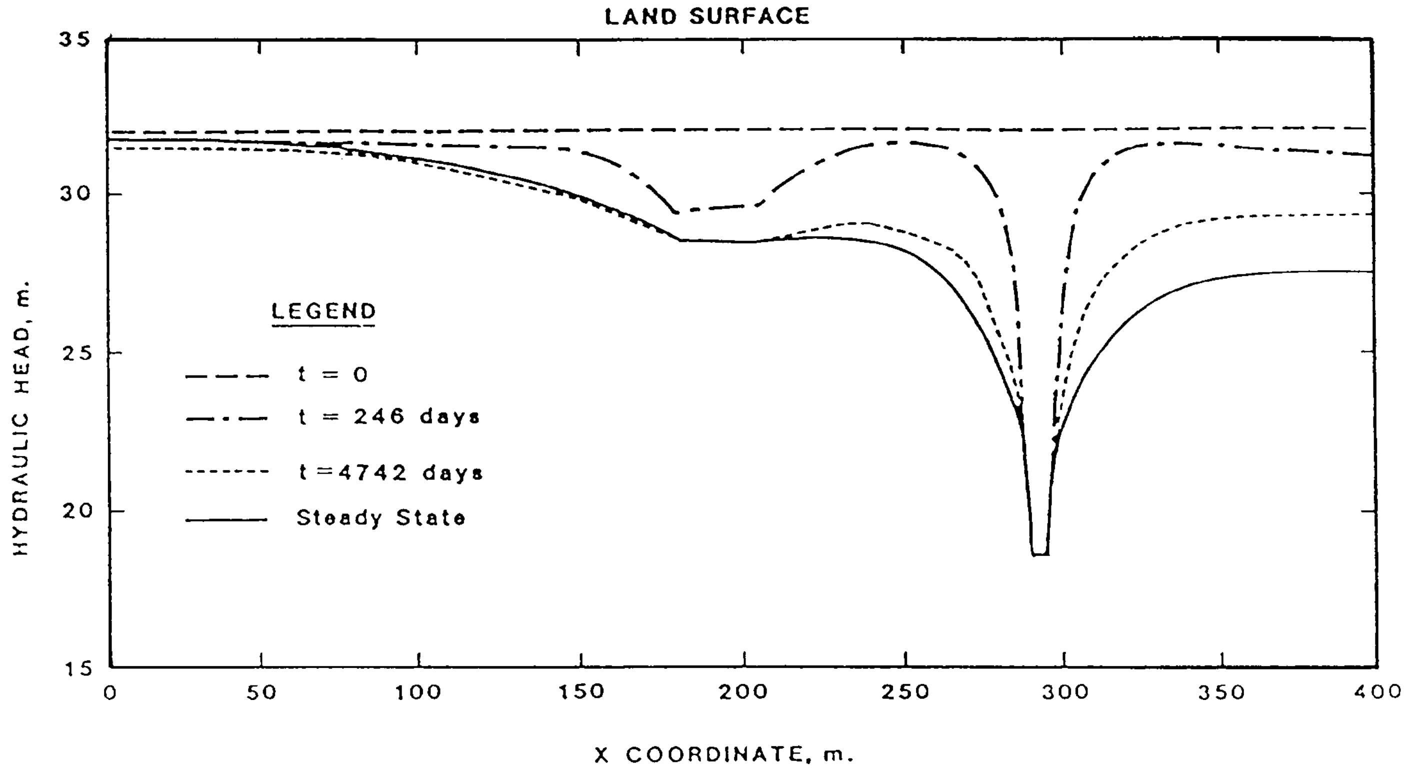


Figure 4.13. Hydraulic head distributions along y = 18.5m.

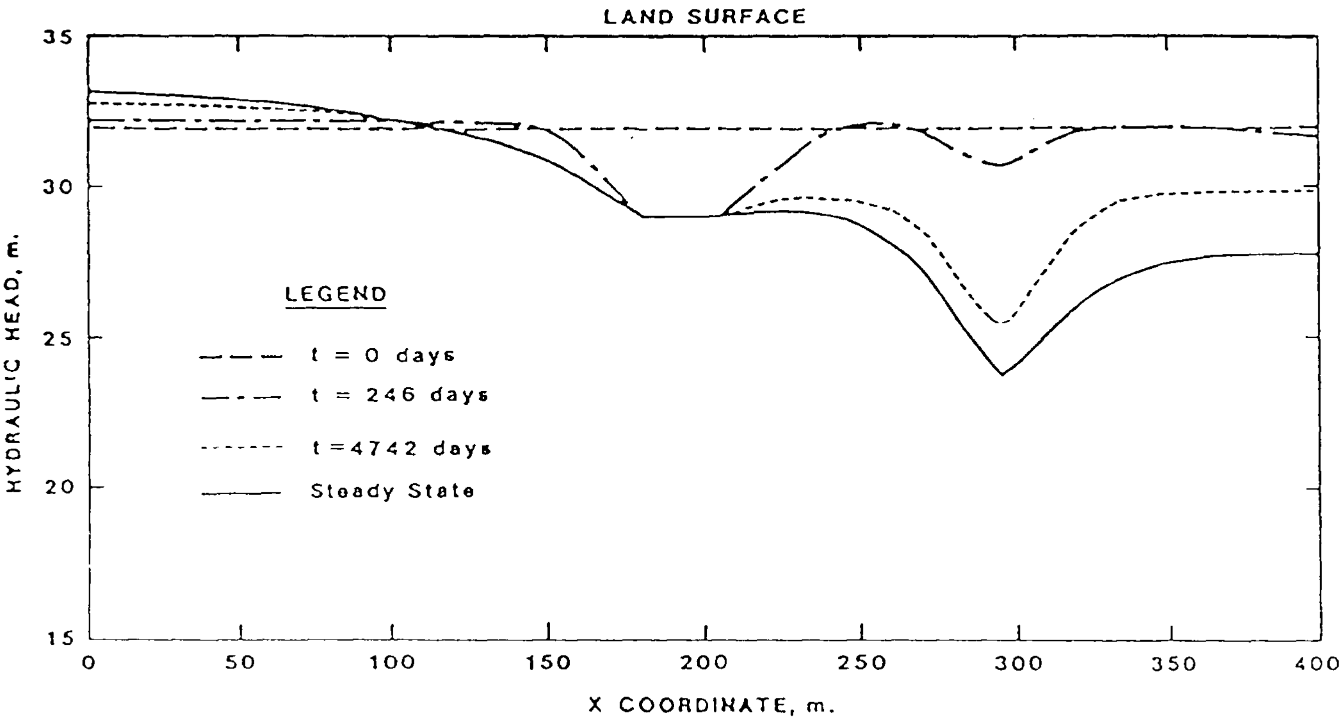


Figure 4.14. Hydraulic head distributions along y = 29m.

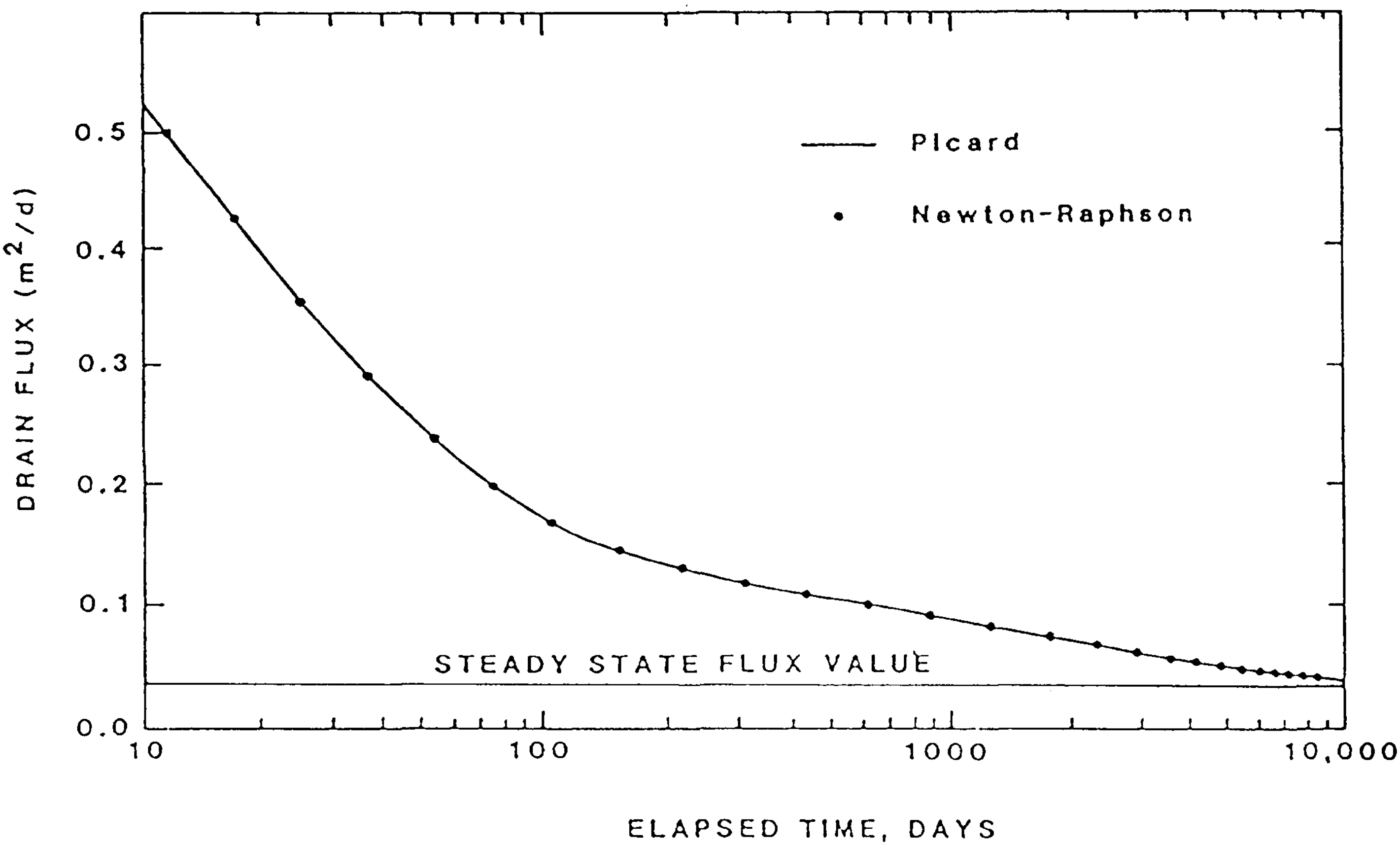


Figure 4.15. Temporal variation of drain flux.

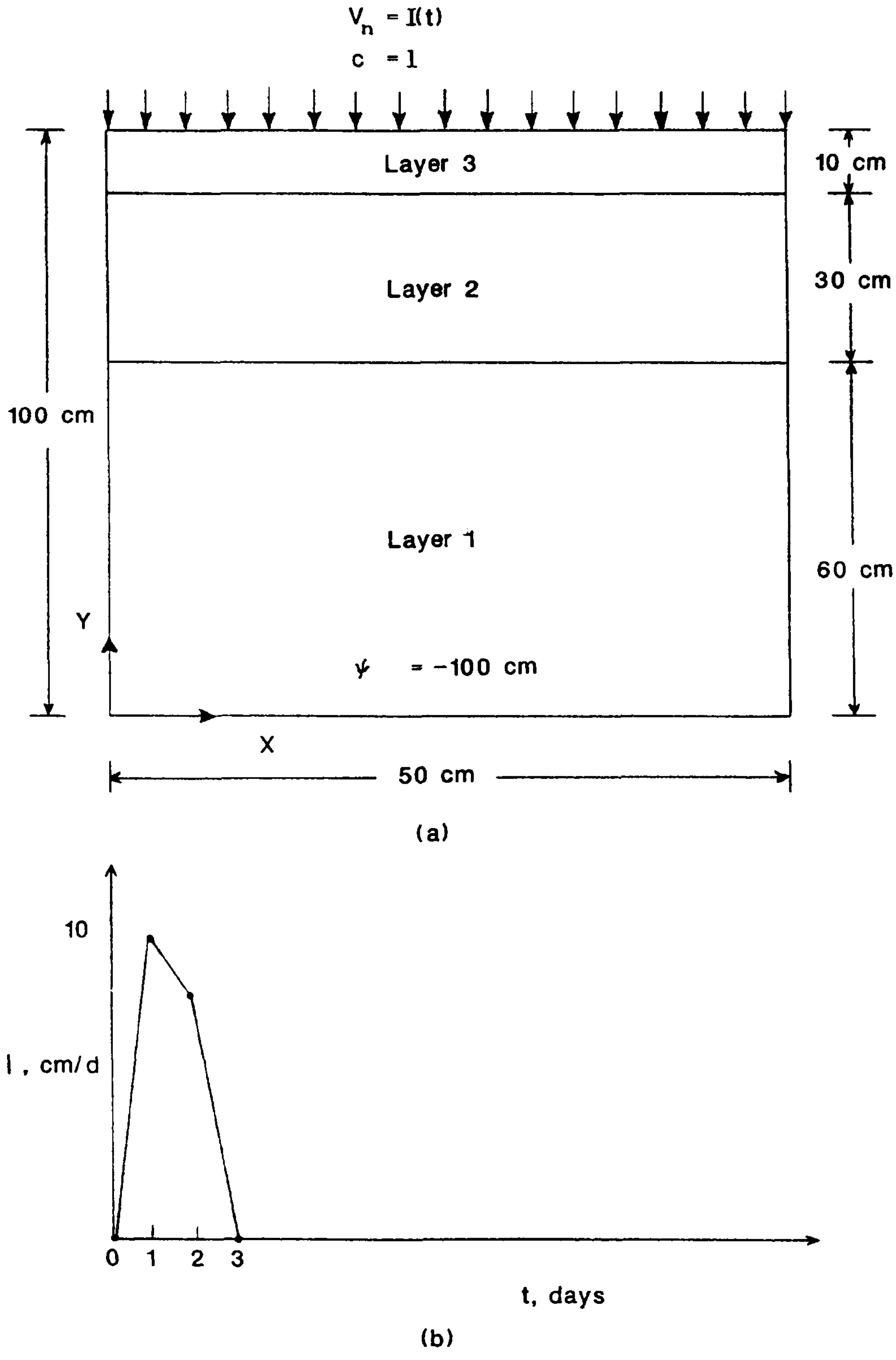


Figure 4.16. Schematic description of the root zone problem.

material properties used in the flow simulation are summarized in Table 4.5. Initially, it was assumed that the pressure head distribution in the root zone system was hydrostatic. Transient infiltration was then applied to the top soil for a period of 3 days. The flow simulation was performed for 20 time steps using the Picard scheme with a constant time step value of 0.5 days. Shown in Figures 4.17 and 4.18 are pressure head and water saturation profiles, respectively. The ability of the VAM2D code to accommodate rapid response and contrasting properties of the soil system may be noted.

4.2.6 Steady-State Two-Dimensional Flow Beneath a Landfill

This problem concerns moisture movement and groundwater flow in the unsaturated and saturated zones of an unconfined aquifer system beneath a sanitary landfill. A steady-state analysis of the flow scenario depicted in Figure 4.19 is required before a transient simulation of leachate migration from the landfill can be made. The hydraulic properties of the aquifer are assumed to be homogeneous and isotropic. The hydraulic conductivity, K, and the effective porosity, ϕ, are 750 m/yr and 0.25, respectively. The constitutive relations used to describe soil moisture characteristics in the vadose zone are as follows:

$$k_{rw} = ((S_w - 0.25)/0.75)^4$$

and

$$(S_w - 0.25)/0.75 = [1 + (0.2\psi)^2]^{-1}$$

Note that the soil moisture relations for this particular problem are highly nonlinear. A rectangular grid consisting of 651 nodes and 600 elements was set up to represent the flow region. The nodal spacings in the x and y directions were kept uniform and equal to 5 m and 1.75 m, respectively. The steady-state simulation was performed in one step (without time marching) using the Newton-Raphson scheme. Satisfactory convergence was achieved in 9 iterations. Shown in Figure 4.20 are simulation results. For the vertical section directly below the center of land disposal unit, water saturation profiles computed by VAM2D and a simplified one-dimensional finite element code (VADOFT, documented by Huyakorn et al., 1987) are compared in Figure 4.20a. There is reasonable agreement between the two-dimensional (VAM2D) and the one-dimensional (VADOFT) numerical solutions. It can be seen in Figure 4.20b, flow in the unsaturated zone is vertically dominant up to a depth of approximately 5 m above the water

Table 4.5. Material properties used in the simulation of root zone problem.

Layer no.	K, cm/d	ϕ	S_s cm^{-1}
1	350	0.41	0
2	25	0.43	0
3	10.8	0.45	0

Layer no.	S_{wr}	n	α cm^{-1}	β
1	0.14	1	0.124	2.28
2	0.18	1	0.036	1.56
3	0.15	1	0.02	1.41

Constitutive relations:

$$k_{rw} = S_e^n$$

$$S_e = 1/[1 + (\alpha \mid \psi \mid)^{\beta}]^{\gamma}$$

where $S_e = (S_w - S_{wr})/(1 - S_{wr})$

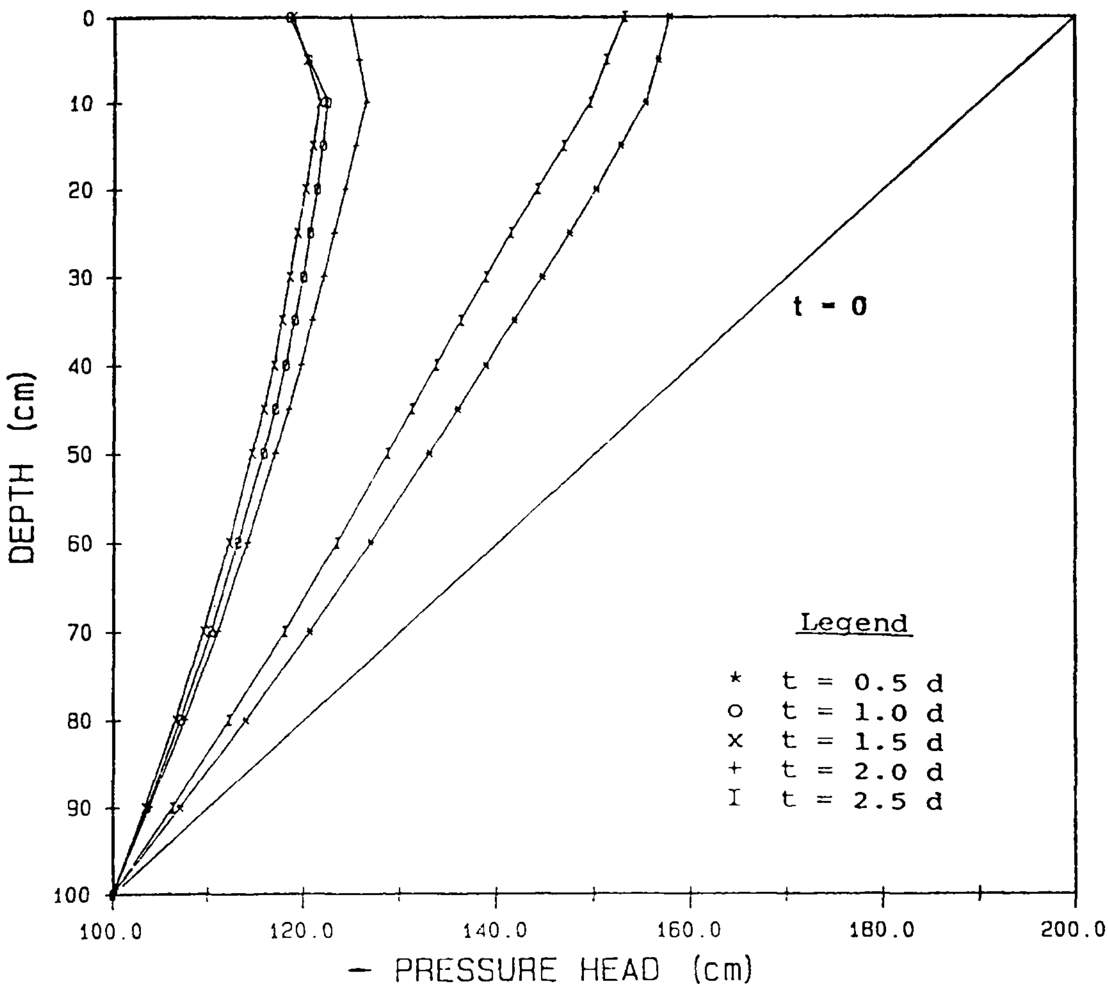


Figure 4.17. Simulated profiles of pressure head in the root zone.

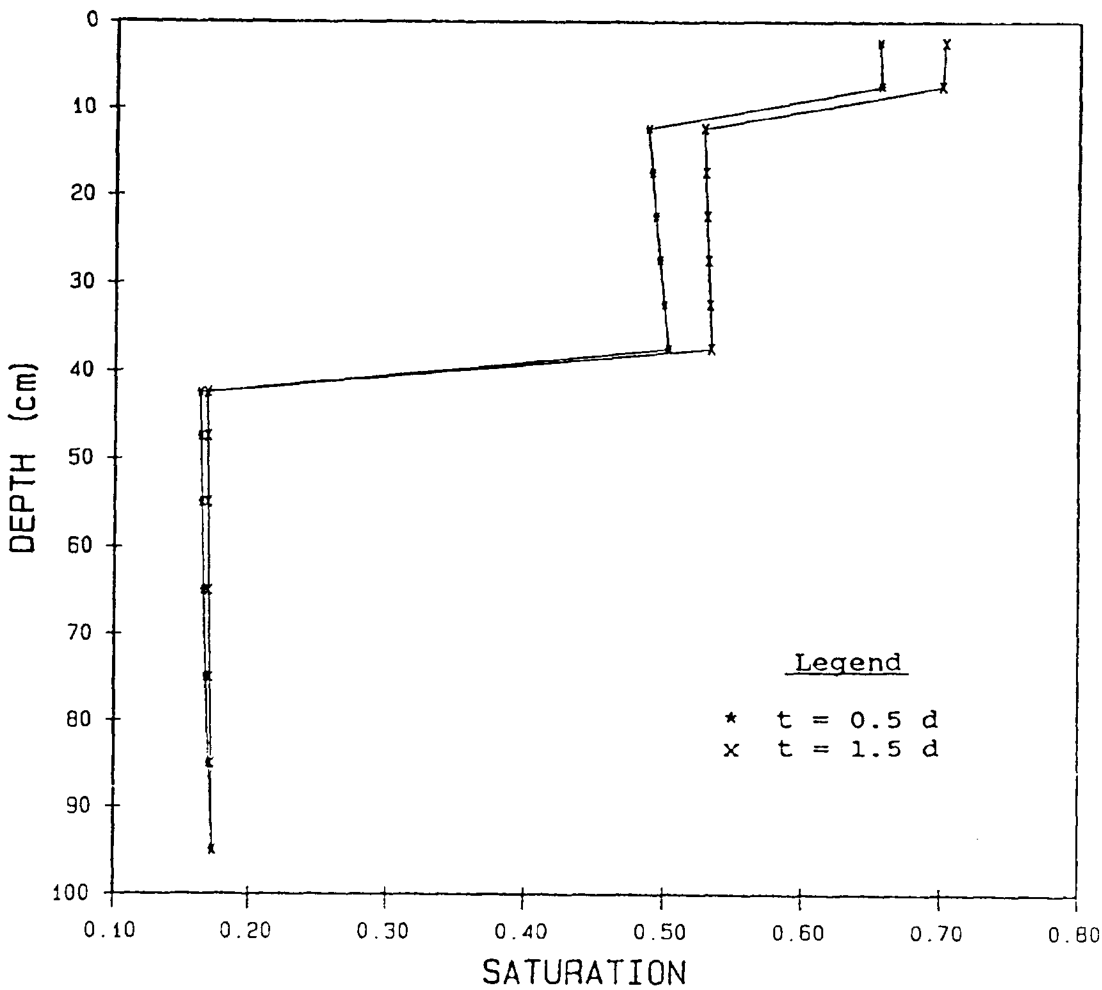


Figure 4.18. Simulated profiles of water-phase saturation in the root zone.

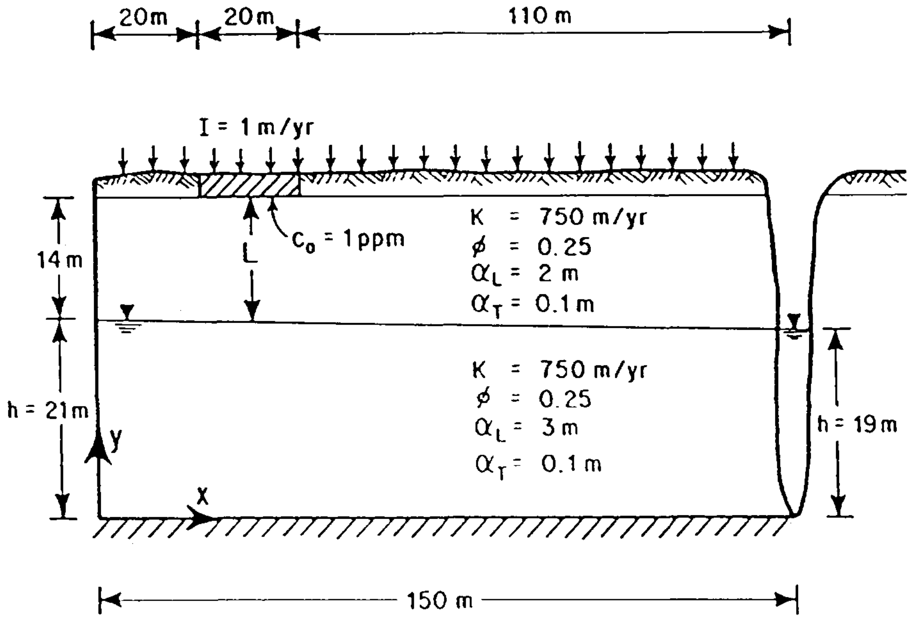
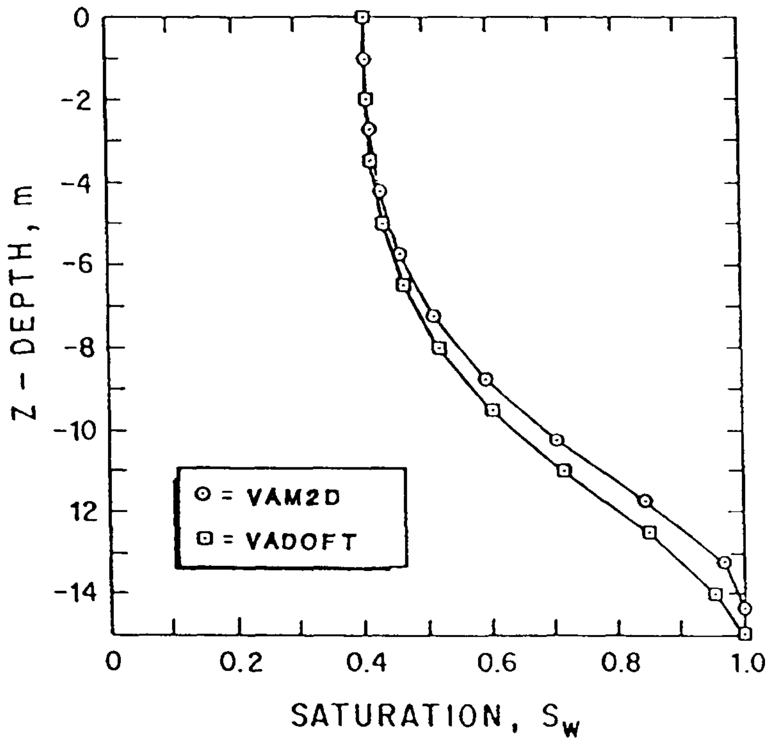
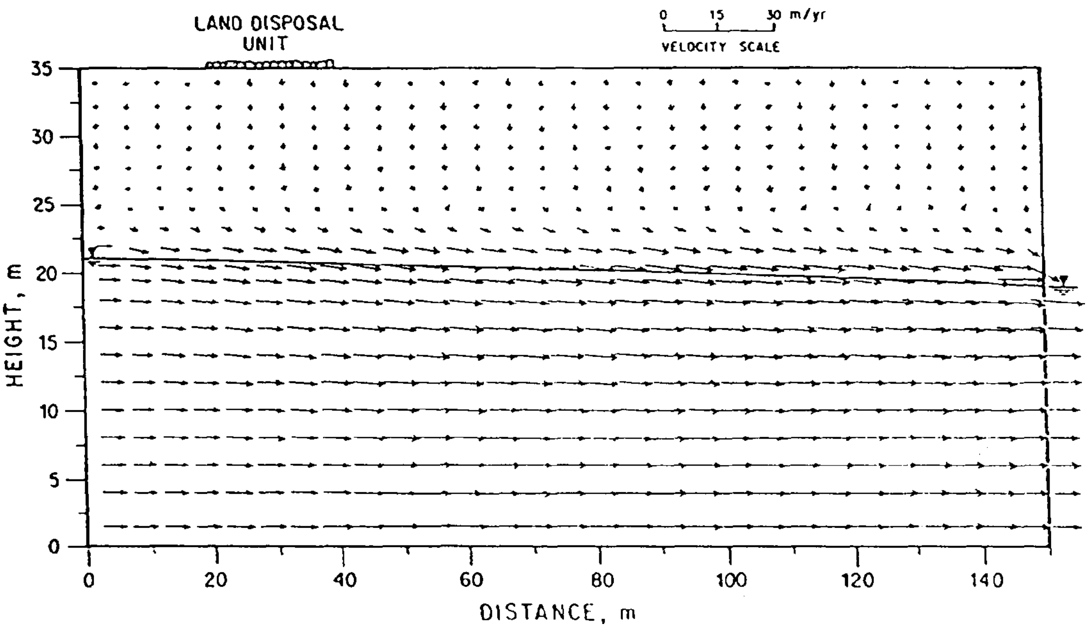


Figure 4.19. Schematic description of the simulated case of water flow and leachate migration in an unconfined system beneath a landfill.



(a)



(b)

Figure 4.20. Simulated saturation profiles and velocity field.

table. As the water particle approaches the water table its flow direction becomes laterally dominated. This deviation from the strict one-dimensional flow assumption used in the VADOFT code is likely to be the cause of the difference in the two saturation profiles depicted in Figure 4.20a.

4.2.7 Transient Infiltration Under Dry Soil Condition

This problem concerns transient vertical infiltration under an initially dry soil condition and a severely nonlinear soil moisture characteristics. The scenario considered is typical situation of infiltration in the vadose zone of a deep groundwater system in a semi-arid region. Shown in Figure 4.21 are the temporal variation of infiltration and characteristic curves used in the simulation. The functional description of these curves and other relevant hydraulic properties for the simulated case are presented in Table 4.6. The moisture characteristic curves plotted in Figure 4.21 are fitted curve derived from moisture data reported by Abeele et al. (1981) for solid Bandelier tuff. The water table was assumed to be located at a depth of 350 m below the soil surface. A column grid consisting of 101 rectangular elements and 202 nodes was adopted. The simulation was performed over a time period of 5 yr using target step values of 0.1 yr. To handle the highly nonlinear condition, the Newton-Raphson scheme with upstream weighting and lumping of storage matrix was used. The code took between 3 and 10 iterations to achieve satisfactory convergence. Shown in Figure 4.22 are simulated profiles of water saturation corresponding to 5 annual time values. As expected, the profiles exhibit steep fronts and varying shape in response to the temporal variation of infiltration.

4.3 SOLUTE TRANSPORT PROBLEMS

4.3.1 One-Dimensional Transport in a Soil Slab

The purpose of this problem is to test the coding of the finite element formulation for a case involving advective-dispersive transport in an unsaturated porous medium. The problem concerns one-dimensional transport of a non-conservative species in an unsaturated soil slab identical to that described in Section 4.2.1. Velocities obtained by solving the corresponding unsaturated flow problem were used as input data for the current transport problem. Initial and boundary conditions required by the model are depicted in Figure 4.23 together with values of the physical parameters used.

The numerical solution was obtained using a mesh consisting of 20 rectangular elements, each with Δx=1 cm. The problem was run for 20 time steps with a constant value of

Table 4.6. Material properties used in the simulation of transient vadose-zone infiltration problem.

Saturated hydraulic conductivity, K	35 m/d
Saturated water content, ϕ	0.4
Specific storage, S_s	0 m^{-1}

Constitutive relations:

$$k_{rw} = S_e^{3.69}$$

$$S_e = 1/[1 + (\alpha|\psi|)^{\beta}]^{\gamma}$$

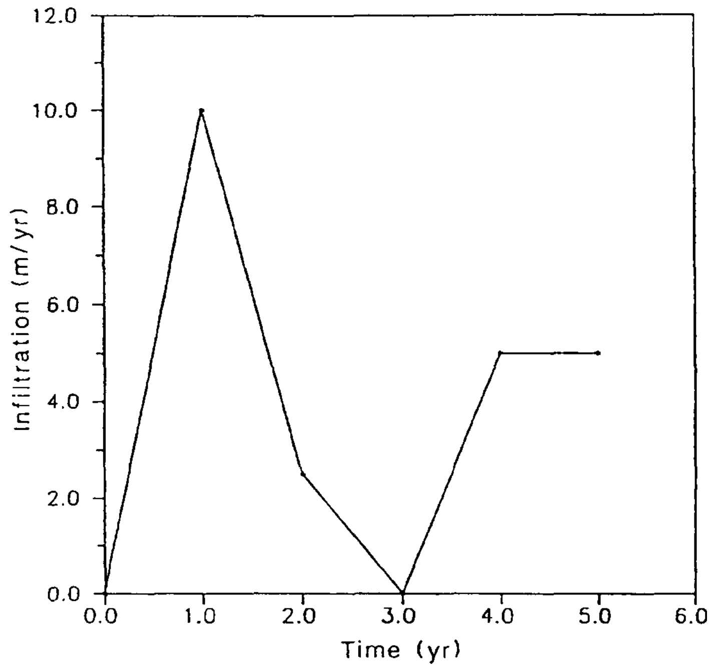
where

$$S_e = (S_w - S_{wr})/(1 - S_{wr})$$

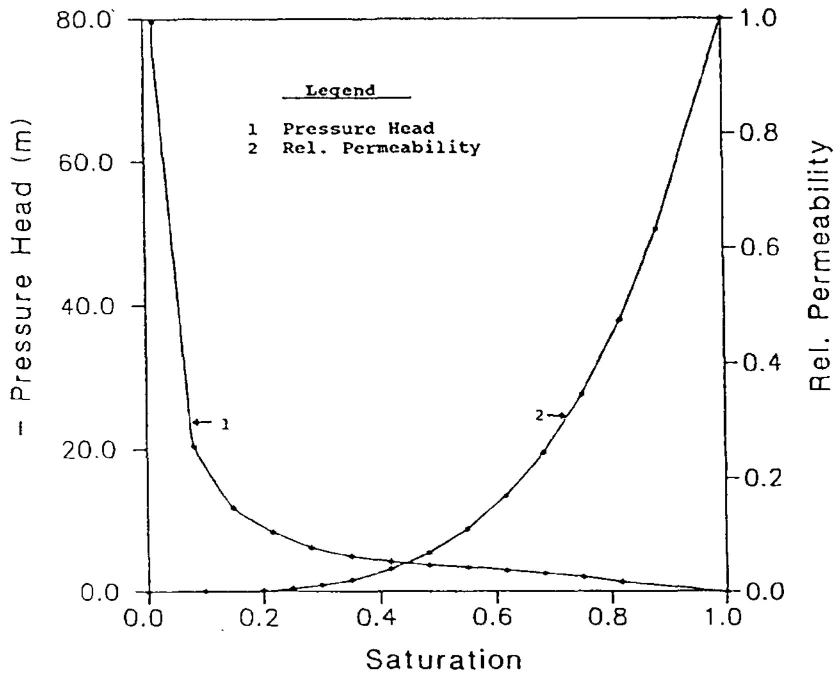
$$\alpha = 0.423\ m^{-1},\ \beta = 2.22$$

$$\gamma = 1 - 1/\beta$$

$$S_{wr} = 0.025$$



(a)



(b)

Figure 4.21. Infiltration data and moisture characteristic curves used in the simulation of the vadose-zone infiltration problem.

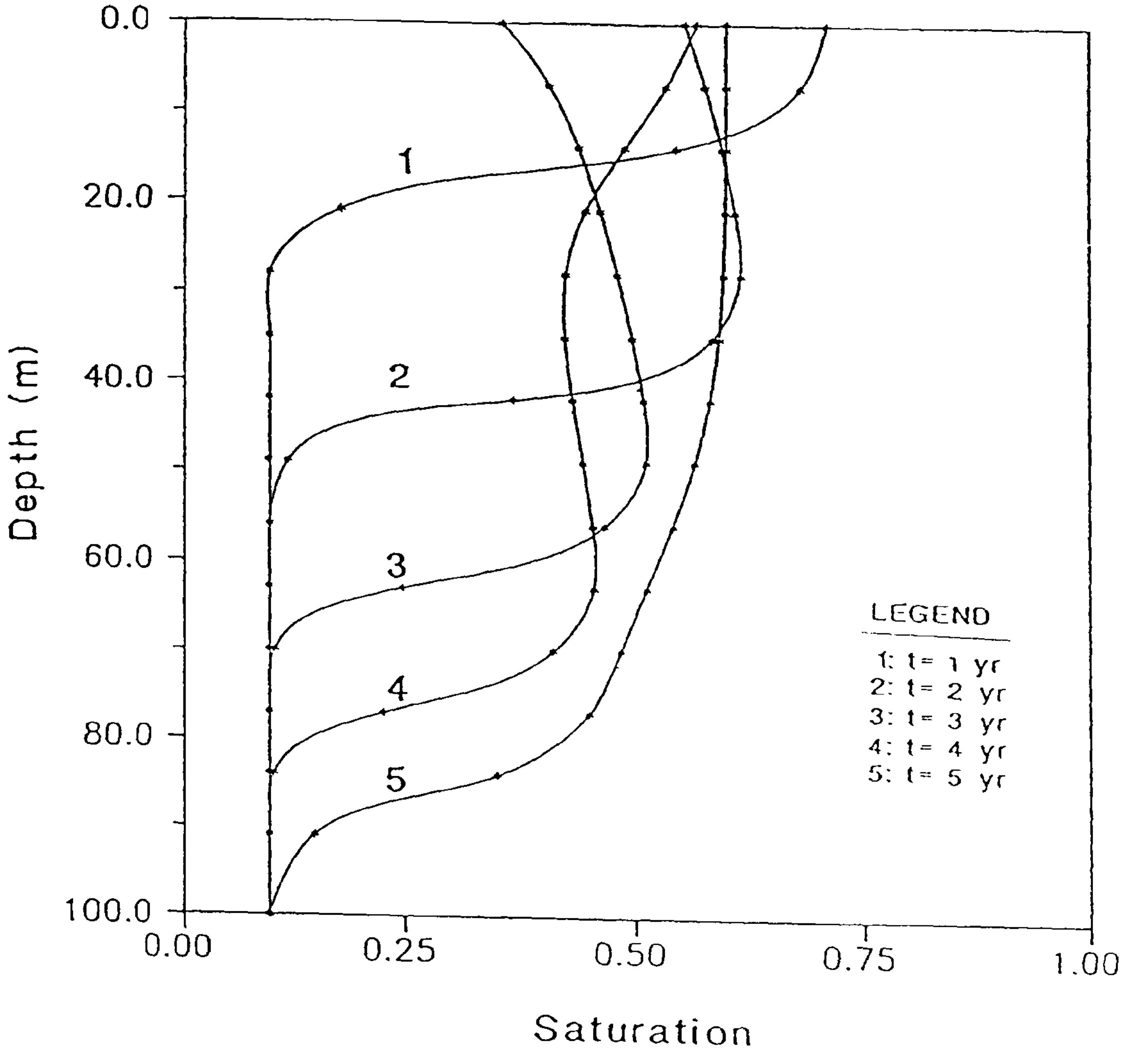
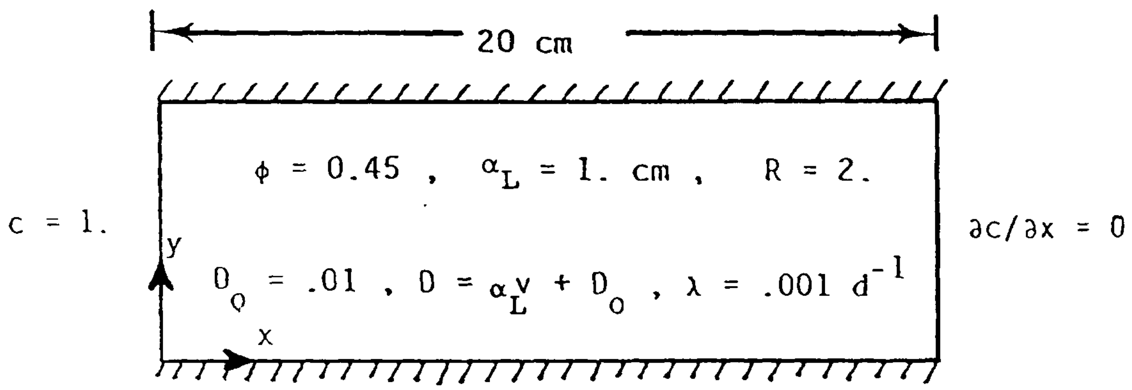


Figure 4.22. Simulated profiles of water-phase saturation at 5 annual time values.



Initial Conditions : $c(x,t=0) = 0.$

Discretization Data: $\Delta x = 1$ cm , $\Delta t = .01$ d

Figure 4.23. Schematic description and data for the problem of transport in a soil slab.

$\Delta t=0.01$ days. Typical velocity profiles used in the transport calculation are illustrated in Figure 4.24. It is important to recognize that for the unsaturated flow case considered, the velocity distribution is time-dependent and this fact must be taken into account in the mass balance calculation to avoid obtaining an incorrect result. Computed concentration profiles at 0.04 and 0.2 days are depicted in Figure 4.25. The result of the mass balance calculation is displayed by the plots shown in Figures 4.26 and 4.27. The behavior of the mass balance error versus time relationship should be observed. Note that the mass balance error for this particular case is very small.

4.3.2 Two-Dimensional Transport in a Soil Slab

This problem concerns transport of a nonconservative solute in a rectangular cross section of an unsaturated soil. As illustrated in Figure 4.28, the soil is initially dry and water and solute are allowed to enter the system at the upper portion of the left-hand boundary, $x = 0$ and $6 \leq y \leq 10$ cm. The right-hand boundary, which corresponds to the outlet, is maintained at the same initial pressure head value. At the inlet, the pressure head is maintained at $\psi = 6 - y$, and the solute concentration is assumed to be 1 ppm. No flow and zero normal concentration gradients are applied to the remaining portions of the entire boundary.

Values of the physical parameters required are given in Table 4.7. Values of water saturation and Darcy velocities at different times were determined by analyzing the associated flow problem. Both flow and transport were simulated using a medium rectangular grid. The grid was a uniform 11 x 16 grid comprised of 176 nodes and 150 elements. The nodal spacings were $\Delta x = \Delta y =$ 1 cm. Time increment values were generated within the code using the algorithm: $\Delta t_1 = 0.01$ days, $\Delta t_k = 1.2\Delta t_{k-1} \leq 0.05$ days.

The transport simulation was performed for 15 time steps using the Galerkin scheme. (Upstream weighting was not applied in this case because the cell Peclet number, $Pe = \Delta x/\alpha_L$, was not large enough to create numerical oscillations.) For verification purposes, the solution obtained using the present finite element model is compared in Figures 4.29 and 4.30 with the corresponding Galerkin solution obtained using the FEMWASTE code. Evidently, the overall agreement between the two numerical solutions is reasonable. The horizontal concentration distributions depicted in Figure 4.29 are all smooth, although the profile predicted by the present model appears to be slightly ahead of that predicted by FEMWASTE. Note, however, that at the two later time values the vertical concentration distributions computed by FEMWASTE exhibit undesirable oscillations and incorrect representation of the zero normal gradient boundary condition at the top boundary,

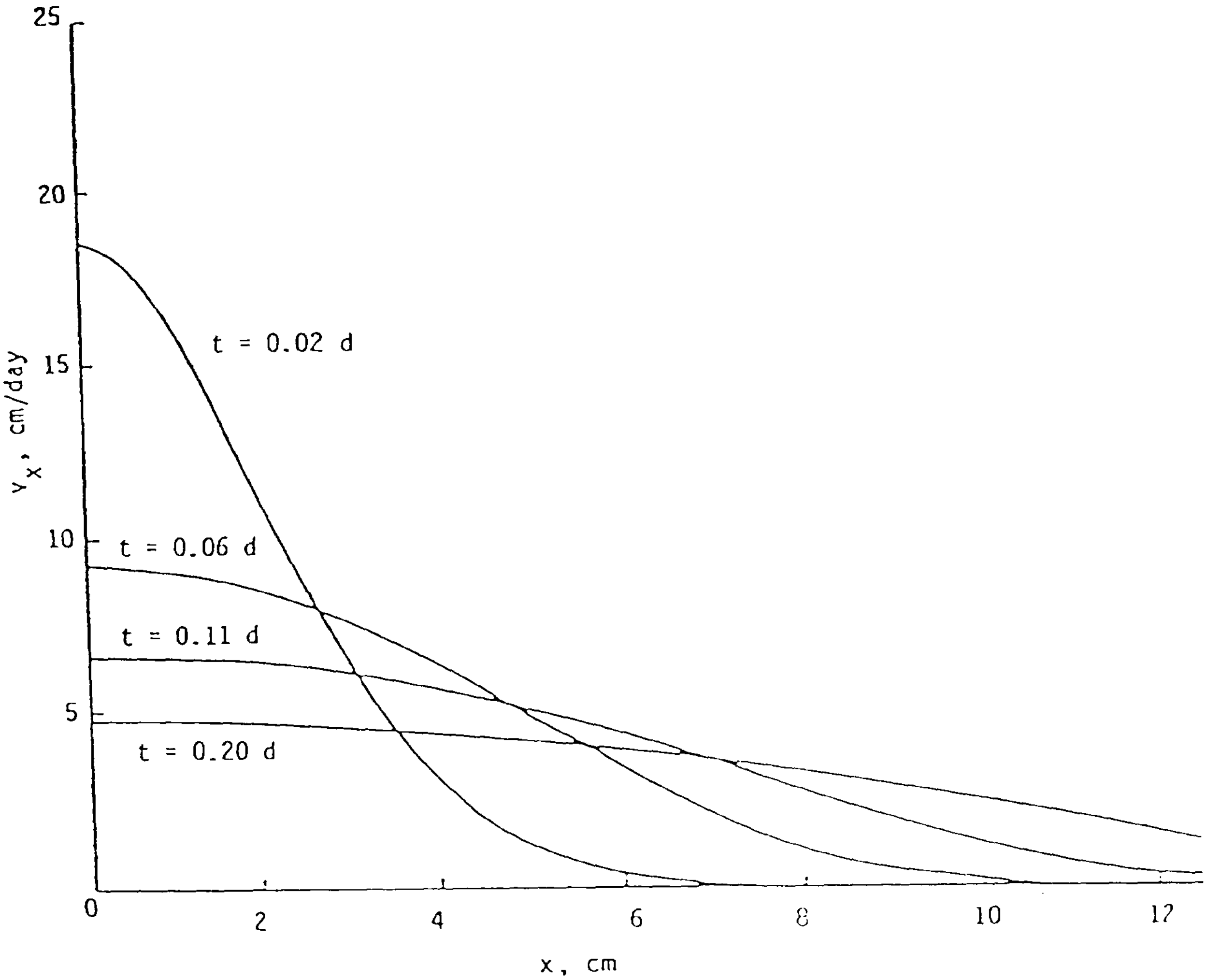


Figure 4.24. Typical velocity profiles used in the one-dimensional transport analysis.

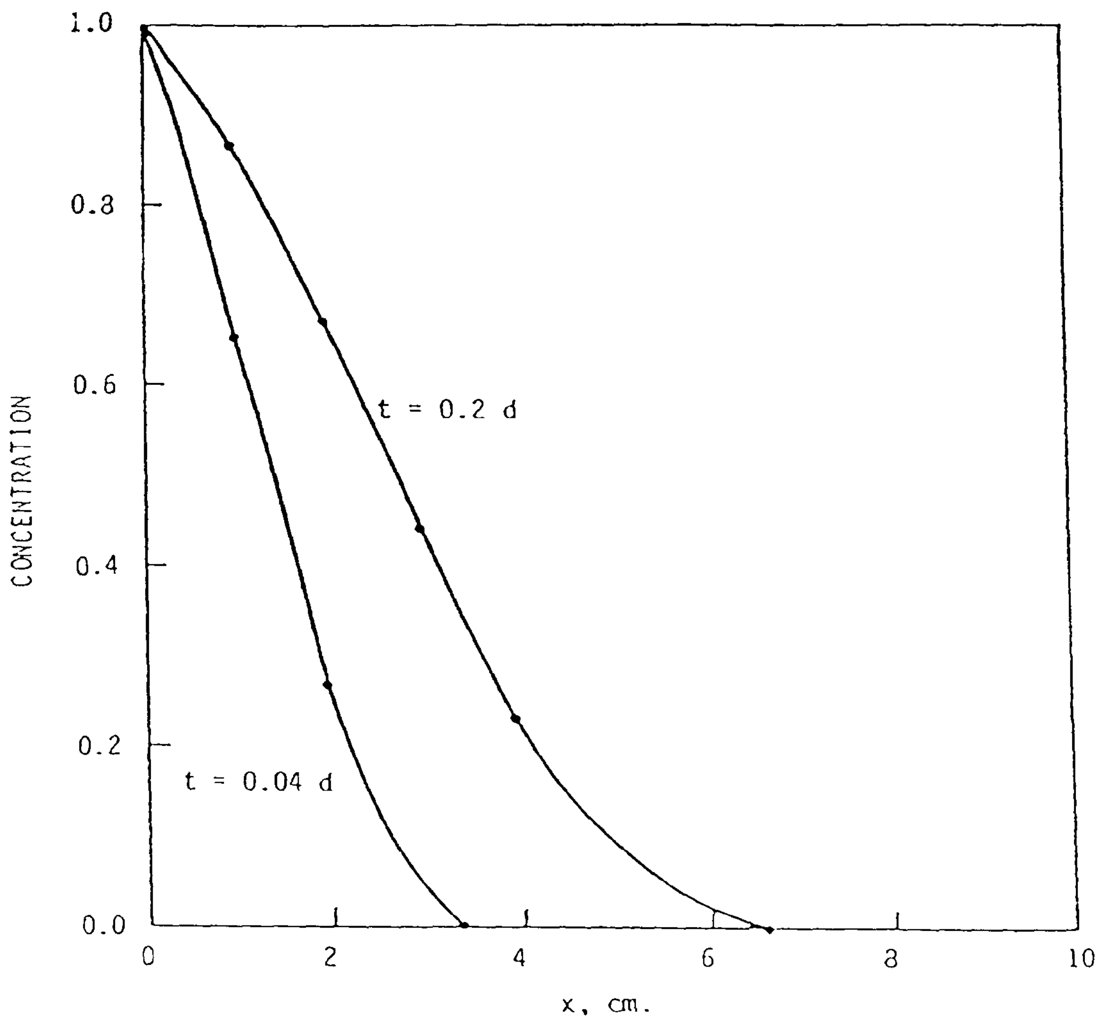


Figure 4.25. Simulated concentration profiles for the one-dimensional transport problem.

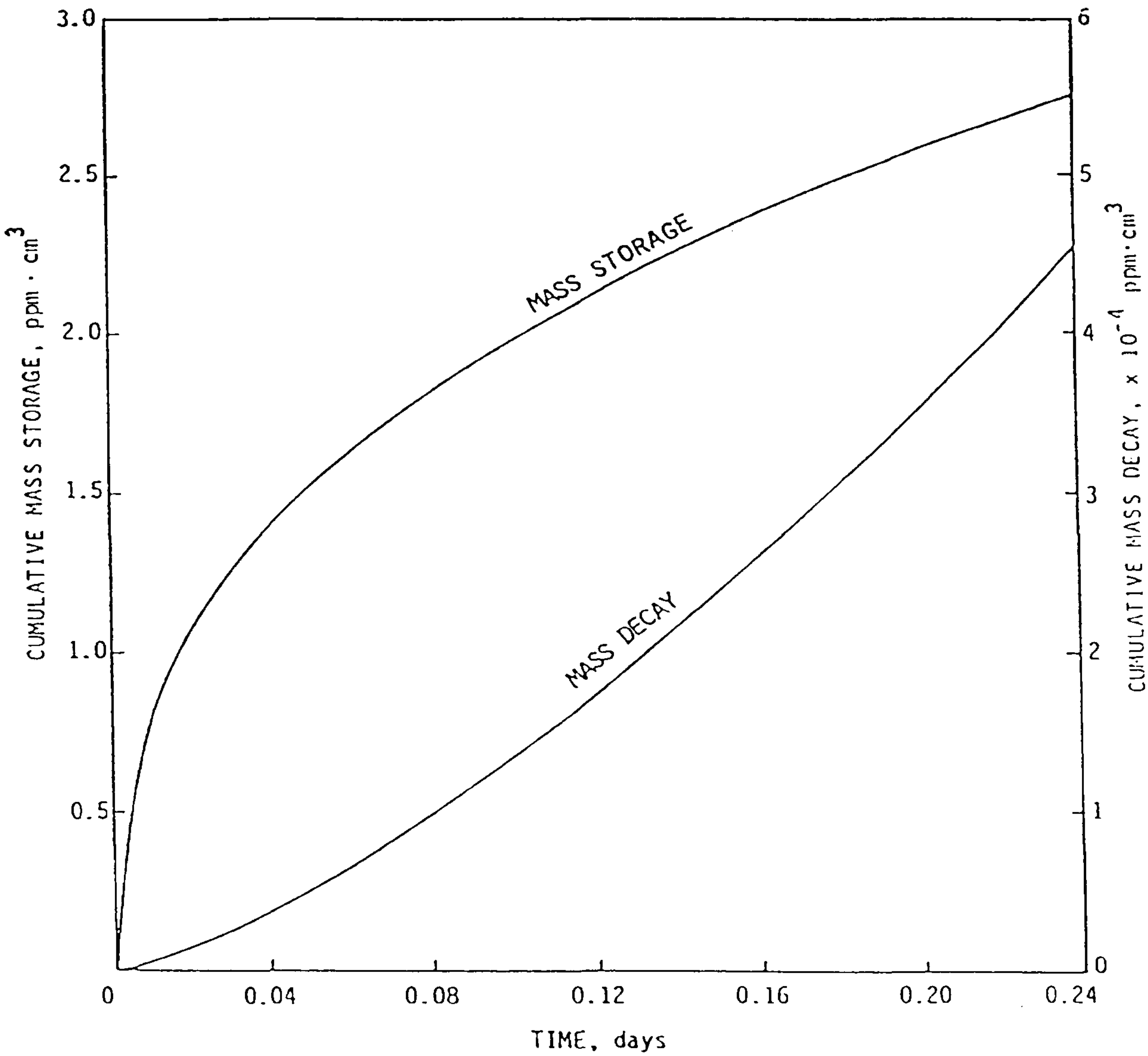


Figure 4.26. Mass storage and mass decay curves computed by VAM2D.

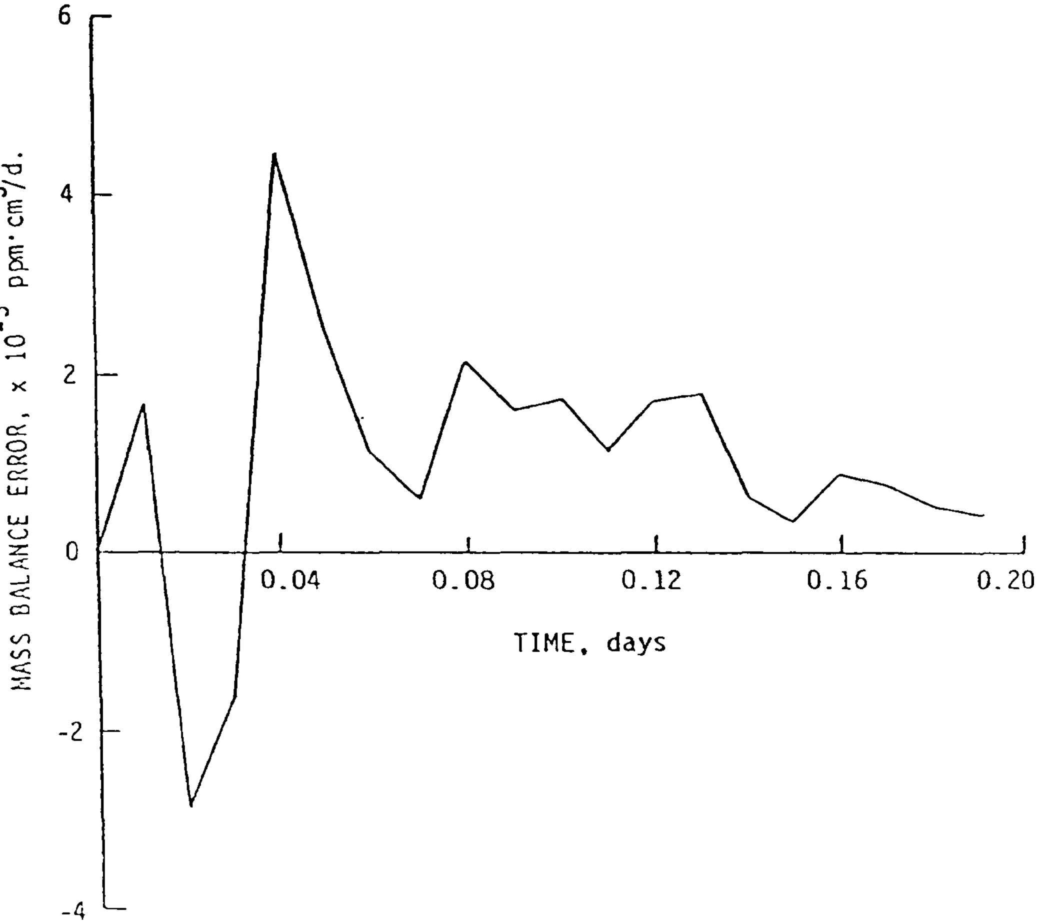


Figure 4.27. Mass balance error versus time relationship for the 1-D solute transport problem.

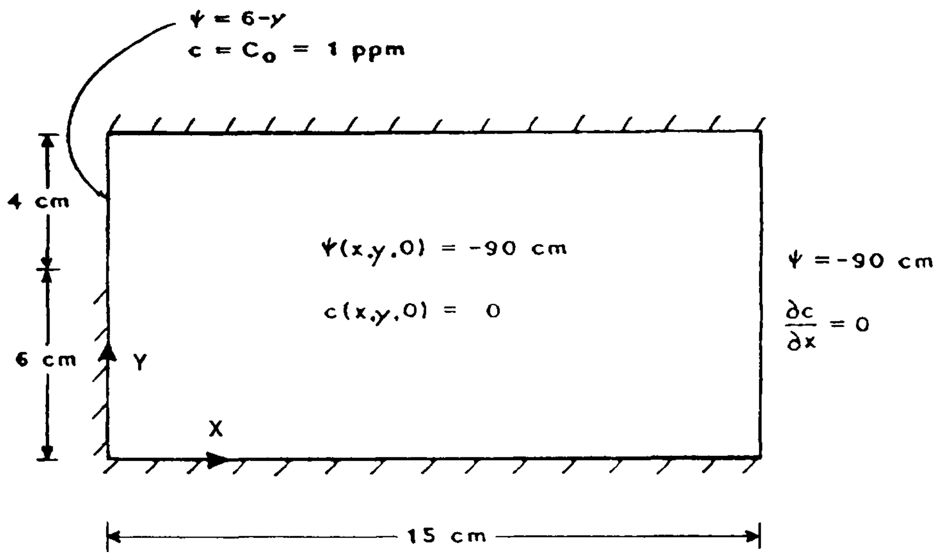


Figure 4.28. Schematic description and data for the problem of two-dimensional transport in a soil slab.

Table 4.7. Values of physical parameters used in the simulation of 2-D transport in a soil slab.

Parameter	Value
Hydraulic conductivity, K	1 cm/d
Porosity, ϕ	0.45
Initial pressure head, ψ_o	-90 cm
Initial concentration, c_o	0
Longitudinal dispersivity, α_L	1 cm
Transverse dispersivity, α_T	0 cm
Apparent molecular diffusion, D_o	0.01 cm^2/d
Decay coefficient, λ	0.001 d^{-1}
Bulk density, ρ_B	1.46 g/cm^3
Distribution coefficient, k_d	0.308 cm^3/g

Soil moisture relations used are the same as those given in Section 4.2.1.

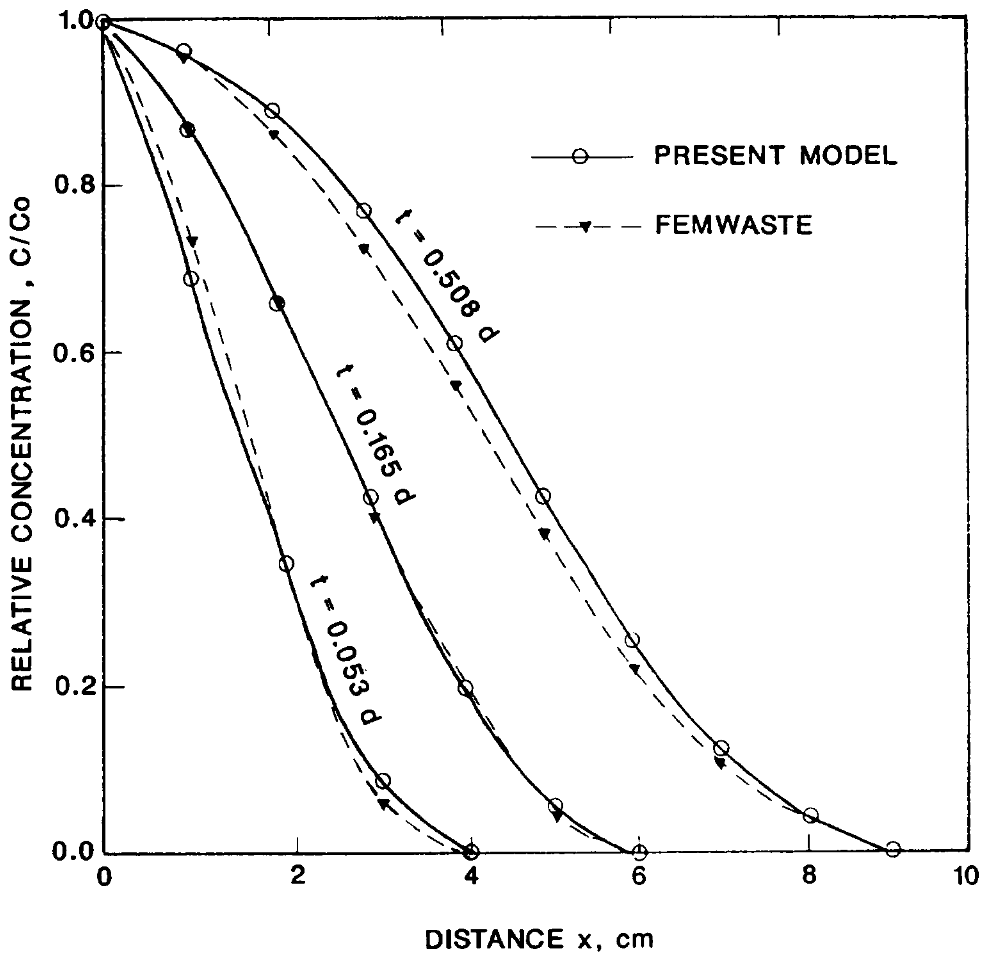


Figure 4.29. Computed horizontal profiles for typical time values.

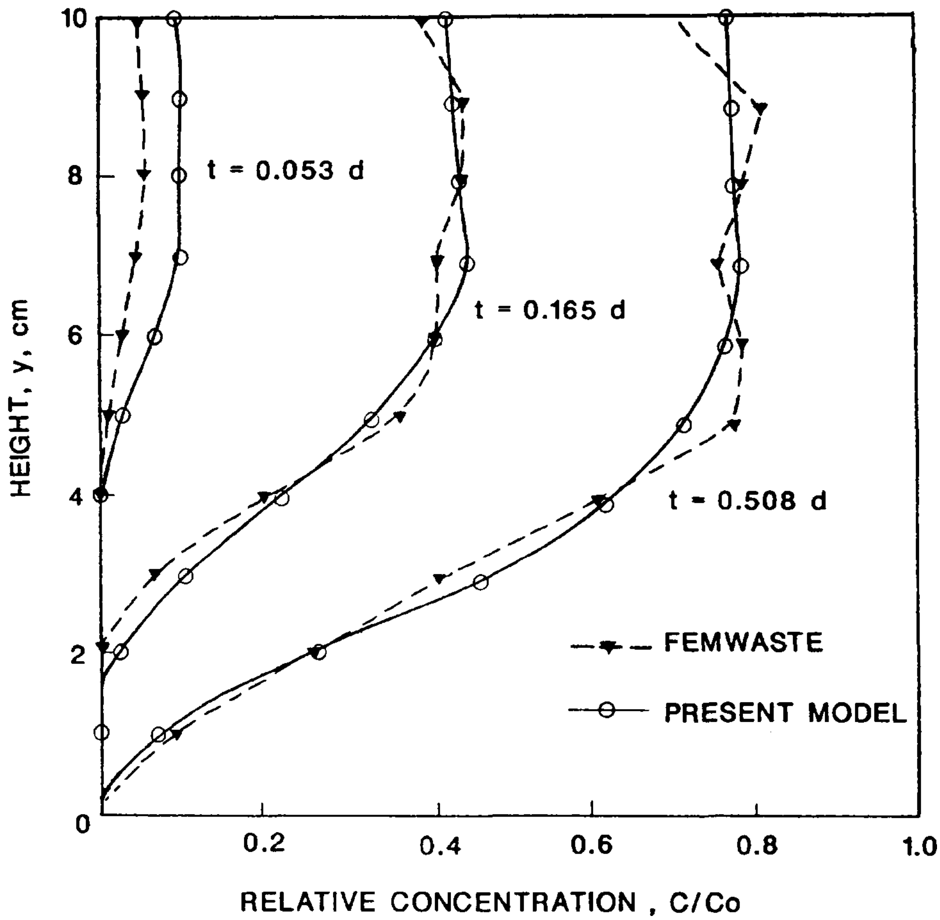


Figure 4.30. Computed vertical profiles for typical time values.

y = 10 cm. In contrast, the vertical concentration profiles computed by the present model are smooth. Furthermore, the zero normal gradient condition at y = 10 cm is very well duplicated.

We believe that the numerical oscillation problem experienced by FEMWASTE is associated with the manner in which the Galerkin approximation of the transport equation is performed. As described by Duguid and Reeves (1976) and Yeh and Ward (1981), the finite element formulation employed in FEMWASTE is achieved by applying Green's theorem to both the dispersive and the advective terms of the primitive transport equation. Such a formulation provides a convenient way to accommodate third-type material flux boundary conditions. Unfortunately, it is highly sensitive to errors in the computation of Darcy velocity and fluid flux values (see Huyakorn and Pinder, 1983, p. 199). In other words, small errors in the estimate of the fluxes can trigger sizable oscillations of concentration values adjacent to the flow boundary. Experience indicates that these oscillations may be dampened as time goes on or they may persist throughout the remaining simulation time period.

Unlike the finite element formulation used in FEMWASTE, the present formulation is achieved by using the transformed version of the transport equation and applying Green's theorem only to the dispersive term. This leads to the numerical scheme that is much less oscillation prone. In addition, the mass balance computational algorithm also works well in two dimensions. This is evident in the result presented in Figure 4.31. In Figure 4.31a, the behavior of the mass storage and decay curves may be noted. In Figure 4.31b, it is seen that the mass balance error for the problem solved behaves in a similar manner to that in the previous one-dimensional example problem. Of particular interest is the fact that the mass balance error corresponding to the medium grid with 176 nodes is substantially less than that corresponding to a coarser grid consisting of 96 nodes. The reason for this is the manner in which the finite element solution and the mass balance schemes are formulated. It may be recalled that the mass balance criterion used is an integral representation of the original transport equation. On the other hand, the numerical solution is formulated using the converted transport equation, which is equivalent to the original transport equation, provided the continuity equation for water flow is satisfied. If the velocity field and the water saturation distribution used in the transport analysis do not satisfy the continuity equation for flow, a significant mass balance error will be detected when the computed concentration is substituted into the solute mass balance integral equation. As depicted in Figure 4.31, the mass balance error is greater with the coarse grid than with the medium grid because the velocity field and water saturation distribution computed using the coarse grid are less accurate than those computed using the medium grid.

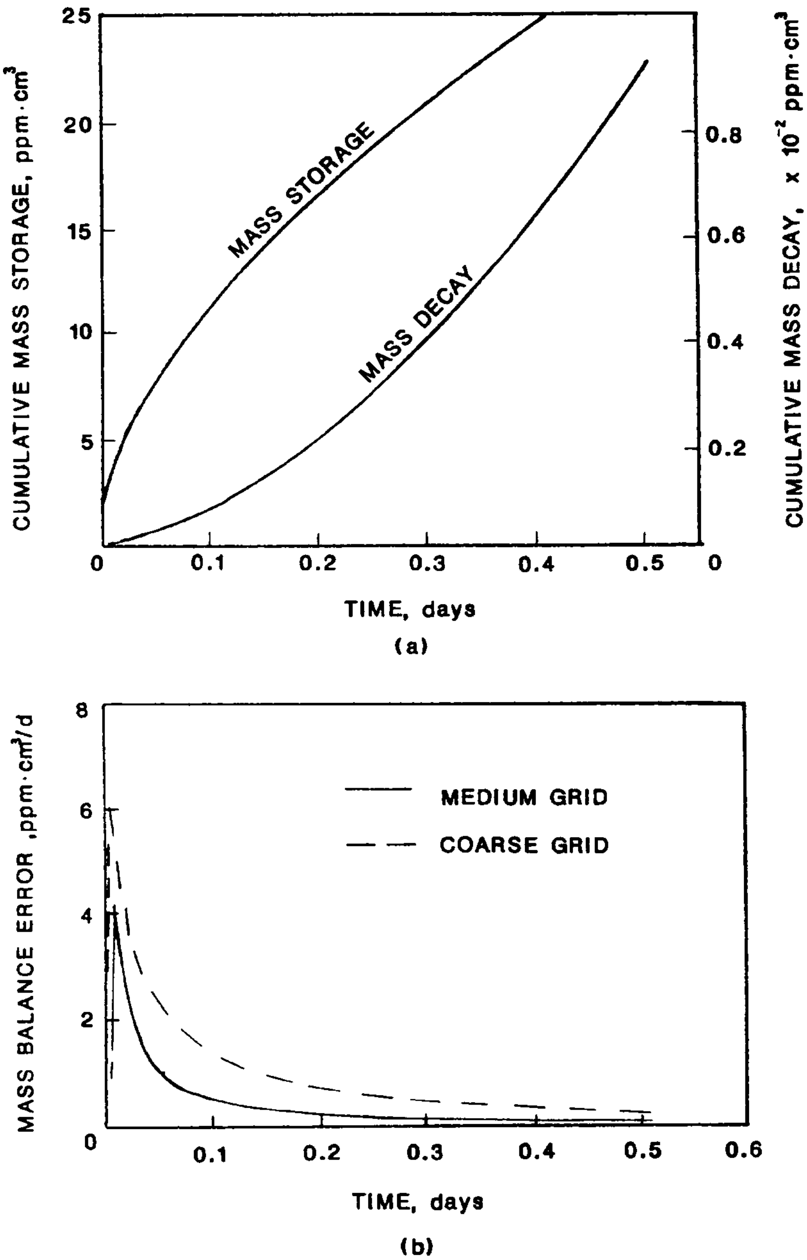


Figure 4.31. Mass storage and decay curves and mass balance error computed by VAM2D.

4.3.3 One-Dimensional Transport of a Three-Member Chain of Radionuclides

This problem is depicted schematically in Figure 4.32. The problem was selected to test the implementation of the upstream weighting and Galerkin Schemes, and the programming features in VAM2D designed to handle chain decay and time dependent flux boundary conditions. VAM2D input and output files for this problem are presented in Section 10.5. The problem concerns transport of a chain of three radionuclides released from a source located at $x = 0$ in a confined porous medium reservoir. For the case of a straight three-member chain, an analytical solution can be found in Coats and Smith (1964). The flow region and the reservoir properties used in the present simulation are also depicted in Figure 4.33. The properties of the three radionuclide components employed are given in Table 4.8. Two cases involving straight and branch chains were simulated. For the branch chain, it was assumed that the mass fractions for transformation of component 1 to 3 and 1 to 2 are equal to 1/2. A decaying source with step release boundary condition was assumed at the inlet. For comparison purposes, the transport parameter values were selected to correspond to the data used in a previous study on a three-member straight chain transport simulation reported by Reeves and Cranwell (1981). This study utilized a block-centered finite difference technique that is of a lower order of accuracy than the consistent mass finite element approximation.

To obtain the finite element solution, the flow region was discretized into 20 linear line elements of equal length, thus giving $\Delta x = 32.8$ ft (~10 m) and a mesh Peclet number Pe = 3.86. (The mesh Peclet number is defined as $Pe = V\Delta x/D_L = \Delta x/\alpha_L$.) In view of the fact that the Peclet number well exceeds a critical value of 2, a numerical experiment was first performed to study the behavior of Galerkin and upstream weighted solutions. At first the problem was solved for 15 time steps using the Galerkin and the upstream weighted schemes with upstream weighting factor $\alpha = 0.1$. A constant time step value of 18.2 yrs was also used. For $t = 273.9$ yrs, the complete results (concentration distributions of all three components) obtained using the upstream weighted scheme are shown in Figure 4.33 and 4.34 for cases 1 and 2 respectively. Excellent agreement with the analytical solutions may be observed.

4.3.4 Two-Dimensional Transport in Uniform Groundwater Flow

This problem concerns two-dimensional dispersion of solute species released from a point source in the horizontal plane of uniform groundwater flow. It was selected to test the transport

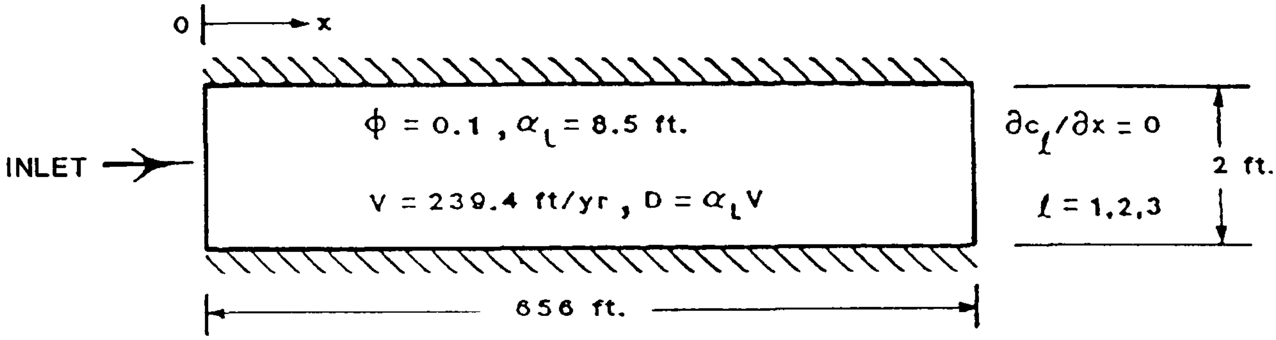


Figure 4.32. Schematic description and data for the problem of one-dimensional multi-component transport.

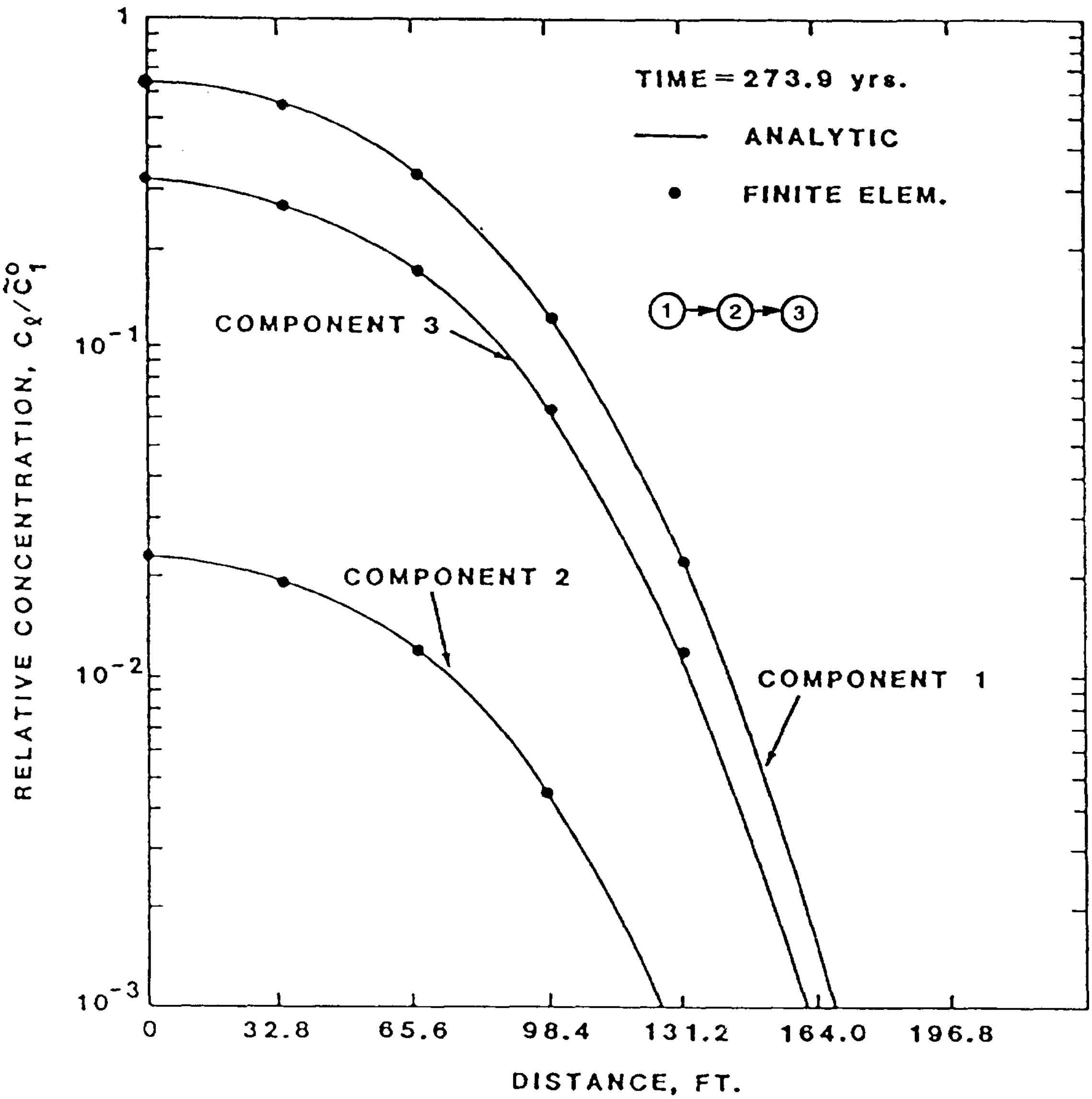


Figure 4.33. Simulated concentration profiles for the case of straight chain, showing comparison of analytical and finite element solutions.

Table 4.8. Parameter values for the problem of one-dimensional transport of three-member radioactive decay chains.

	Radionuclide properties			
Component ℓ	$t_{\frac{1}{2},\ell}$ yrs	λ_ℓ yrs^{-1}	R_1	c_ℓ°
1	433	0.0016	9352	1
2	15	0.0462	9352	0
3	6540	0.0001	9352	0

Case 1: straight chain 1 ----> 2 ----> 3

Case 2: branch chain 1 ------------> 3

($\xi_{31} = \xi_{21} = 0.5$) 2

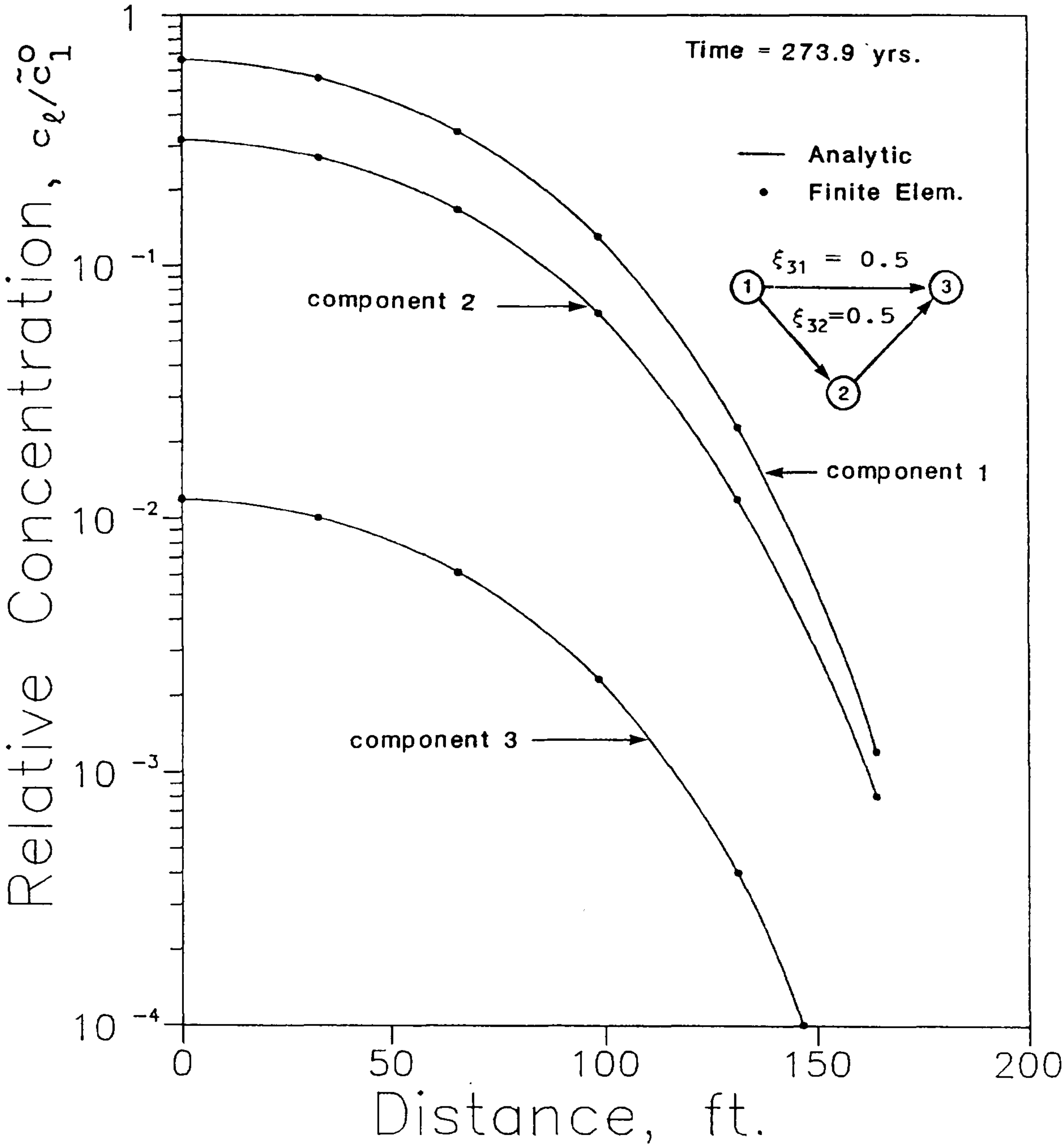


Figure 4.34. Simulated concentration profiles for the case of branch chain, showing comparison of analytical and finite element solutions.

numerical schemes in the VAM2D in two-dimensions for single-component and multi-component simulations. Parameter values used to run the code are listed in Table 4.9. A medium uniform grid consisting of 440 nodes and 390 rectangular elements was used. The grid with Δx = 60 m and Δy = 30 m is bounded by $-360 \leq x \leq 1980$ and $0 \leq y \leq 300$ m. It represented the upper half of the modeled flow region because of symmetry about the x-axis. Three cases, two single-species and one chain decay transport of components 1 and 2, were simulated. In each case, the standard Galerkin scheme with central difference time stepping was used, and the simulation was performed for 28 time steps with Δt = 100 d. Results obtained for the first two single-specie cases are depicted in Figures 4.35 and 4.36, respectively. For both of these cases, it was assumed that the contaminant source was non-decaying and contaminant leaching occurred at a uniform rate of Qc_0 = 704 g/d per unit aquifer thickness. The numerical solutions from VAM2D are compared with the single-component analytical solution presented by Wilson and Miller (1978). Note that the concentration profiles along the x-axis (plume center line) are plotted in dimensionless form with the given definition of dimensionless variables. As can be seen, the numerical and analytical solutions are in fairly good agreement. In Figure 4.36, the numerical result obtained using a fine mesh with Δx = 60 and Δy = 15 m is also presented to provide an illustration of the convergence behavior of the numerical solution. Case 2 corresponds to a field situation involving transport of hexavalent chromium. Observed plume data reported by Permlmutter and Lieber (1970) is compared with the VAM2D simulation result as shown in Figure 4.37. Considering the uncertainties in the values of the transport parameters used in the simulation, the agreement between the predicted and observed plumes is quite reasonable.

To demonstrate a further potential field application of the VAM2D code in the investigation of multi-component contaminant transport, case 3 was also considered. In this case, it was assumed that component 1 decays to component 2, which has zero decay and distribution coefficients (conservative specie). The source was treated as a decaying source and the initial mass fluxes of components 1 and 2 were 704 g/m.d) and 0, respectively. Simulated concentration profiles along the plume center line are depicted in Figure 4.38. The profiles behave in the manner expected because of contrasting transport properties of the two solute components.

4.3.5 Transient Transport in a Root Zone

This problem is associated with the flow problem described in Section 4.2.5 and Figure 4.16. Transport of pesticide uniformly applied over the top soil is considered. A first-type

Table 4.9. Parameter values used in the simulation of 2-D transport in uniform groundwater flow.

Parameter	Value
Darcy velocity, V	0.161 m/d
Porosity, ϕ	0.35
Longitudinal dispersivity, α_L	21.3 m
Transverse dispersivity, α_T	4.3 m
Aquifer saturated thickness, b	33.5 m
Contaminant mass flux, Qc_o (per unit thickness of aquifer)	704 g/(m.d)
Bulk density, ρ_B	1.46 g/cm^3
<u>Solute Component 1</u>:	
Decay coefficient, λ	1.9×10^{-4} d^{-1}
Distribution coefficient, k_d	0.308 cm^3/g
<u>Solute Component 2</u>:	
Decay coefficient, λ	0
Distribution coefficient, k_d	0

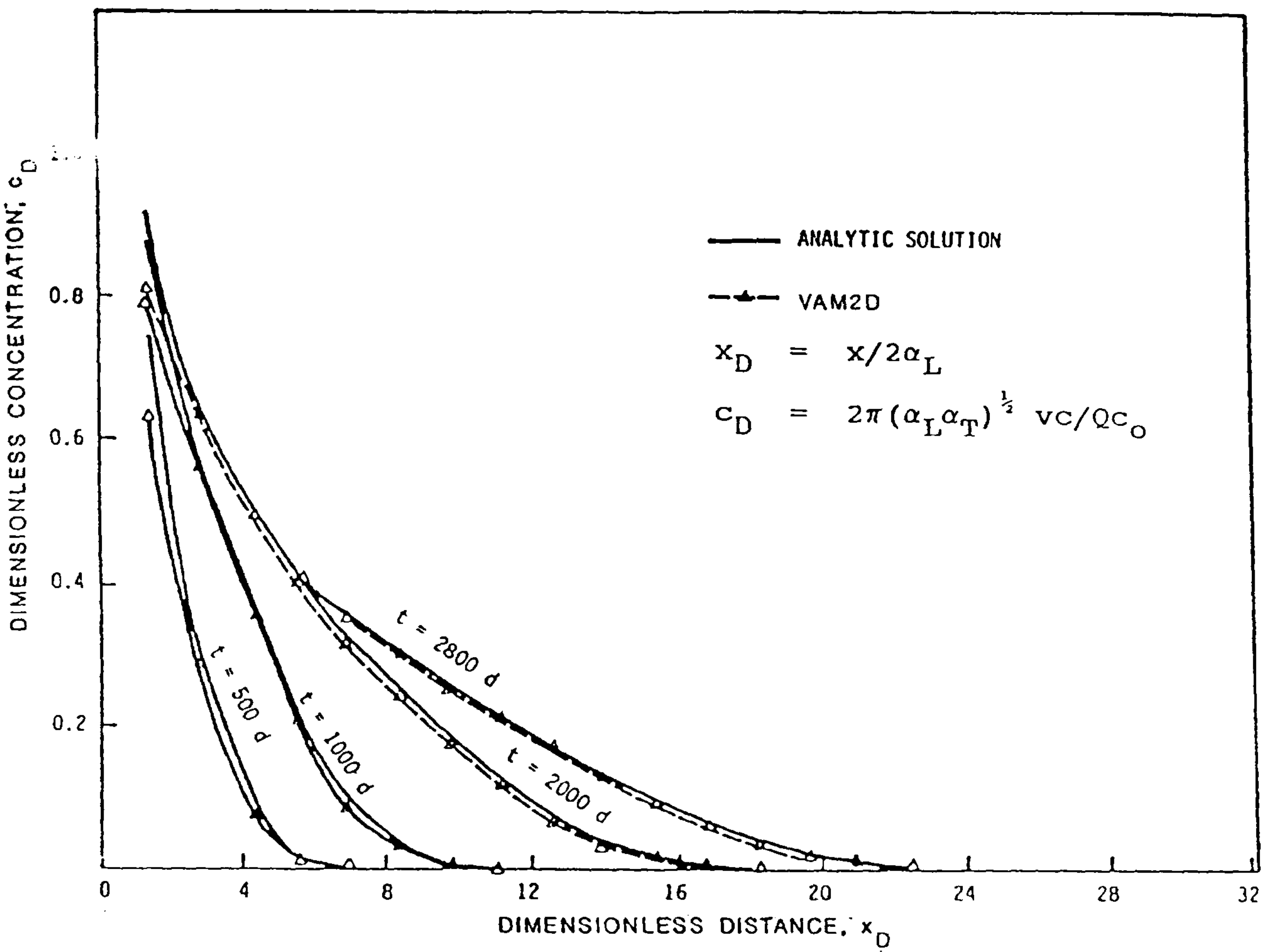


Figure 4.35. Simulated profiles of dimensionless concentration along the x-axis (single-specie transport, case 1).

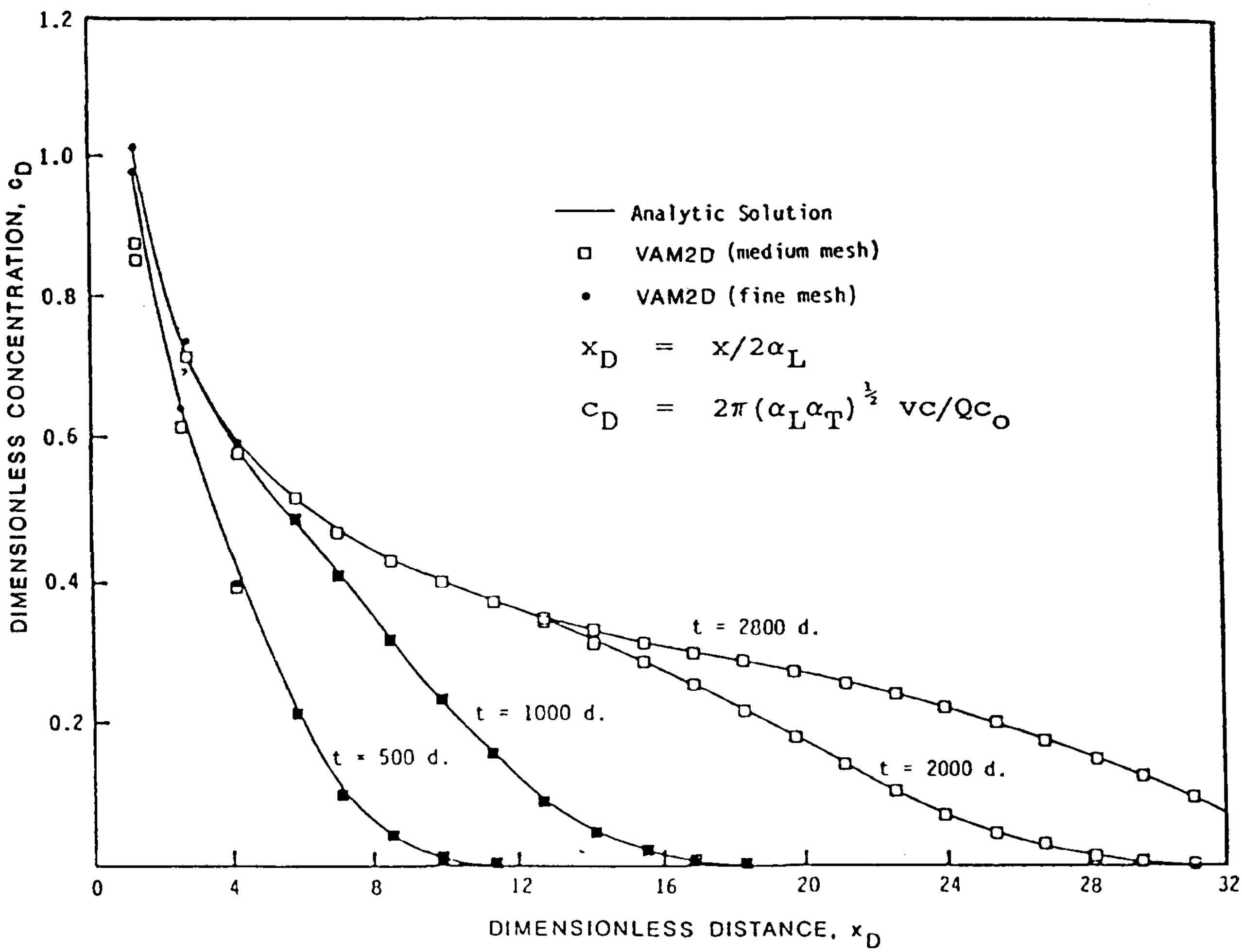


Figure 4.36. Simulated profiles of dimensionless concentration along the x-axis (single-specie transport, case 2).

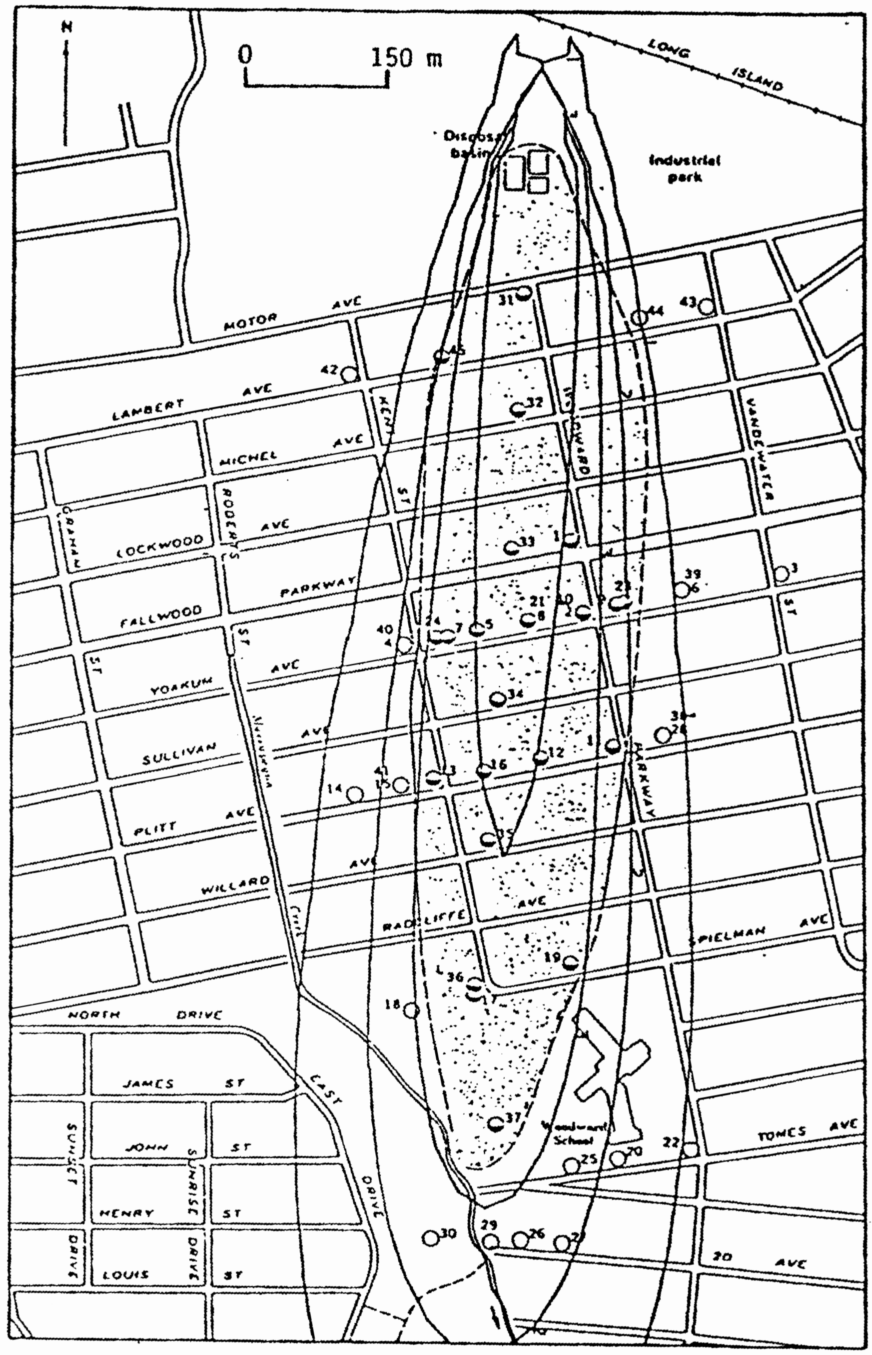


Figure 4.37. Simulated and observed plumes of hexavalent chromium.

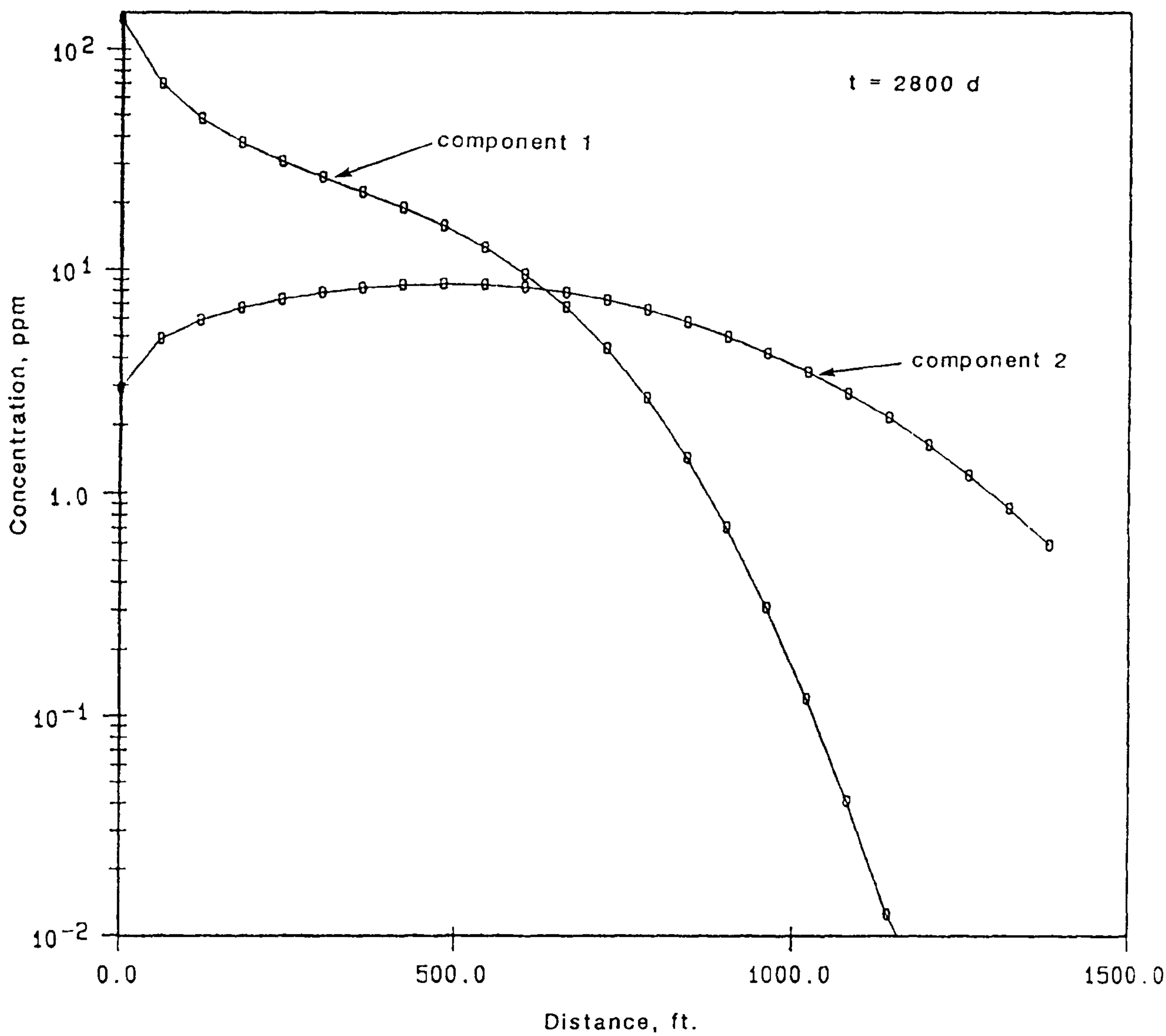
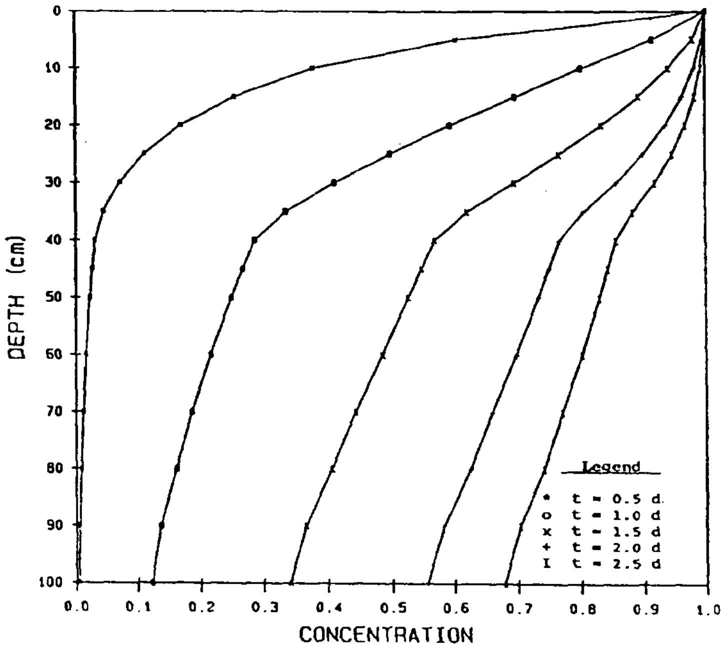


Figure 4.38. Simulated profiles of concentration along the x-axis (two-member chain transport, case 3).

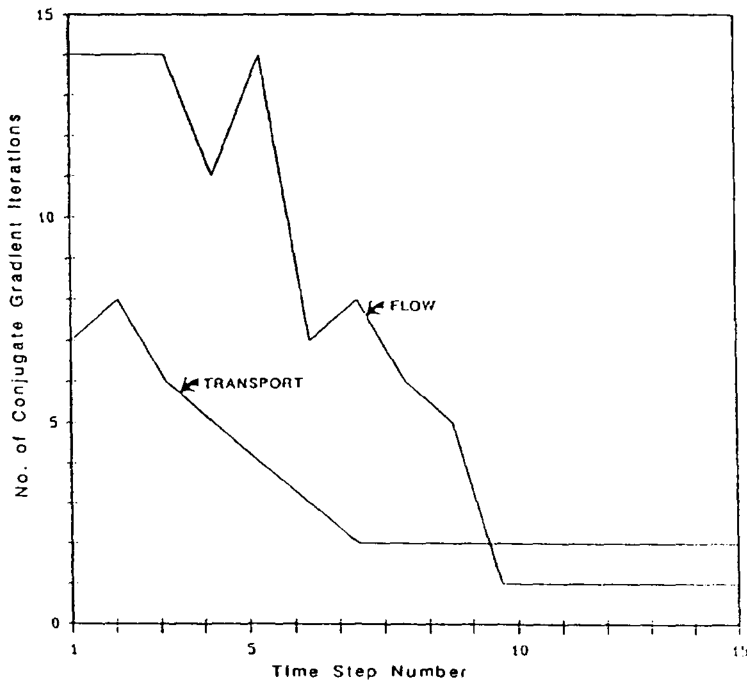
boundary condition of unit concentration was assumed at the top surface, and a second type (outflow) boundary condition was assumed at the bottom of the root zone. The transport simulation was performed for 20 time steps using the velocity and water saturation data obtained from the previous flow simulation. VAM2D input and output files for this transport problem are presented in Section 10.3. The corresponding files for the simultaneous flow and transport simulation are given in Section 10.4. Shown in Figure 4.39a is the plot of concentration profiles for five time values. The profiles behave in the manner expected for a layered system. As indicated previously in Section 4.2.5, the Preconditioned Conjugate Gradient (PCG) solvers were used to solve the symmetric and asymmetric matrix equations for the flow and related transport problems. The performance of the PCG solvers is illustrated in Figure 4.39b, where the total number of CG iterations performed over a time step is plotted against the time step number. The pressure head and normalized concentration tolerances were prescribed as 0.001 cm and 0.001, respectively. As can be seen, the maximum numbers of CG iterations are 14 for the nonlinear flow problem and 8 for the linear transport problem. The number of CG iterations continually drops as time marching progresses. After the fluctuation of transient flow boundary condition tapers off the number of CG iterations eventually decreases to minimum values of 1 and 2 for the flow and transport problems, respectively. This behavior of PCG solvers indicates a significant advantage over direct matrix solvers in handling transient simulations, particularly when one is dealing a large number of nodal unknowns (say on the order of 1000 or more). In such a situation, the PCG algorithms usually far outperform the direct banded matrix solution algorithms both in terms of computational time and core storage.

4.3.6 Leachate Migration from a Landfill

This transport problem is associated with the variably saturated flow problem described in Section 4.2.6. It was selected to demonstrate another potential application of VAM2D in the investigation groundwater contamination due to land disposal of toxic waste. Shown in Figure 4.40a and 4.40b are the transport scenario modeled and a steady-state contaminant plume predicted by VAM2D using the flow field and water saturation distribution obtained from the related flow simulation. Note that the simulated plume exhibits limited lateral and vertical dispersion. Within the vadose zone, the concentration contours are tightly spaced and confined to narrow bands near the landfill boundary. The plume center line shows a significant dip in the in the saturated zone due to the effect of downward vertical groundwater flow components caused by a slight mounding of the water table.

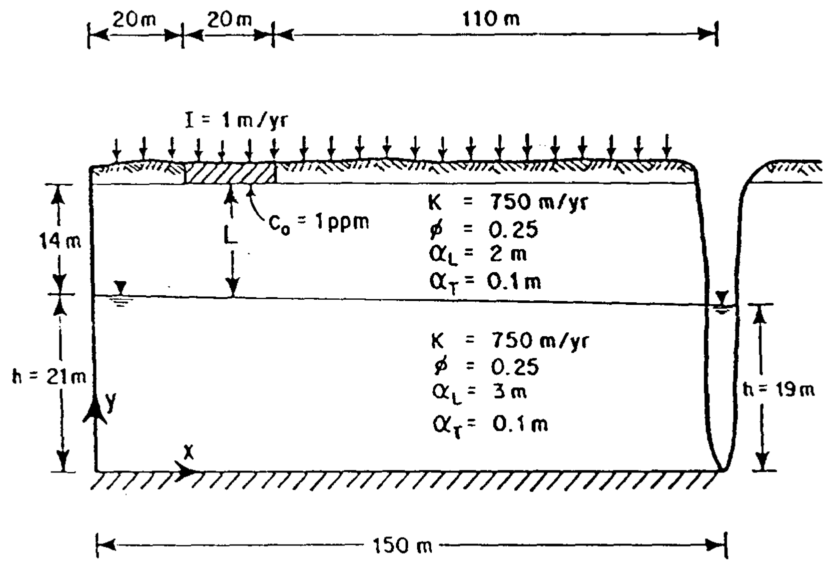


(a)

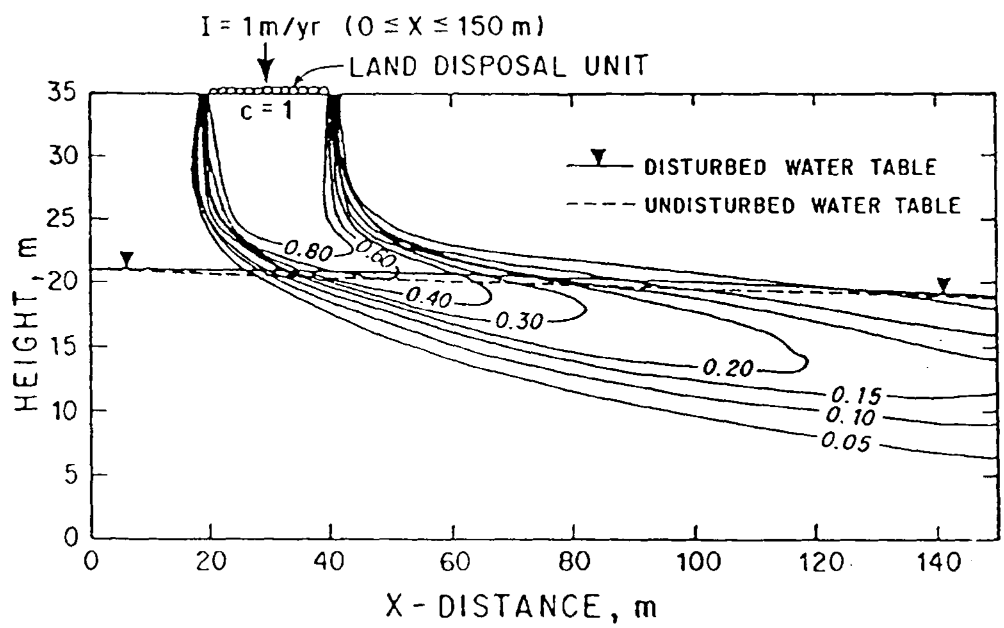


(b)

Figure 4.39. Plot of concentration profiles and plot showing the performance of Preconditioned Conjugate Gradient algorithms for the root-zone flow and transport problems.



(a)



(b)

Figure 4.40. Problem description and simulation result for the scenario of leachate migration from a land disposal unit.

4.3.7 Simulation of Solute Transport Caisson Experiment

In this example, VAM2D was used to simulate an intermediate field-scale experiment conducted at Los Alamos in a large Caisson (3 m internal diameter by 6 m height). Data from this experiment have been reported by Nyhan et al. (1986). The experiment set up is shown schematically in Figure 4.41. The Caisson was filled with crushed Bandelier Tuff, which consists mostly of silicic glass and has a grain-size distribution similar to that of a silty sand. At the bottom of the Caisson, the drain was covered with a coarse screen. Approximately 0.25 m of gravel was placed over the screen, and above this was placed approximately 0.25 m of coarse sand. Solute application was made uniformly at the top of the Caisson. Concentration breakthrough data were measured at six different depths by analyzing water samples collected from access ports using hollow fiber suction cups.

One-dimensional simulations of transport of bromide were performed using VAM2D and a column grid consisting of 55 elements. A summary of parameter values is presented in Table 4.10. These parameter values were based on the result of previous model calibrations by Huyakorn et al. (1987) and van Genuchten et al. (1987). The two cases referred to in Table 4.10 represent two estimates of the key transport parameters controlling the position and shape of breakthrough curves at various depths. Evidently, the measured concentration data indicate some deviations from the one-dimensional flow and transport assumptions due to possible effects of material heterogeneity and boundary effects. Case 1 may correspond to a faster velocity zone that occurred in part of the Caisson that intersected the 264-cm depth sampler. Case 2 parameter values were chosen to provide the best overall fit of breakthrough curves at depths over 264 cm. Comparisons of simulated breakthrough curves and measured data are depicted in Figures 4.42 and 4.43 for the two cases, respectively. It can be seen that agreement between the predicted and observed concentrations is reasonable.

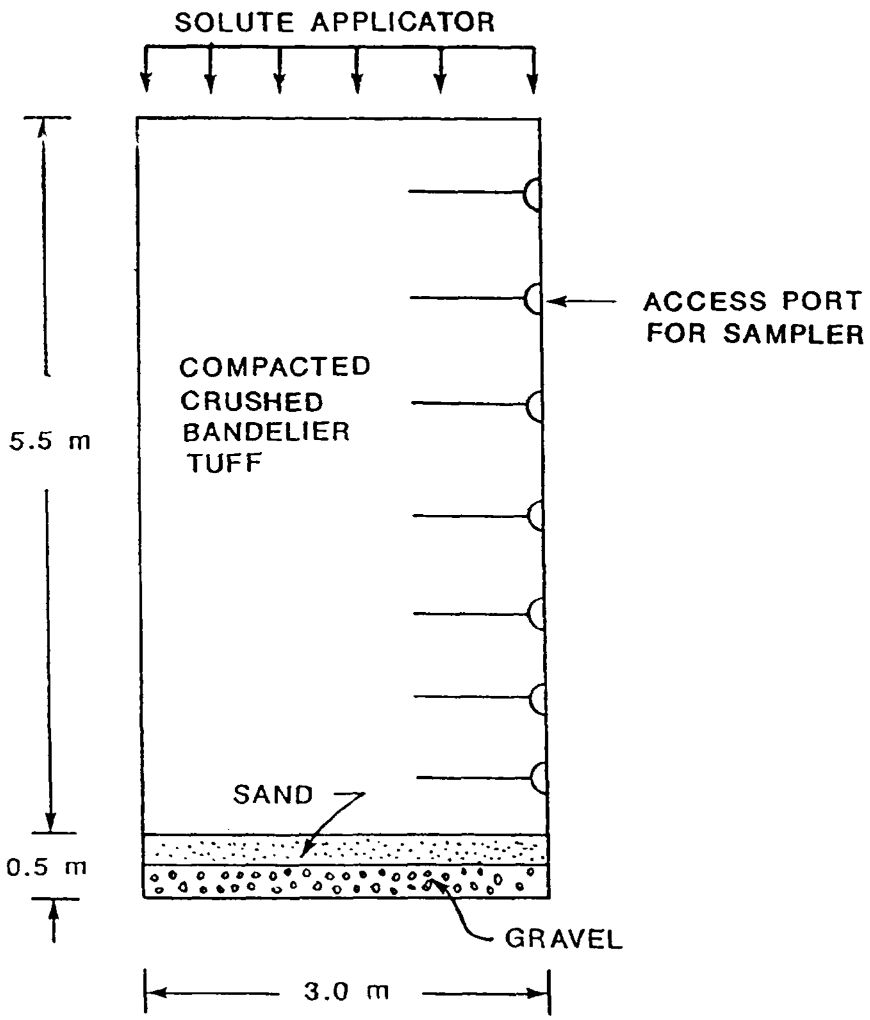


Figure 4.41. Schematic description of Caisson experiment on solute transport in unsaturated crushed Bandelier Tuff.

Table 4.10. Parameter values for one-dimensional transport of bromide in the Caisson.

Effective porosity, ϕ	=	0.331
Water saturation, S_w	=	0.834
Soil bulk density, ρ_B	=	1.60 g/cm^3
Injection Br concentration, c^*	=	70 mg/ℓ
Background Br concentration, c_o	=	0.0
Case 1		
Darcy velocity, V	=	4.07 cm/d
Longitudinal dispersivity, α_L	=	2.5 cm
Pulse duration, T	=	6.0 d
Case 2		
Darcy velocity, V	=	3.22 cm/d
Longitudinal dispersivity, α_L	=	0.50 cm
Pulse duration, T	=	5.43 d

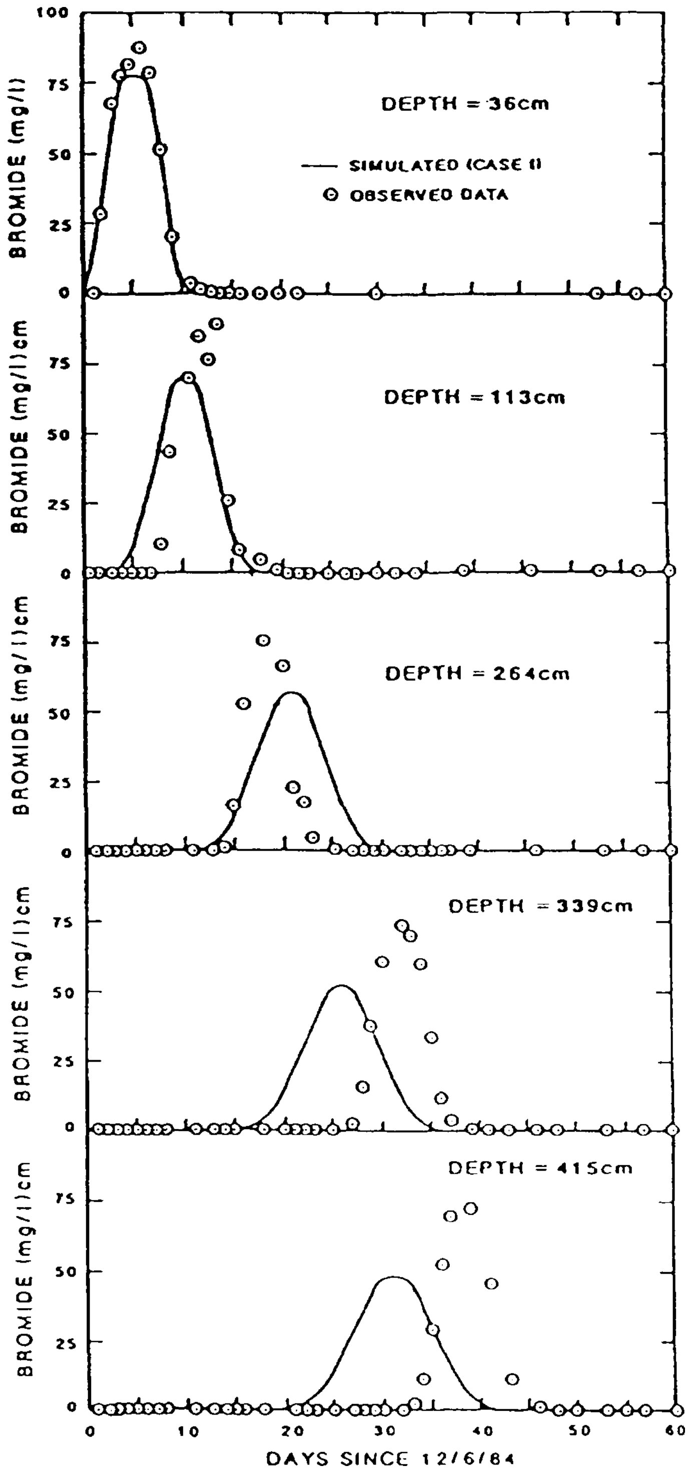


Figure 4.42. Simulated and observed bromide concentrations (case 1 simulation).

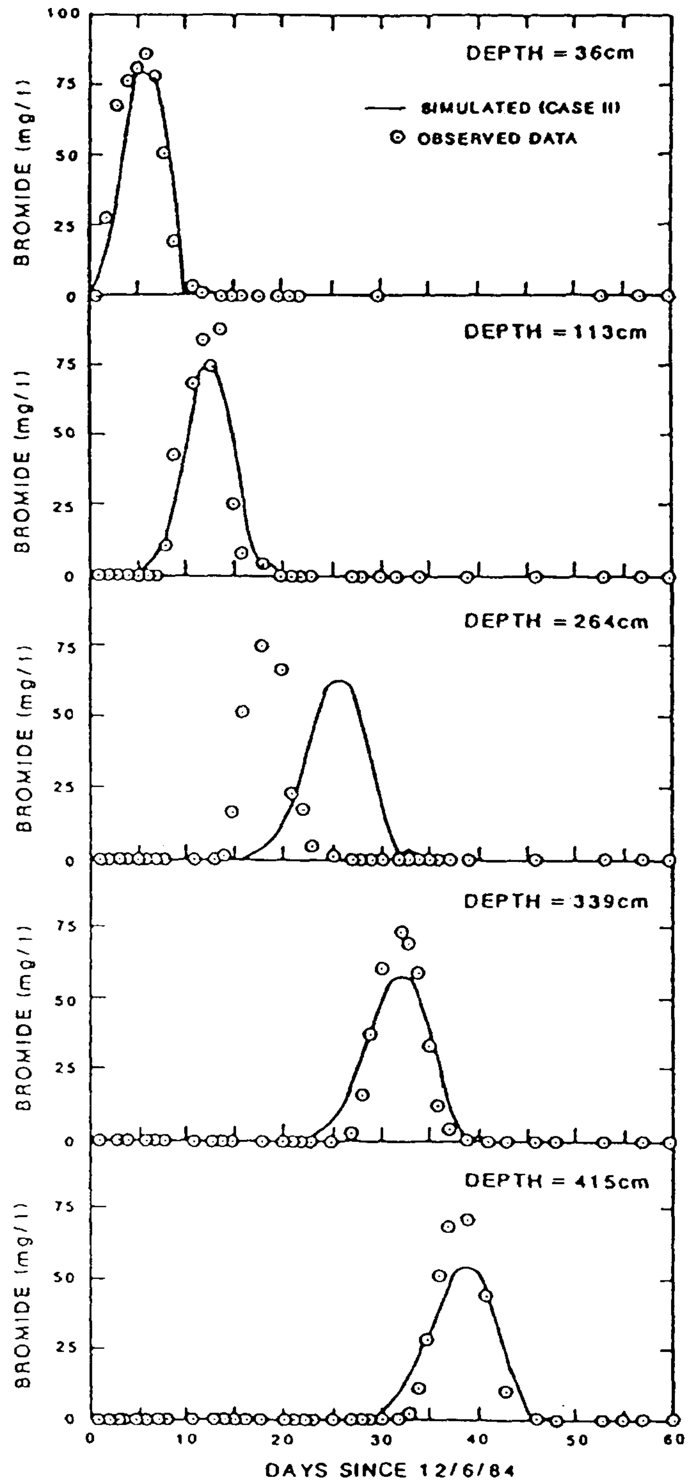


Figure 4.43. Simulated and observed bromide concentrations (case 2 simulation).

PART II

USER'S MANUAL

5 PROBLEM DEFINITION AND SIMULATION PROCEDURE

5.1 TYPES OF PROBLEMS

The VAM2D code can be used in several types of investigations of water flow and moisture movement in subsurface systems. For demonstrative purposes, four typical examples are described. The first example (Figure 5.1) has application to the conceptual design and risk assessment for a low-level radioactive waste disposal site. It involves variably saturated flow around gravel and wick layers surrounding a low-level radioactive waste container placed in the unsaturated zone above a water table (Frind et al., 1977). For this study, VAM2D can be used to predict the flow pattern resulting from vertical recharge at the soil surface. The velocity field determined from flow simulations can be used as input to subsequent contaminant transport simulations. For the investigation or risk analysis of the potential for migration of radionuclides, VAM2D can be used to perform single-component and/or chained decay transport simulations. The code has the capability to accommodate straight and branch chains as well as taking into account of decaying source boundary conditions.

The second example (Figure 5.2) applies to drainage or mine dewatering problems involving analyses of seepage into a drain or mine pit. For this example, VAM2D can be used to perform saturated-unsaturated flow simulations taking into account groundwater recharge and seepage boundary conditions.

The third example applies to a landfill above an unconfined groundwater system intercepting a river (Figure 5.3). To evaluate the environmental impact of a land disposal unit (landfill or surface impoundment), it is essential to predict water flow and contaminant migration in both unsaturated and saturated zones between the landfill and the river. VAM2D can be used to perform both the flow and transport simulations.

The fourth example concerns soil and groundwater contamination problems due to application of pesticides. In the situation depicted in Figure 5.4), VAM2D may be used to provide coupled transient simulations of moisture movement, groundwater flow and pesticide migration through the root zone, the vadose zone and the saturated zone of unconfined aquifer system. If chemical transformation and chained reactions of pesticides are important, the code may also be used to study these effects on the fate and transport.

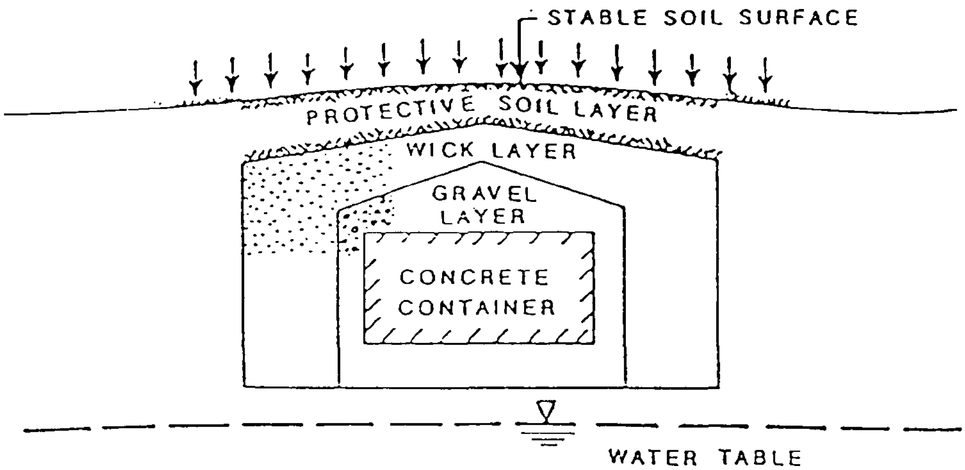


Figure 5.1. Basic geologic environment for a low-level waste container (Frind et al., 1977).

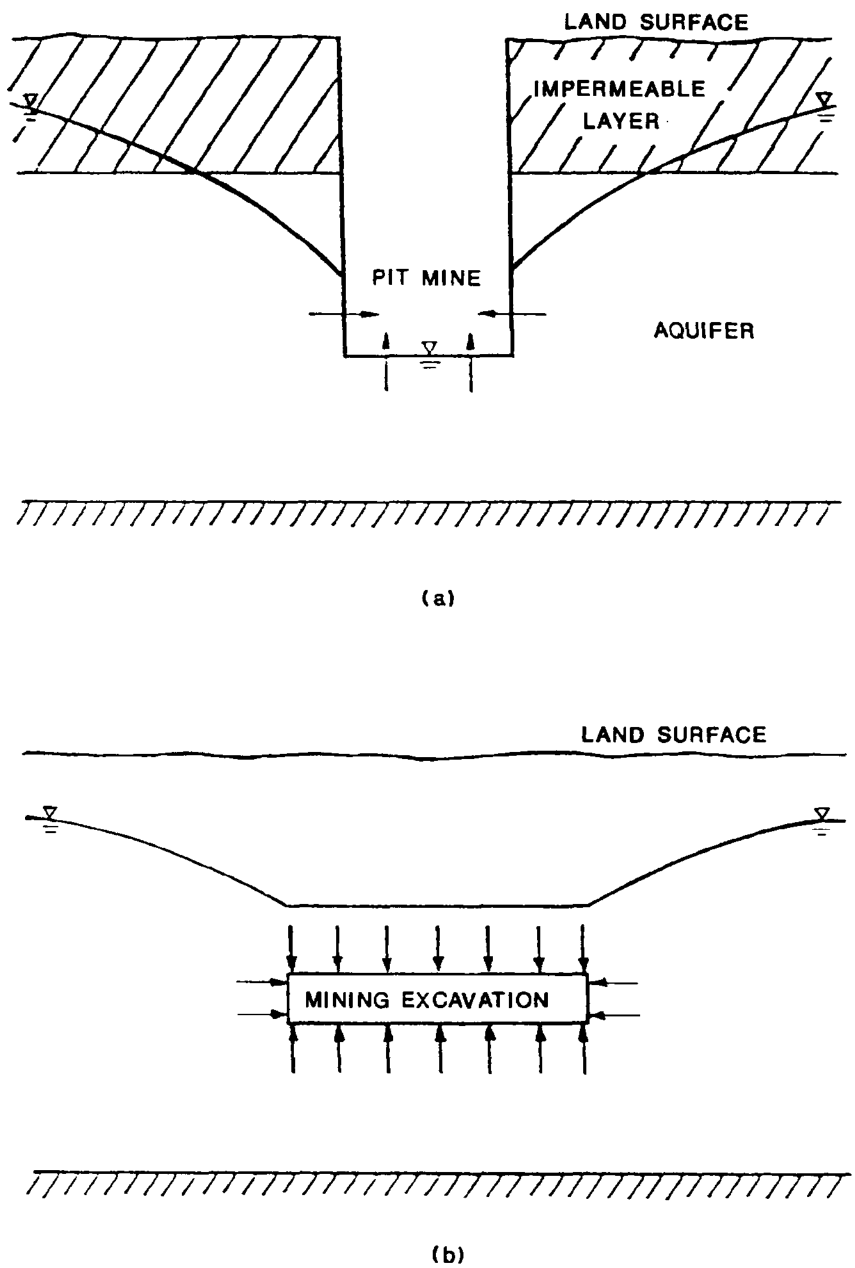


Figure 5.2. Groundwater seepage due to mine dewatering or underground drainage operations.

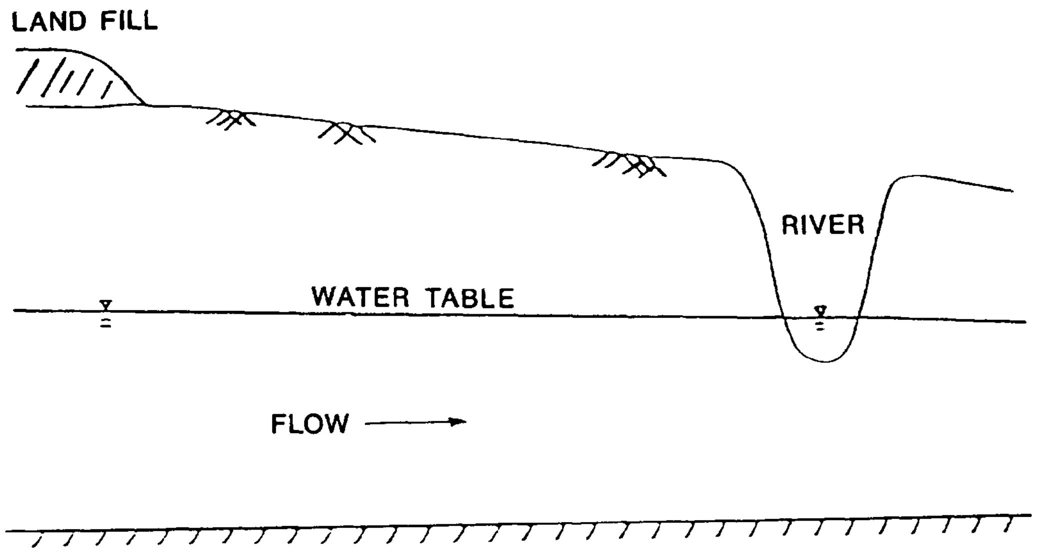


Figure 5.3. Groundwater contamination caused by a landfill.

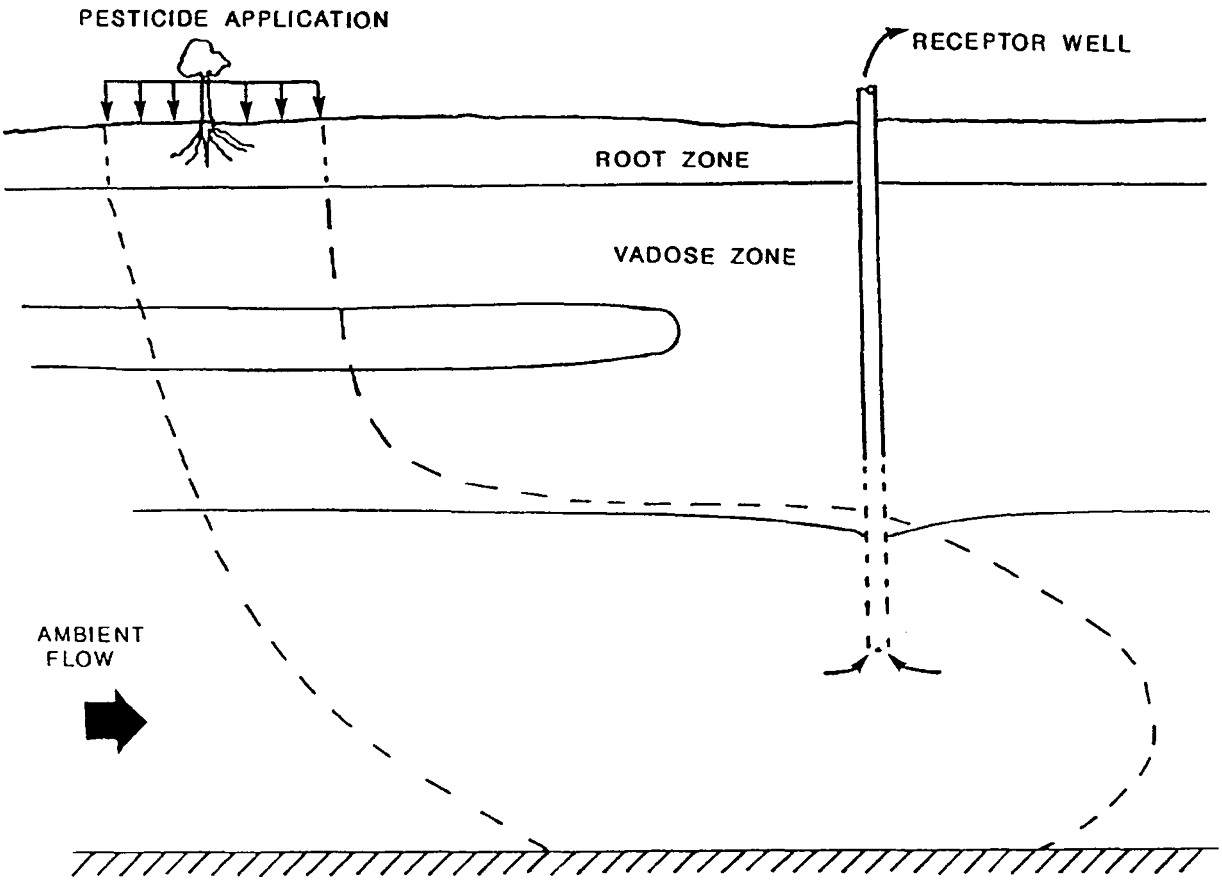


Figure 5.4. Soil and groundwater contamination caused by application of pesticides.

5.2 DATA REQUIREMENTS

Data required for the simulation of saturated flow include the hydraulic conductivity and specific storage of the porous media, the geometry and configuration of the flow region, as well as initial and boundary conditions associated with the flow equation. For the simulation of variably saturated flow, the following relationships are required: relative permeability versus water phase saturation and pressure head versus water phase saturation. These relationships may be supplied to the code using functional parameters.

Data required for the analysis of solute transport problems include longitudinal and transverse dispersivities of the porous media, solute properties (i.e., distribution and decay coefficients), information on groundwater recharge and withdrawal, as well as contaminant source characteristics (source location, geometry, concentration, fluxes, and decay constants), groundwater velocities, water saturation, and initial and boundary conditions associated with the transport equations.

5.3 SIMULATION PROCEDURE

The general procedure for using VAM2D to simulate water flow and/or solute transport in subsurface systems is outlined below.

- Prepare a diagrammatic description of the problem such as those shown in Figures 5.1 through 5.4. The diagram should depict the solution region together with a description of the zones of different material properties and boundary conditions.

- Prepare a list of material numbers and properties to be supplied to the code.

- Prepare a sketch of a given region showing the orientation of the coordinate axes and sequential numbers of the nodes and the elements (Figure 5.5).

- Prepare steady-state boundary condition data. These data are classified into two sets. The first set consists of global node numbers and prescribed values of dependent variables to be determined. The second set consists of global node numbers and prescribed values of integrated nodal fluxes. If there are no steady-state boundary conditions, this step of the simulation procedure may be omitted.

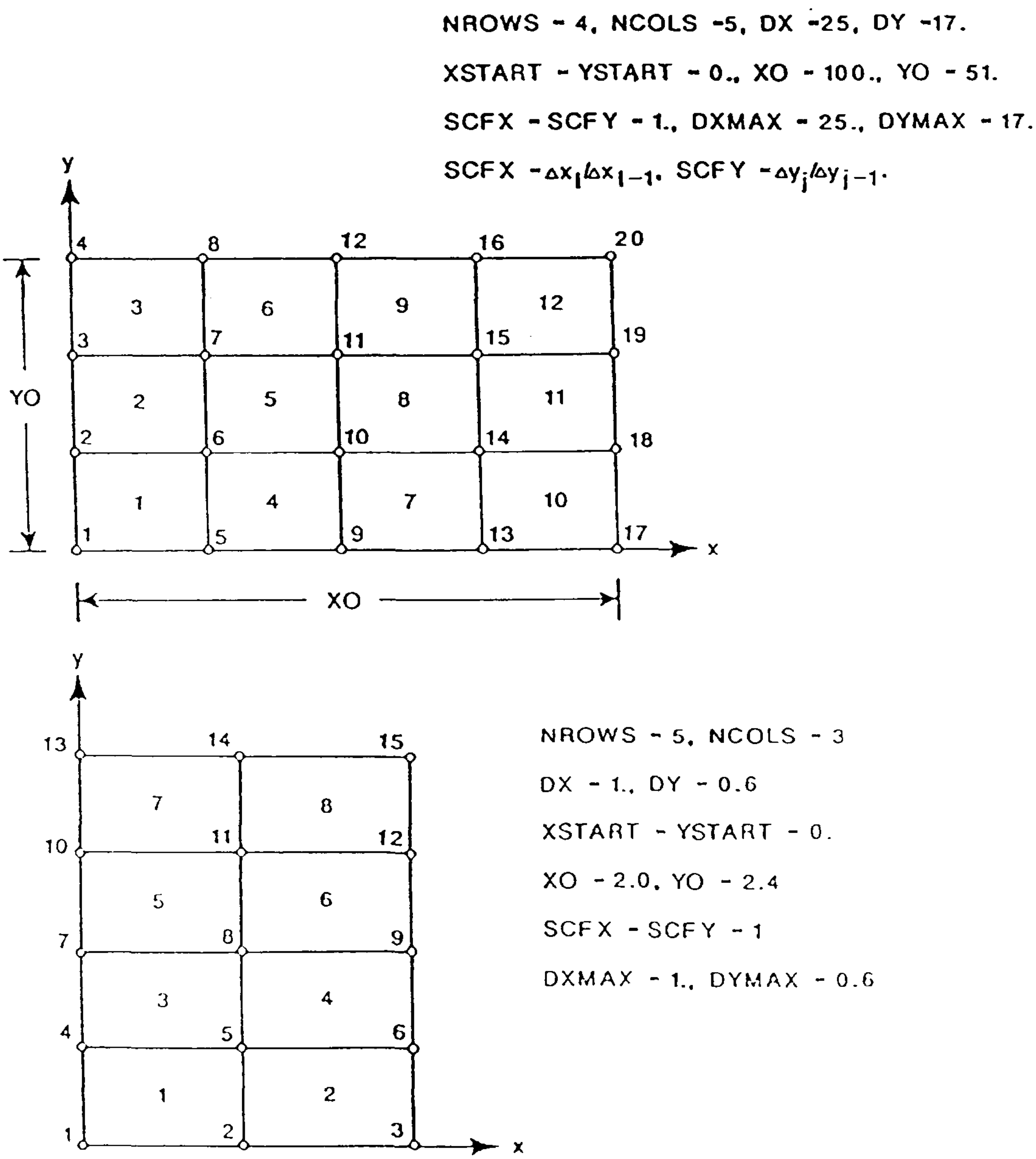


Figure 5.5. Typical rectangular meshes generated automatically by the VAM2D code using the option of IXYRED = 0.

- Prepare transient boundary condition data. The data are also classified into two sets. The first set consists of global node numbers and the time graph of prescribed values of dependent variables to be determined. The second set consists of global node numbers and the time graph of prescribed values of integrated nodal fluxes.

- Follow the input data preparation instructions given in Chapter 8 and supply the required input to the code.

- Run the code and interpret the output using the guide provided in Chapter 9.

5.4 SPECIFICATION OF MESH PARAMETERS

A rectangular mesh is used by VAM2D Version 5.0 and the mesh is automatically generated by the code when the following mesh parameters are specified. Note that the x- and y-coordinates correspond to the horizontal and vertical axis, respectively, if a cartesian coordinate system is used. If an axisymmetric coordinate system is used, x and y correspond to the radial and vertical axis, respectively.

<u>Record type 12</u> (see Chapter 8)

NROWS: Number of grid lines parallel to the x-axis.

NCOLS: Number of grid lines parallel to the y-axis.

DXMAX: Maximum value of spatial increment allowed in the x-direction.

DYMAX: Maximum value of spatial increment allowed in the y-direction.

IXYRED: Parameter for indicating if the grid line coordinates are to be input or generated by the code,
= 0 if coordinates are to be computed using generated values of spatial increments,
= 1 if coordinate input is needed,
= 2 if coordinates are to be computed using specified values of spatial increments.

For IXYRED=1, record types 13a and 13b data need to be supplied. For IXYRED=0, record type 14a data needs to be supplied. For IXYRED=2, record type 14b data needs to be supplied.

Record type 13a

Number of records = NCOLS/8 + 0 or 1.

Col.	1-10 11-20 etc.	XW(J): J = 1, NCOLS	x-coordinates of grid lines 1 through NCOLS.

Record type 13b

Number of records = NROWS/8 + 0 or 1.

Col.	1-10 11-20 etc.	YW(I): I = 1, NROWS	y-coordinates of grid lines 1 through NROWS.

Record type 14a

Col.	1-10	DX:	Starting value of spatial increment in the x-direction.
	11-20	DY:	Starting value of spatial increment in the y-direction.
	21-30	XO:	Maximum value of x-coordinate.
	31-40	YO:	Maximum value of y-coordinate.
	41-50	SCFX:	Scale factor in the x-direction.
	51-60	SCFY:	Scale factor in the y-direction.
	61-70	XSTART:	Minimum value of x-coordinate.
	71-80	YSTART:	Minimum value of y-coordinate.
		ISWAP:	Code for indicating the sequential numbering of the nodes in the rectangular mesh to be generated, = 0 if the nodes are sequentially numbered in the y-direction, = 1 if the nodes are sequentially numbered in the x-direction.

Record type 14b

First subset

Each record contains the following information:

Col.	1-10	DELTAX:	Spatial increment in the x-direction.
	11-15	ISTC:	Starting element column number.
	16-20	IENDC:	Ending element column number.
	21-25	IPAUSE:	Parameter indicating if this is the last record in the subset; = 1 if yes; = 0 if no.

Second subset

Each record contains the following information:

Col.	1-10	DELTAY:	Spatial increment in the y-direction.
	11-15	ISTR:	Starting element row number.
	16-20	IENDR:	Ending element row number.
	21-25	IPAUSE:	Parameter indicating if this is the last record in the subset; = 1 if yes; = 0 if no.

Note: (1) the last values of IENDC and IENDR must be equal to NCOLS-1 and NROWS-1, respectively;
(2) the sum of DELTAX*(IENDC-ISTC + 1) must be equal to XO-XSTART; and
(3) the sum of DELTAY*(IENDR-ISTR + 1) must be equal to YO-YSTART.

Note how the nodes are sequentially numbered in Figure 5.4 to achieve a minimum matrix bandwidth. The parameter that specifies how the nodes are to be numbered is in record group 3, cols. 51-55.

Although VAM2D Version 5.0 requires the use of rectangular mesh, the code allows an irregular region to be treated in a convenient manner. To achieve this, the user needs to overlay the selected regular and the modeled region. Elements that are outside the interested region can then be blocked out by zeroing components of the property array IPROP that correspond to such elements.

5.5 INITIAL AND BOUNDARY CONDITION SPECIFICATIONS

To perform a transient flow or transport analysis or a steady-state flow analysis, an initial distribution of the dependent variable to be solved must be supplied to the code. If the initial distribution is uniform, it is sufficient to supply constant default values of head and/or concentration to the code. The default initial head may be specified in terms of either pressure head (ψ_0) or hydraulic head (h_0). If the hydraulic head h_0 is used, the user needs to tell the code to convert it to pressure head by setting input control parameter INTSPC = 1.

In a case of a nonuniform initial distribution, it is necessary to supply initial nodal values to the code. The number of nodes where initial values differ from the default value (NPIN) may be less than or equal to the total number of nodes (NP).

Boundary conditions can be given in terms of either the pressure head or concentration at boundary nodes, or in terms of the fluid or solute flux at boundary nodes. Specification of a first-type boundary condition is very straight-forward and requires no further explanation. Specifying the nodal boundary condition values in the case of a flux-type boundary condition is more involved. The procedure is explained below by means of an example.

Suppose we wish to simulate migration of a contaminant through the unsaturated zone, where the contaminant originates from a leaky container placed on the soil surface. A close-up of the finite element grid just below the container is shown in Figure 5.6. The boundary nodes that are in contact with the container are represented with the solid circles and are arbitrarily labeled i,j...m. Other nodes are represented by open circles. Nodal spacings between the boundary nodes in the horizontal direction are Δx_a, Δx_b,..Δx_d. Let's further assume that the container loses liquid at a rate of Q cubic meters per day. The liquid is distributed uniformly over the area (S,m^2) of the container which is in contact with the soil. The so-called <u>distributed liquid flux</u> is then $q = Q/S$ m/d. The contaminant concentration in the liquid is c_0 mg/ℓ. The <u>distributed solute flux</u> is thus $q \cdot c_0$ gr/(m^2/d).

We must now translate this distributed flux into the correct flux boundary conditions at the boundary nodes. Starting at node i, the procedure is as follows: The total liquid flux applied over the boundary segment between nodes i and j is $q \cdot \Delta x_a$. One-half of this is a apportioned to node i and one-half to node j. In addition, node j receives one-half of the flux entering through the segment between nodes j and k. The resulting nodal flux values are called <u>integrated</u> (or concentrated) flux boundary conditions. For the current example, the integrated nodal fluid and solute flux boundary conditions are:

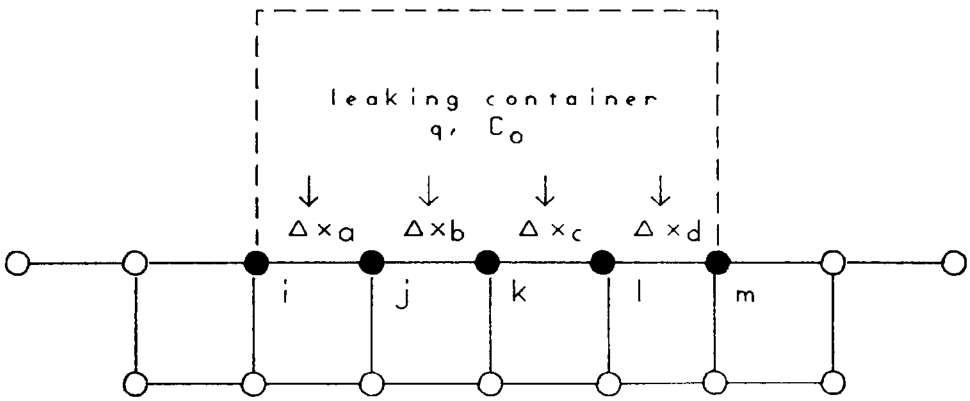


Figure 5.6. Example illustrating calculation of integrated nodal fluxes. Closed dots represent nodes along boundary segment receiving flux. Open dots represent remaining nodes.

node	nodal fluid flux	nodal solute flux
i	$\frac{1}{2}q\Delta x_a$	$\frac{1}{2}qc_o\Delta x_a$
j	$\frac{1}{2}q(\Delta x_a + \Delta x_b)$	$\frac{1}{2}qc_o(\Delta x_a + \Delta x_b)$
k	$\frac{1}{2}q(\Delta x_b + \Delta x_c)$	$\frac{1}{2}qc_o(\Delta x_b + \Delta x_c)$
l	$\frac{1}{2}q(\Delta x_c + \Delta x_d)$	$\frac{1}{2}qc_o(\Delta x_c + \Delta x_d)$
m	$\frac{1}{2}q\Delta x_d$	$\frac{1}{2}qc_o\Delta x_d$

In general, the integrated nodal fluxes are obtained by multiplying the areally distributed flux by the effective nodal length. The example also illustrates that the nodal fluid flux has dimensions of length x length/time = L^2/T.

Steady-state boundary conditions are handled simply by specifying the node numbers and prescribed concentration or solute mass flux and fluid flux values. Transient boundary conditions are also handled in a convenient manner by specifying the node numbers and relationships of time versus concentration or flux values. The code admits both continuous and stepped temporal variations (Figure 5.7). A continuous variation is represented using the piecewise linear approximation passing through a number of control points. A discontinuous variation is represented using a stepped approximation passing through control points. The total number of control points is equal to the number of steps plus one.

Chained decay source boundary conditions can also be handled by VAM2D. In this case, the code needs data for the node numbers of the nodes representing the decaying sources. Data describing the source characteristics are also needed. These data include the leach time duration of the source, source decay coefficients, and initial solute mass flux or concentration data. The analytical solution of the Bateman equations is used to compute the source concentration and solute mass flux released from the source at a specified time value. This computation is performed for all components along each chain (or reaction path). The number of paths is 1 for a straight chain and greater than 1 for a branch chain.

5.6 GENERAL GUIDANCE ON SELECTION OF GRID SPACINGS AND TIME STEPS, AND THE USE OF SOLUTION ALGORITHMS

In designing a finite element grid, one should select nodal spacings that will yield reasonable approximations to the expected moisture profiles, head and/or concentration distribu-

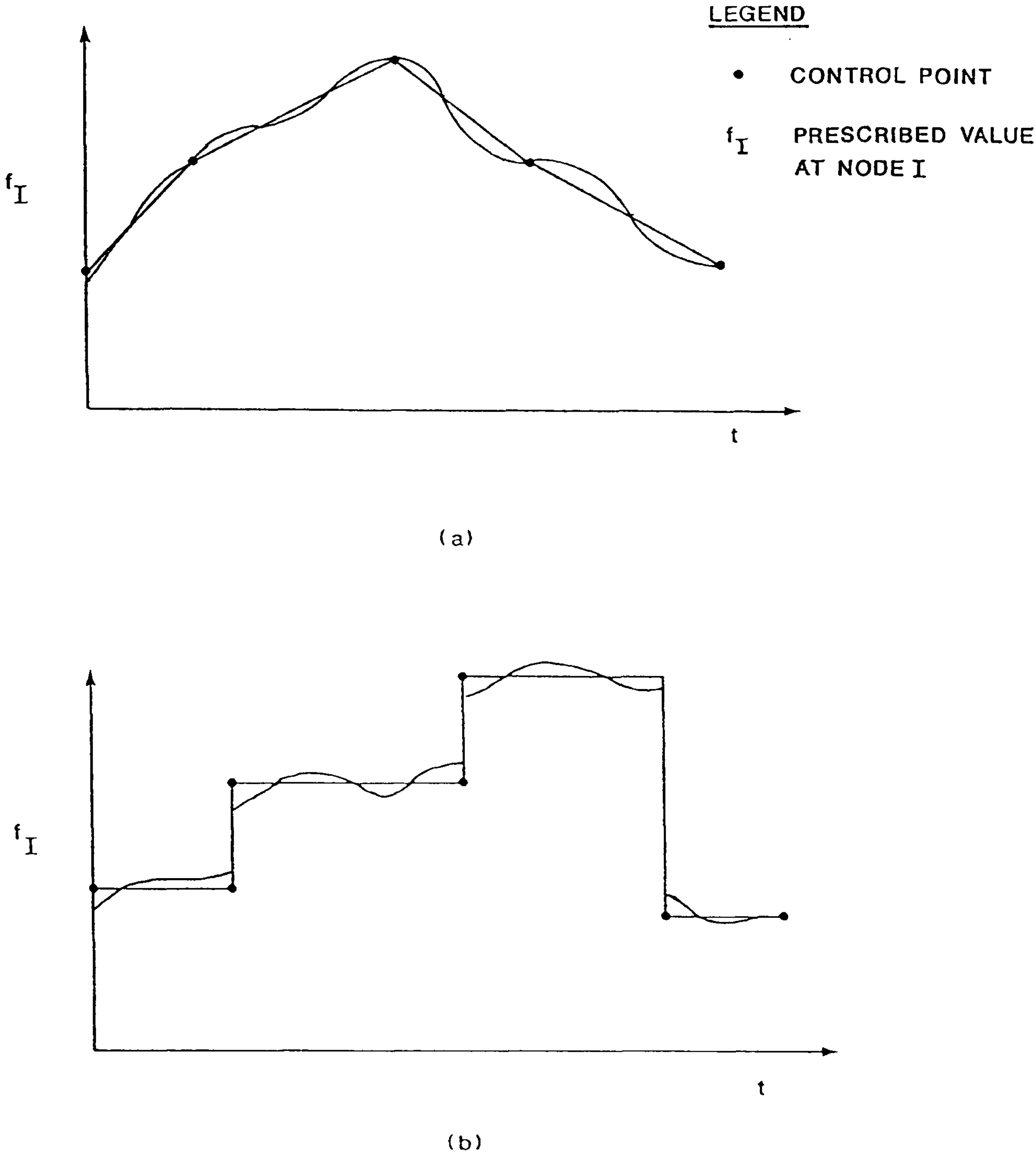


Figure 5.7. Modeled approximations for continuous and discontinuous variations of prescribed function at node I.

tions. Small nodal spacings should be used in the zones where head (and/or concentration) gradients or moisture fronts are steep. The nodal spacings may be gradually increased in the zones where no abrupt changes in hydraulic conductivities occur and the gradients are fairly mild.

The variably saturated flow simulation can be performed using either the Picard or the Newton-Raphson solution algorithm. We generally recommend the use of the Picard algorithm with mass lumping option for cases where convergence difficulties are not expected. For certain steady cases involving highly nonlinear soil moisture characteristics, the use of the Newton-Raphson algorithm with mass lumping and upstream weighting is preferable, particularly when its counterpart fails to converge within a reasonable number of iterations (say between 10 and 20). The Newton-Raphson procedure is more strongly convergent than the Picard method, but requires substantially more operations per iteration. In order to achieve optimal computational efficiency for transient flow problems, VAM2D allows the user to specify the use of Newton-Raphson for certain time periods during a simulation and the use of Picard iteration during remaining time periods. For instance, the user can select the Newton-Raphson method for periods of infiltration, where convergence problems are most likely, and use of Picard iteration for periods of redistribution. Optionally, the VAM2D code will automatically switch from Picard to Newton-Raphson when convergence difficulties are encountered. If this option is enabled, the code will use Newton-Raphson iteration if the solute fails to converge in a specified number (NITMAX) of iterations.

Transient analysis of a nonlinear variably saturated flow problem is performed with automatic control of time step values when convergence difficulties occur. VAM2D allows the user to input target time step or time values that cover the desired simulation time period. Alternatively, the code can also generate the target time steps using an initial time step value and time grading factor and maximum allowable time step value supplied by the user. For a transport simulation, the target time steps are also the actual, computational time steps used by the code. For a variably saturated flow simulation on the other hand, each target time step may be divided up into 2 or more computational time steps. At the start of each new target time step, the computational time step is set equal to the new target time step. Each time the solution fails to converge within a prescribed maximum allowable number of iterations (NITMAX), the computational time step is reduced by a factor of 1/2 of its current value. The iteration process continues until either convergence is achieved or the maximum allowable successive reductions of time step (IRESOL) is exceeded. If convergence occurs, the code continues the analysis (over the remaining portion of the target time step) using the most recent value of computational time step. This time step control marching procedure is used over the entire flow simulation period. If convergence does not occur and IRESOL is exceeded, VAM2D execution is automatically terminated. The upshot of this is that if a combined flow and transport simulation is performed, the transport analysis is performed using the target time steps, while the flow analysis may use smaller computational time steps to ensure convergence.

There is no strict guide that can be given for the selection of appropriate time step values for the variably saturated flow analysis. As a general guide, the time steps chosen should be tied in with the degree of nonlinearity of the flow scenario or problem being considered. A rough (order of magnitude) estimate of the target time size may be made using the following formula: $\Delta t = \tau \Delta x / \kappa$, where Δx is a characteristic grid length, κ is a characteristic front velocity that may be set equal to infiltration rate or saturated conductivity depending on the flow scenario, and τ is a dimensionless time factor on the order to 0.01 to 1 depending on the degree of nonlinearity of the problem (dictated by moisture characteristic curves and boundary conditions).

In VAM2D, a transient transport analysis can be performed concurrently with the associated transient flow analysis. If this option is used, the code will assume that the mesh and the target time values for the flow problem also apply to the transport problem. Another option available is to perform the transport simulation separately from the flow simulation. Via this option, the finite element mesh for flow and transport is still the same but time steps for both analyses may be different. The user can specify to the code time values where velocity and water saturation output is to be written on a backup file on unit 9. These target time values (which need not correspond to the target time values for the non-linear flow analysis) can then be adopted for the subsequent transport analysis. The selection of time steps for the transport simulation can be made based on the use of the following Courant's criterion:

$$\Delta t = \Delta x / (V_{solute})$$

where V_{solute} is a characteristic solute velocity defined as $V_{solute} = V/(\theta R)$, in which V is the Darcy velocity, θ is the water content, and R is the retardation coefficient, respectively.

5.7 MASS BALANCE ASSESSMENT

At the conclusion of a steady-state analysis or at the conclusion of each target time step of a transient analysis, the VAM2D code can perform an assessment of mass balance. As part of a problem setup, the user has the option of specifying whether volumetric flow (or solute mass) balance and/or flux calculations are to be performed. If either are to be done, the user must specify nodes where integrated flux values are to be calculated. The sign convention adopted for summing these fluxes is positive for influent and negative for effluent fluxes.

For the flow simulation, the volumetric balance summary printed to file number 6 includes the following:

1. Total flow rate because of boundary flux and sinks,

2. Rate of fluid accumulation,

3. Volumetric flow balance error,

4. Normalized flow balance error, and

5. Cumulative volumetric storage of fluid.

The first item is a summation of influent and effluent fluid fluxes calculated at the user-specified nodes. For example, if a steady-state flow field is simulated and all boundary and source/sink nodes are identified for the flow balance, then the total flow rate should be identically zero. The second item is the fluid accumulation rate. This quantity is an element-by-element summation of the change in fluid volume from one time step to another. Note that fluid accumulation rate is identically zero for steady-state flow fields. Volumetric flow balance error, the third item, is the difference between the previous two items. The fourth item is a normalized version of the flow balance error. It uses a summation of the absolute value of boundary and source/sink integrated nodal fluxes as the normalizing quantity. Obviously, the user-specified nodes for the flow balance or flux calculations influence the flow balance characterization of a simulation. These nodes must be selected to represent all fluxes in and out of the problem if the resultant calculations of fluxes are to accurately reflect the mass balance of the problem. The final item is the current value of cumulative volumetric storage of fluid inside the flow domain.

For the transport simulation, the solute-component mass balance summary printed to file unit number 6 includes the following:

1. Total net value of dispersive and advective solute mass fluxes,

2. Net rate of solute mass decay and transformation,

3. Net rate of solute mass accumulation (storage + decay + transformation),

4. Mass balance error,

5. Normalized mass error,

6. Cumulative mass cumulation, and

7. Cumulative mass decay and transformation.

The first item is the net sum of integrated values of dispersive and advective fluxes at the user-specified nodes. The second item is the sum of mass decay rate of the component being considered and the rate of mass transformation to that component. The third item is the net sum of the rate of mass storage and the second item. The fourth item is the mass balance error computed by taking the difference between items 1 and 3. The fifth item is a normalized mass balance error obtained by normalizing item 4 with respect to absolute sums of all fluxes and mass storage, decay and transformation terms. The last two items, 6 and 7, are cumulative values of net mass accumulation, and decay and transformation, respectively.

5.8 DATA PREPROCESSING AND OUTPUT POSTPROCESSING

An interactive data preprocessor code that facilitates the preparation of a proper formatted input file for running VAM2D has recently been developed. This processor is written in FORTRAN for convenient use on a personal computer using MS DOS operating system. It is user friendly and equipped with many salient features. These include the following:

- Automatic material zone identification for the elements in the rectangular grid
- Automatic identification of nodes receiving different types of boundary conditions mentioned earlier
- Automatic identification of locations of nodes corresponding to point sinks or sources (e.g., wells).

Output from the preprocessor is written on a file that can be used directly as an input file on unit 5 for VAM2D.

As an alternative option to using the preprocessor, the user may elect to prepare manually the required input data file for VAM2D. In this case, the input data preparation guide given in Chapter 8 needs to be used.

6 CODE STRUCTURE

6.1 SUBROUTINE LIST

The VAM2D code contains a main program and 35 subroutines. The functions of these program segments are as follows:

PROGRAM SEGMENT	FUNCTION
MAIN Program	Reads and writes input data and calls a number of key subroutines.
ASSEMV	Assembles element matrices.
BALCHK	Computes nodal values of fluxes and water and solute balance for the entire solution region.
BATEMN	Computes the Bateman analytical solution.
BUPDAT	Updates source boundary conditions.
DEFINT	Initialize nodal hysteresis parameters.
DSWCRU	Computes upstream weighted values of nonlinear soil functions at element centroids.
DSWCOM	Compute values of nonlinear soil functions at element centroids.
DSWFUN	Computes moisture capacity function.
DXYGEN	Generates spacings (Δx and Δy) of vertical and horizontal grid lines of the rectangular grid.
EBFIND	Computes maximum bandwidth of the global matrix.
EBFOR1	Computes seepage element matrices for rectangular elements.

PROGRAM SEGMENT	FUNCTION
EBFOR2	Computes transport element matrices for rectangular elements.
EIBCHK	Updates boundary conditions for the nodes having infiltration or evaporation.
EVISET	Identifies the global sequential numbers of the nodes having infiltration or evaporation, and computes nodal areas and initial estimates of flux values.
FIXQEV	Updates nodal flux values for the nodes having infiltration or evaporation.
HDEST	Obtains the first estimate of head values at the current time level.
HFINTP	Determines the prescribed head or flux values by interpolation.
MESHGN	Generates nodal coordinates and element connections for a simple rectangular grid.
PBC	Allocate prescribed Dirichlet and flux boundary conditions.
PKWFUN	Computes relative permeability function.
RFINTP	Performs linear interpolation using tabulated values of root effectiveness function versus elevation (depth coordinate).
SOLVEC	Solves a linear set of algebraic equations using a Gauss elimination scheme for an unsymmetric banded matrix.
SOLVEP	Solves a set of algebraic equations taking into account the symmetric banded feature of the coefficient matrix.

PROGRAM SEGMENT	FUNCTION
SWHFUN	Computes water saturation function.
SWICOM	Computes nodal and element water saturation values using pressure head from previous time value.
SSUPDT	Updates values of effective storage coefficient at element centroids.
TLOOP1	Computes nodal values of the specified dependent variable (head or concentration) for the specified number of time steps.
TLOOP2	Computes nodal values of both head and concentration for the specified number of time steps.
TRANSP	Implements the procedure for constrained maximization of the water uptake by plant roots. This procedure is described in Section 3.2.5.
TRANST	Computes effective surface area of the nodal columns in the root zone, and computes values of root effectiveness function at the nodes in the columns.
UPDATE	Update nodal values of hysteresis parameters.
VARCAL	Performs updating of boundary conditions and setting nonlinear iteration loop.
VANISO	Computes unsaturated hydraulic conductivity for variable anisotropy case.

PROGRAM SEGMENT	FUNCTION
VSWCOM	Computes values of water saturation and Darcy velocity components at element centroids.
WYSET	Sets the magnitude and sign of the upstream weighting factors, α and β, associated with the upstream weighting functions.

6.2 INTERNAL DATA STRUCTURE

Data necessary for the finite element analysis performed by the code is classified as follows:

(1) Material properties. These data are read in and stored in three common blocks labeled MDATA, RDATA, and VARANI, respectively. The block MDATA contains material numbers and values of hydraulic and transport properties of different porous materials. The block RDATA contains properties of solute species. Finally, the block VARANI contains values of the variably anisotropy parameters for each material type.

(2) Nodal coordinates and element nodal connections. These data are either read in or generated by the code. They are stored in the common blocks labeled as WAVE.

(3) Boundary condition data. These data are read in and stored in two common blocks labeled DBATA and FDATA. The block BDATA contains node numbers and prescribed values of the dependent variables to be determined, i.e., hydraulic head, pressure head or concentration. The block FDATA contains node numbers and values of nodal fluxes.

(4) Initial condition data and computed values of dependent variables with time level. These are also stored in the common block labeled WAVE.

(5) Global coefficient matrix. This matrix is generated and modified during simulation. It is stored in a common block labeled WDUM.

6.3 DIMENSION LIMITS

No dynamic dimensioning is employed in the code. All of the important arrays are stored in labeled common blocks. The dimension limits of the principal arrays are summarized below.

These must be observed by the user when applying the code to practical problems.

Maximum total number of nodal points	=	1666
Maximum total number of elements	=	1600
Maximum number of time steps	=	299
Maximum number of different sets of material properties	=	20
Maximum number of steady-state Dirichlet boundary conditions	=	309
Maximum number of steady-state flux boundary conditions	=	1666
Maximum semibandwidth of global coefficient matrix for fluid flow modeling	=	90
Maximum full bandwidth of global coefficient matrix for transport modeling	=	90
Maximum number of time-dependent, Dirichlet boundary nodes	=	50
Maximum number of time-dependent, flux boundary nodes	=	50
Maximum number of nodes for which flux computation is required	=	309
Maximum number of elements subjected to evaporation or infiltration	=	101
Maximum number of nodes subjected to evaporation or infiltration	=	202
Maximum number of observation nodes	=	75
Maximum number of plant nodal columns	=	35
Maximum number of plant species	=	5
Maximum number of elements in the root zone	=	155
Maximum number of nodes in the root zone	=	350
Maximum number of specie components for chain decay transport modeling	=	4

Maximum number of nodes representing decaying sources = 20

6.4 INITIALIZATION

All of the important variables are initialized in the main program. The initialization procedure is outlined in Table 6.1.

6.5 RESTART PROCEDURE

A restart option is provided in the code to continue the solution of time-dependent problems. To use this option, the user must provide data for the initial nodal values of the dependent variables. These nodal values are to be supplied as input data in data file number 5. If the restart option is selected, the user should adopt the following procedure:

(1) Before restarting a run, a provision must be made in the run for the code to write the last set of nodal values (computed at the final time step) on file number 8. This is achieved by setting the value of the input variable NOWRIT to 1.

(2) Prepare input data for the file number 5 of the restart run in the usual manner, keeping in mind that data type 19 "initial value cards," can be readily obtained from the contents of file number 8. Note also that the variable NONU of data type 3 must be set equal to 1 and the variable NPIN of data type 6 must be set equal to the total number of nodal points in the finite element mesh.

Table 6.1. Initialization of Important Variables.

ARRAY VARIABLE	INITIALIZATION PROCEDURE
IPROP	IPROP(1) through IPROP(NE) are initialized to the default value of 1. This means that initially the code assumes that the material number corresponding to each element is 1.
HINT	HINT(1,1) through HINT(NP,NDF), where NP = number of nodes and NDF = number of dependent variables, are initialized to the default values which are read in by the code.
VELX	VELX(1) through VELX(NE), where NE = number of elements, are initialized to the default value, VCX, which is read in by the code.
VELY	VELY(1) through VELY(NE) are initialized to the default value VCY, which is read in by the code.

7 DATA FILES

There are five data files in the code. These are described as follows.

1. File number 5. This is the card input file containing the essential input data for each run of the code. The content of this file as well as the description of input variables and their formats are provided in Chapter 8, which deals with input data.

2. File number 6. This is the output file containing the line printer output from the code. The content of this file as well as the description of output variables are provided in Chapter 9, which deals with output.

3. File number 8. This is the output file containing nodal values of the dependent variables which correspond to the final time step of the current run. Information in this file can be used as the initial condition for the next restart run. File number 8 is written only when the control input variable NOWRIT is set equal to 1. This file (TAPE 8) contains the following information:

- Title Heading giving final time value; written in the FORMAT (20A4).
- List of Nodal Values of the unknown function (head or concentration, depending on whether one is dealing with flow or transport) at the final time level. For a hysteretic flow simulation, the element values of water saturation and wetting-drying index are also written to the TAPE 8 file. These values are written in FORMAT (8E10.3).

The nodal values in TAPE 8 can be used as an initial condition for the next flow or transport restart run (not flow to transport). To do this, the user should delete the heading record of the TAPE 8 file and append this file onto the TAPE 5 file (see section 8.2 for details on TAPE 5 input data set up). Note that the TAPE 8 file corresponds to card type 18b. Next, the user should edit the input TAPE 5 file to set the initial condition control parameters NONU (record group 3, col. 66-70) equal to 1, and NPIN (group 5, cols. 11-15) equal to the total number of nodal points in the mesh.

4. File number 9. This file is written when the flow simulation is performed and the value of the output control

parameter NVWRIT is greater than 0. For each user-selected time step of the flow simulation, this output file (Tape 9) contains the following information, written in binary format:

- Title heading, giving the time value.
- List of element values of the x and y components of Darcy velocity.
- List of element water saturation values.
- List of storage capacity values at the nodes. This information is written only when the mass balance calculation option, IMBAL, is set equal to 1.

The output file TAPE 9 from the flow simulation can be used as a direct input into the subsequent transport simulation. To do this, the user should proceed by editing TAPE 5 as follows:

- Set the control parameter NVREAD (group 5, cols. 1-5) equal to 2. This directs the code to read velocity and saturation data from TAPE 9.
- Make sure that IMBAL (record group 5, col. 46-50) on TAPE 5 is set to the value used in the flow simulation. This is necessary to insure compatibility of FORMAT and avoid I/O format error.

5. File number 10. This file is written when the value of the plotting control parameter NPLOT (record group 5, col. 31-35) is greater than zero.

For NPLOT=n, the output file TAPE 10 contains the following data for each n-th time step:

- Heading, giving the time step value.
- Nodal x and y coordinates followed by the nodal values of the dependent variables pressure head and/or concentration, written in FORMAT 7E10.3.

6. File number 11. This file is written when a flow simulation is performed, IMODL = 1 or 2 (group 3, col. 1-5) and NPLOT is greater than zero. For NPLOT = n the file TAPE 11 contains the following data for each n-th time step:

- Heading, giving the time step value.
- x and y coordinates of the element centroids followed by values of element water saturation and x and y components of the Darcy velocity, written in FORMAT 5E10.3.

8 INPUT DATA PREPARATION

8.1 GENERAL CONSIDERATIONS

VAM2D is designed to perform the analysis of one problem or several consecutive problems in a single computer run. Several features are incorporated into the code for automatic generation of a substantial portion of the input required for the finite element analysis of each problem. These are summarized as follows:

(1) Automatic mesh generation. The mesh generation is limited to a rectangular grid consisting of linear rectangular elements. Each grid must have constant number of nodal rows and constant number of nodal columns. The grid spacings can be uniform or variable.

(2) Default initial value option. This option is invoked by setting the input variables NONU and NPIN equal to zero. When this is the case, all nodal values of the dependent variables will be set equal to the default initial values.

(3) Default velocity and default water saturation option. This option is invoked by setting NVREAD equal to zero.

8.2 RESTART PROCEDURES

A restart option is provided in the code for a continuation of the solution of time-dependent problems. To use this option the user must provide data pertaining to the initial nodal values of the dependent variables. These nodal values are to be supplied as input data on FORTRAN data files. If the restart option is selected, the user should adopt the following procedures:

(1) Before restarting, a provision must be made in the preceding run for the code to write the last set of nodal values (computed at the final time step) on file unit 8. This is achieved by setting the value of the input variable NOWRIT (group 5, cols. 51-55) equal to 1.

(2) Prepare input data for file unit 5 of the restart run in the usual manner but keeping in mind that Record Type 18 and 22 initial value can be derived from information contained in

file unit 8. Note also that the variable NONU (group 3, cols. 66-70) must be set equal to 1 and NOWRIT must be set equal to 0.

8.3 INPUT RECORDS

The main stream of input data is to be supplied from input file unit 5. The VAM2D code simulates two-dimensional flow and solute transport in a variably saturated medium. The program can solve the following problems: (1) variably-saturated flow, (2) transport of single component or multi-component chain in a variably saturated porous medium, and (3) combined flow and transport. The main stream of input data is to be supplied from input file unit 5. To facilitate data entry, the input data is divided into groups, arranged as follows:

1. Number of problems to be solved
2. Problem title
3. Simulation control parameters
4. Time stepping and iteration control parameters
5. Input and output control parameters
6. Temporal discretization data
7. Default initial values
8. Element property numbers
9. Hydraulic parameters of soil
10. Soil physical transport parameters
11. Soil-solute transport parameters
12. Mesh parameter specification
13. Grid line coordinates
14. Mesh generation data
15. Boundary condition data

16-I Transient dirichlet boundary conditions

16-II Transient flux boundary conditions

17. Decaying source boundary condition data

18. Initial nodal value data

19. Default value data

20. Element Darcy velocity data

21. Element water saturation data for transport simulation

22. Initial element water saturation data for hysteretic flow simulation

23. Boundary nodal data

24. Evaporation and infiltration control data

25. Plant species data

26. Root zone element and node data

27. Observation node data

28. Velocity file output time specification data

The above sequence must be strictly followed when entering data into the program. The selection of units to be used is arbitrary (e.g., hour or day for time, centimeter or meter for length) but must be consistent. Where appropriate the type of unit (e.g., L(ength), T(ime), M(ass) etc.) for the input variabale is given together with the format description. Following are descriptions of the input variables and data formats.

1. <u>Number of problems</u> (I5)
   One record.

   Col. 1-5 NPROB: Number of problems to be solved in this run.

   *** The following record types are to be repeated for each problem.

2. <u>Problem title</u> (A80)

   One record.
   Col. 1-80 TITLE: Title of problem.

3. <u>Simulation control parameters</u> (16I5)

   One record.

   Col. 1-5 IMODL: Parameter indicating the type of modeling required;
   = 0 for solute transport modeling,

		= 1 for water flow modeling, = 2 for simultaneous flow and transport modeling.
6-10	IHYST:	Parameter indicating if hysteresis is to be included in flow simulation; = 1 if yes, = 0 if no. (Set IHYST = 0 if IMODL = 0.)
11-15	IANI:	Parameter indicating if variable anisotropy of hydraulic conductivity is to be included in flow simulation; = 1 if yes, = 0 if no. (Set IANI = 0 if IMODL = 0.)
16-20	INTSPC:	Parameter specifying if initial head values supplied to the code by the user are to be converted to initial pressure head values; = 1 if yes, = 0 if no. Set INTSPC = 0 if dealing with the transport equation (IMODL = 0).
21-25	ICHAIN:	Parameter indicating if chained chemical reactions or radioactive decay is to be accounted for in the transport simulation; = 1 if yes, = 0 if no. When only flow simulation is required (IMODL = 1), ICHAIN is set to zero.
26-30	ISSTA:	Parameter indicating if a steady-state analysis of the problem is required; = 1 if yes, = 0 if no.
31-35	ITSGN:	Parameter indicating if simulation time values are to be generated by the code; = 0 if no, = 1 if yes and time values are to be computed using generated time steps, = 2 if yes and time values are to

be computed using specified time step values.

36-40	NTS:	Number of target time steps (see Section 5.6). Set = 1 if a steady-state analysis of the problem is required.
41-45	NP:	Total number of nodal points in the finite element grid.
46-50	NE:	Total number of elements in the finite element grid.
51-55	ISWAP:	Parameter indicating the sequential numbering of the nodes in the rectangular mesh to be generated; = 1 if the nodes are sequentially numbered in the x-direction, = 0 if the nodes are sequentially numbered in the y-direction. The purpose of ISWAP is to achieve a smaller matrix bandwidth.
56-60	IAXSYM:	Parameter indicating if the problem is axisymmetric with x and y corresponding to radial and vertical coordinates respectively; = 1 if yes, = 0 if no.
61-65	NMAT:	Number of different porous materials.
66-70	NONU:	Parameter indicating if initial condition values are nonuniform; = 0 if no, = 1 if yes and initial condition data are to be input as part of this input file (see group 18 and 22), = 2 if yes and initial condition data are to be supplied by reading from a file on unit 8. <u>Do not use the NONU = 1 option if dealing with multispecies solute transport simulation</u>.
71-75	NEIEVP:	Number of finite elements that are subject to infiltration or evaporation.

76-80	NPLANT:	Number of different plant species.

4. Time stepping and iteration control parameters (5I5, 2E10.3,3I5)

One record.

Col. 1-5	IKALL:	Parameter indicating the type time stepping scheme required; = 1 for backward difference scheme, = 0 for central difference scheme. Note IKALL is automatically set to 1 if steady-state analysis is required.
6-10	INEWT:	Parameter indicating the type of iterative procedure to be used in solving the variably-saturated flow equation. = 0 for Picard procedure = 1 for Newton-Raphson procedure INEWT is set to 0 when dealing with the transport model only (IMODL = 0).
11-15	NITMAX:	Maximum number of non-linear iterations allowed. If only solute transport is required (IMODL = 0), NITMAX is set equal to 1. Otherwise set NITMAX equal to the desired maximum number of iterations.
16-20	IRESOL:	Maximum number of refinements of time steps allowed if the solution of the variably-saturated flow equation does not converge (recommended value is 3 or 4). Set to zero or leave blank if transport simulation only is required (IMODL = 0).
21-25	ILUMP:	Parameter indicating if mass lumping procedure is to be applied in formulating the element matrix of the flow equation; = 1 if yes, = 0 if no.
26-35	HTOL:	Iteration tolerance for head during flow simulation (L). For a

transport simulation, HTOL is automatically set = 0.0.

36-45 HWWT: Underrelaxation factor for the nonlinear solution of a variably saturated flow problem. Set HWWT = 0.5 if underrelaxation is desired, otherwise leave blank. For a steady-state analysis, HWWT must be left blank.

46-50 IUPSTR: Upstream weighting control parameter for relative permeability;
= 1 if upstream weighting is required;
= 0 otherwise.

51-55 INSTOC: Parameter indicating the procedure to be used in computing the storage of the Newton-Raphson formulation of the flow problem;
= 0 if computed in terms of $(dS_w/d\psi)\ \partial\psi/\partial t$,
= 1 if computed directly from $\partial S_w/\partial t$. Leave blank if not used.

56-60 ISELSC: Parameter indicating if a combined use of Newton-Raphson and Picard nonlinear schemes is to be made in the transient simulation of the flow problem;
= 1 if yes,
= 0 if no.

5. <u>Input and output control parameters</u> (12I5)

One record.

Col. 1-5 NVREAD: Parameter specifying if element velocity and water saturation data are to be input;
= 0 if no velocity and saturation input are needed (this option is used for a flow run),
= 1 if the velocity and saturation data are to be included in this data file (this option is used for a transport run when the flow is steady state),
= 2 if these data are to be input

using a separate data file unit number 9.
Note: NVREAD is set to 0 if IMODL = 1 or 2.

6-10 IOUTLT: Parameter indicating if boundary node data (see group 23) are to be read in;
= 1 if yes,
= 0 if no.

11-15 NPIN: Number of nodes for which initial nodal values to be input as part of this input file. NPIN is automatically set = 0 unless NONU = 1.

16-20 IPRD: Parameter indicating output requirement;
= 0 if complete mesh data print-out is required,
= 1 if element connection data printout is not needed,
= 2 if the whole mesh data printout is not needed,
= 3 if mesh and initial condition data printouts are not needed.

21-25 NVWRIT: Parameter specifying if computed values of element velocities and water saturation are to be written on file unit 9;
= 0 if no,
= 1 if yes and output is to be written for each time step;
= 2 if yes and output is to be written for selected time steps as specified in record group 28.
Note: NVWRIT is set to 0 if IMODL = 2.

26-30 NVPR: Parameter controlling printout of computed element velocities and water saturation;
= 0 if no output is to be written,
= n if the output is to be written for each nth time step.

31-35 NPLOT: Parameter indicating if time and computed nodal values of the

		variables concerned (head, saturation, or concentration) are to be written on file unit 10 for use in subsequent plotting; = 0 if no output is to be written, = n if the output is to be written for each nth time step.
36-40	NSTEP:	Parameter controlling printout of computed nodal values; = 0 if no output is to be written, = n if the output is to be written for each nth time step.
41-45	IOBSND:	Parameter indicating if values at some specified nodes are to be recorded for all time steps (see group 27); = 1 if yes, = 0 if no.
46-50	IMBAL:	Parameter specifying if mass balance calculation is required, = 1 if yes, = 0 if no.
51-55	NOWRIT:	Parameter indicating if computed values of head or concentration at the final time level are to be written on file unit 8; = 1 if yes, = 0 if no.
56-60	IPRCHK:	Print check option parameter; = 1 if element matrix and boundary condition print check is required, = 0 if no.

6. Temporal discretization data

(a) Time discretization parameters (4E10.3)

One record.

Col. 1-10	TIMA:	Initial time value (T).
11-20	TIN:	Initial time step size (T).
21-30	TFAC:	Time step multiplier.
31-40	TMAX:	Maximum value of time step allowed (T).

Note: if ITSGN = 0 or 2 (group 3, col. 31-35), TIN and TFAC are not used. Their values may be left blank or set = 0.0

(b) Time values (8E10.3)

*** Omit if ITSGN (group 3, col. 31-35) is equal or greater than 1.

Number of records = NTS/8 + 0 or 1.

Col. 1-10	TMVEC(I):	Time values at the end of time
11-20	I=1,	steps 1 through NTS (T).
etc.	NTS	

(c) Time discretization parameters (3E10.3,I5)

*** Omit unless ITSGN = 2.

Number of records = as many as needed.

Each record contains the following information:

Col. 1-10	TMST:	Starting time value (T).
11-20	TMEND:	Ending time value (T).
21-30	DTS:	Time step used between TMST and TMEND (T).
31-35	IPAUSE:	Parameter indicating if this is the last record for subgroup 6c; = 1 if yes, = 0 if no.

(d) Nonlinear Scheme Selection Parameters

*** Omit if ISELSC = 0.

(i) Control record (I5,E10.3)

One record.

Col. 1-5 ISWICH: Parameter indicating whether a switch from the Picard to Newton-Raphson scheme is to be made if convergence difficulty occurs;
= 1 if yes,
= 0 if no.

6-15 ENRFAC: Relaxation factor used to reduce the degree of nonlinearity when convergence difficulty occurs. Suggested value of ENRFAC lies between 0.75 and 1. If no reduction of the degree of nonlinearity is required set ENRFAC = 1. In any case, ENRFAC must not be greater than 1.

(ii) Nonlinear scheme selection records (4I5)

Number of records = as many as needed.

Col. 1-5 ISC: Nonlinear scheme indicator;
= 1 for Newton-Raphson,
= 0 for Picard scheme.

6-10 ITST: Starting time step number when the specified value of ISC (the selected nonlinear scheme) is to be applied.

11-15 ITEND: Ending time step number when the specified value of ISC is to be applied.

16-20 IPAUSE: Parameter indicating if this is the last record of subgroup 6d;
= 1 if yes,
= 0 if no.

7. Default initial values

(a) Dependent variables (2E10.3)

One record.

Col. 1-10 HEADI: Default initial value of the pressure head (or hydraulic head if INTSPC = 1) (L). Leave blank if dealing with transport simulation only (IMODL = 0).

11-20 CONCI: Default initial value of the solute concentration (M/L^3). Leave blank if dealing with flow simulation only (IMODL = 1).

(b) Saturation (E10.3,I5)

*** Omit if IHYST (group 3, col. 6-10) = 0

One record.

Col. 1-10 SWINT(1): Default initial value of element saturation.

11-15 KHYST(1): Default initial value of the hysteresis index,
= -1 if initial condition is drying,
= +1 if initial condition is wetting.

Note: If the water content value is left blank, the saturation will be computed from the initial pressure head value, using parameters for the main drying retention curve if KHYST(1) = -1, or the main wetting curve if KHYST(1) = +1.

8. Element property numbers (16I5)

*** Omit this group if NMAT (group 3, col. 61-65) = 1.

Number of records = NE/16 + (0 or 1).

Col. 1-5, 6-10,etc. IPROP(J): J=1, NE — Material number specification for element number 1 through NE.

9. Hydraulic properties of soil

*** Omit this group if IMODL (group 3, col. 1-5) = 0.

(a) Saturated property values (7E10.3)

Number of records = NMAT (group 3, col. 61-65).

Col. 1-10 PROP(I,1): Horizontal component of saturated hydraulic conductivity, K_h (L/T).

11-20 PROP(I,2): Vertical component of saturated hydraulic conductivity K_v (L/T). Set $K_v = K_h$ if dealing with isotropic material.

21-30 PROP(I,3): Cross component of saturated hydraulic conductivity K_{hv} (L/T). Set $K_{hv} = 0$ unless coordinate axes do not coincide with principal directions of anisotropy.

31-40	PROP(I,4):	Specific storage, S_s (1/L).
41-50	PROP(I,5):	Saturated water content, θ_{sat}.
51-60	PROP(I,6):	Air entry pressure head value, ψ_a (L).
61-70	SANGLE(I):	Angle (in degrees) of inclination of the surface of the soil material zone. If the zonal surface is horizontal, set this angle to zero. A positive angle corresponds to counterclockwise rotation.

(b) Variable anisotropy parameters (4E10.3)

*** Omit if IANI (group 3, col. 11-15) = 0.

Number of records = NMAT (group 3, col. 46-50).

Col. 1-10	SIGMF(I):	Variance of ln K-transformed saturated hydraulic conductivity $(L/T)^2$.
11-20	SIGMAL(I):	Variance of average slope of ln [K(ψ)] relation.
21-30	YAMDA(I):	Correlation length normal to stratification (L).
31-40	ANISMX(I):	Maximum allowed anisotropy ratio. Default is 10^7.

10. Soil moisture functional parameters

*** Omit this group if IMODL (group 3, col. 1-5) = 0.

Number of records = NMAT (group 3, col. 46-50, or NMATx2 if IHYST (group 3, col. 6-10) = 1.

(a) Parameters for main drying curve (5E10.3)

Col. 1-10	PROP(I,7):	Residual saturation (S_{wr}) of material number I.
11-20	PROP(I,8):	Control parameter (n) of the Brooks-Corey relative permeability versus saturation relationship, $k_{rw} = (S_w-S_{wr})^n/(1-S_{wr})^n$. Set PROP(I,8) = 0 if the van

Genuchten k_{rw} versus S_w is to be used instead of the Brooks-Corey relationship.

21-30 PROP(I,9): Leading coefficient (α^d) of the van Genuchten saturation versus capillary head relationship (1/L),

$(S_w-S_{wr}) = (1-S_{wr})/[1+(\alpha|\psi-\psi_a|)^\beta]^\gamma$.

31-40 PROP(I,10): Power index (β^d) of the saturation versus capillary head relationship.

41-50 PROP(I,11): Power index (γ^d) of the saturation versus capillary head relationship. If PROP(I,11) is left blank, the code then assumes that $\gamma^d = 1-1/\beta^d$.

(b) <u>Parameters for main wetting curve</u> (E10.3,10X,3E10.3)

*** Omit if IHYST (group 3, col. 6-10) = 0.

Col. 1-10 PROP(I,12): Maximum wetting saturation (S_{ws}) of material number I. Default value is $S_{ws} = 1$.

11-20 blank

21-30 PROP(I,13): Leading coefficient (α^w) of the saturation versus capillary head relationship (1/L). Default is $\alpha^w = \alpha^d$.

31-40 PROP(I,14): Power index (β^w) of the saturation versus capillary head relationship. Default is $\beta^w = \beta^d$.

41-50 PROP(I,15): Power index (γ^w) of the saturation versus capillary head relationship. If PROP(I,15) is left blank, the code assumes that $\gamma^w = 1-1/\beta^w$.

Note: If a non-hysteretic simulation is performed (IHYST = 0), only group 10a is read. If a hysteretic simulation is performed (IHYST = 1), the parameters for the main drying curve are given in group 10a and the parameters for the main wetting curve are given in group 10b.

11a. <u>Soil physical transport parameters</u> (6E10.3)

*** Omit this group if IMODL (group 3, col. 1-5) = 1.

Number of records = NMAT (group 3, col. 61-65).

Col. 1-10	PROPJ(I,1):	Longitudinal dispersivity, α_L (L).
11-20	PROPJ(I,2):	Transverse dispersivity, α_T (L).
21-30	PROPJ(I,3):	Molecular diffusion component, D^o_{xx} (L^2/T).
31-40	PROPJ(I,4):	Molecular diffusion component, D^o_{yy} (L^2/T).
41-50	PROPJ(I,5):	Effective porosity, ϕ.
51-60	PROPJ(I,6):	Bulk density, ρ_b (M/L^3).

11b. <u>Soil-solute transport parameters for single-species simulation</u> (2E10.3)

*** Omit this group if performing flow simulation only (IMODL = 1). Also omit it and proceed to group 11c if multiple-species chained decay simulation is required (ICHAIN = 1).

Number of records = NMAT (group 3, col. 61-65).

1-10 RPROP(I,1,1):	Decay coefficient, λ (1/T). For a conservative solute species set RPROP(I,1,1) = 0.0. Note $\lambda = \ln 2/t_{1/2}$, where $t_{1/2}$ = half life.
11-20 RPROP(I,2,1):	Distribution coefficient, k_d (L^3/M). Note: the unit for k_d must be the reciprocal of the unit for bulk density. For a unretarded solute species set RPROP(I,2,1) = 0.0.

11c. <u>Soil-solute transport parameters for multispecie simulation</u>

*** Omit this group if IMODL = 1 or ICHAIN = 0.

(i) <u>Control record</u> (2I5)

One record.

Col. 1-5	NSPECI:	Number of solute species that need to be considered.
6-10	IDSRCE:	Parameter indicating if decaying source boundary conditions are to

be simulated;
= 1 if yes,
= 0 if no.

(ii) Reaction path indicators

*** Omit if IDSRCE = 0.

Flag record (I5)

Col. 1-5	NPATH:	Number of decay chains or reaction paths. In the case of the straight decay chain, the maximum value of NPATH = 1.

Follow-up record sets (16I5)

*** Omit if IDSRCE = 0.

These record sets are to be repeated for each reaction path.

Col. 1-5	IPATH:	Decay chain or reaction path number.
6-10	NTCOMP:	Number of species components in the chain or path number being considered. For the straight chain case, NTCOMP = NSPECI.
11-15 etc.	KTCOMP(J), J=1, NTCOMP	Sequential component numbers of the transforming components in the decay chain corresponding to the given value of IPATH. For the straight chain case, KTCOMP(J) = J.

(iii) Species transformation data

Number of record sets = NSPECI.

Flag record (2I5)

Col. 1-5	ISP:	Species component number.
6-10	NPA:	Number of immediate parents.

Follow-up records (4(I5,E10.3))

*** Omit if NPA = 0.

Number of records = NPA

Col. 1-5	KPAREN(J):	Species component number of the J-th parent.
6-15	APAREN(J):	Mass fraction of the J-th parent that decays to species ISP.
repeat etc. for J=1, through NPA		

(iv) Decay and distribution coefficient data

Number of record sets = NMAT.

Each set contains the following information:

Flag record (2I5)

Col. 1-5	I:	Soil material number
6-10	IREPET:	Parameter indicating if the following decay and distribution coefficient data are repeated and to be derived from the previous soil material number; = 1 if yes, = 0 if no.

First follow-up records (8E10.3)

*** Omit if IREPET = 1.

Col. 1-10 11-20 etc.	RPROP(I,1,KSP): KSP=1,NSPECI	Decay coefficient values for species components 1 through NSPECI (T^{-1}).

Second follow-up records (8E10.3)

*** Omit if IREPET = 1.

Col. 1-10 11-20 etc.	RPROP(I,2,KSP): KSP=1, NSPECI	Distribution coefficient values for species components 1 through NSPECI (L^3/M).

12. Mesh parameter specification (2I5, 2F10.3, 2I5)

One record.

Col. 1-5	NROWS:	Number of grid lines parallel to the x-direction.

6-10	NCOLS:	Number of grid lines parallel to the y-direction.
11-20	DXMAX:	Maximum value of spatial increment allowed in the x-direction.
21-30	DYMAX:	Maximum value of spatial increment allowed in the y-direction.
31-35	IXYRED:	Parameter indicating if x and y coordinates of the grid lines are to be input or generated; = 0 if coordinates are to be computed using generated values of spatial increments; = 1 if coordinate input is needed; = 2 if coordinates are to be computed using specified values of spatial increments.
36-40	IHORGR:	Parameter indicating if the grid corresponds to a horizontal plane, i.e., gravity terms are to be ignored; = 0 if no (vertical cross-section); = 1 if yes.

13. <u>Grid line coordinates</u>

*** Omit if IXYRED (group 12, col. 31-35) = 0 or 2.

(a) <u>Grid line x-coordinates</u> (8F10.4)

Number of records = NCOLS/8 + 0 or 1 (group 11, col. 6-10).

Col. 1-10 11-20 etc.	XW(J): J=1, NCOLS	x-coordinates of grid lines 1 through NCOLS (L).

(b) <u>Grid line y-coordinates</u> (8F10.4)

Number of records = NROWS/8 + 0 or 1 (group 11, col. 1-5).

Col. 1-10 11-20 etc.	YW(I): I=1, NROWS	y-coordinates of grid lines 1 through NROWS (L).

14. <u>Mesh generation data</u> (8F10.4)

*** Omit if IXYRED (group 12, col. 31-35) = 1.

(a) <u>Coordinate parameters</u>

One record.

Col. 1-10	DX:	Nodal spacing in the x-direction of the first grid block (L).
11-20	DY:	Nodal spacing in the y-direction of the first grid block (L).
21-30	XO:	Maximum value of x-coordinate (L).
31-40	YO:	Maximum value of y-coordinate (L).
41-50	SCFX:	Scale factor in the x-direction.
51-60	SCFY:	Scale factor in the y-direction.
61-70	XSTART:	Minimum value of x-coordinate (L).
71-80	YSTART:	Minimum value of y-coordinate (L).

(b) <u>Spatial increment data</u> (F10.2,3I5)

*** Omit <u>unless</u> IXYRED = 2.

Number of records = as many as needed.

<u>First subset</u>

Each record contains the following information:

Col. 1-10	DELTAX:	Spatial increment in the x-direction (L).
11-15	ISTC:	Starting element column number.
16-20	IENDC:	Ending element column number.
21-25	IPAUSE:	Parameter indicating if this is the last record in the subset; = 1 if yes; = 0 if no.

<u>Second subset</u>

Each record contains the following information:

Col. 1-10	DELTAY:	Spatial increment in the y-direction (L).
11-15	ISTR:	Starting element row number.
16-20	IENDR:	Ending element row number.
21-25	IPAUSE:	Parameter indicating if this is the last record in the subset;

= 1 if yes;
= 0 if no.

Note: (1) the last values of IENDC and IENDR must be equal to NCOLS-1 and NROWS-1, respectively;
(2) the sum of DELTAX*(IENDC-ISTC + 1) must be equal to XO-XSTART; and
(3) the sum of DELTAY*(IENDR-ISTR + 1) must be equal to YO-YSTART.

The boundary conditions and initial condition (groups 15, 16, 17 and 18) are specified for the first and second dependent variables. The first dependent variable is pressure head if the flow simulation is performed (IMODL = 1 or 2). In the case where only transport simulation is performed (IMODL = 0), the first dependent variable corresponds to concentration. The second dependent variable is used only when a combined flow and transport simulation is performed (IMODL = 2). In that case, concentration is the second dependent variable.

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15. Boundary condition data

In supplying boundary condition data to the code, it is necessary to correctly assign sequential number(s) of the dependent variable(s) being considered in the simulation run. For a general case involving concurrent simulation of variably saturated flow and multispecies transport, the sequential numbers of the dependent variables must be assigned such that the first dependent variable corresponds to pressure head (the dependent variable of the flow equation), and the higher dependent variable numbers correspond to concentrations of species component numbers 1 through the last species in the chain. Species indexing must be arranged according to the order of hierarchy in the chain. This ordering notation for the dependent variables can be easily adapted to simpler cases involving flow or transport simulation only and coupled flow and single-species transport simulation.

(a) Boundary condition control record (5I5)

One record.

Col. 1-5 NBTO: Number of nodes with steady-state Dirichlet (prescribed head or prescribed concentration) boundary conditions.

6-10 NDFLUX: Number of nodes with steady-state prescribed flux boundary conditions. Do not count the time-dependent flux boundary conditions when determining NDFLUX.

11-15 NBHVAR: Number of nodes with transient Dirichlet boundary conditions (excluding those corresponding to the decaying source nodes).

16-20 NBFVAR: Number of nodes with transient flux boundary conditions (excluding those corresponding to the decaying source nodes).

21-25 NDCS: Number of nodes where the decaying source boundary conditions are to be applied. For IMODL = 1 (flow simulation only), the code automatically sets NDCS = 0.

(b) Dirichlet boundary condition data (2I5,E10.3)

*** Omit this record if NBTO (group 15, col. 1-5)=0.

Number of records = NBTO.

Col. 1-5 NODV(I): Node number.

6-10 MDEGB(I): Dependent variable number.

11-20 VALVO(I): Prescribed value of the dependent variable (head or concentration) at the boundary node.

(c) Flux boundary condition data (2I5, 2E10.3)

*** Omit this record if NDFLUX (group 15, col. 6-10) = 0.

Number of records = NDFLUX.

Number of cards = NDFLUX. Note that the outward flux is taken to be negative and the inward flux is taken to be positive.

Col. 1-5 NODF(I): Node number.

6-10 MDEGF(I): Dependent variable number.

11-20 FLUXVO(I): For the flow equation, FLUXVO(I) denotes integrated fluid flux at the boundary node (L^2/T). It is to be left blank if the boundary condition at the node is time dependent. For the transport equation FLUXVO(I) corresponds to the integrated solute flux prescribed at the node ($M/L^3 \cdot L^2/T$).

21-30 QVALV(I): For the flow equation, QVALV(I) is to be left blank. For the transport equation, QVALV(I) corresponds to the integrated fluid flux assigned to the boundary node (L^2/T).

16-I <u>Transient Dirichlet boundary conditions</u>

*** To be omitted if NBHVAR (group 15, col. 11-15) = 0.

Number of record sets = NBHVAR.

Each set contains the following records:

(a) <u>Control record</u> (4I5)

One record.

Col. 1-5	NDHVAR(I):	Node number of a time-dependent head (L) or concentration (M/L^3) boundary node.
6-10	MDEGBT(I):	Dependent variable number.
11-15	NTSNDH(I):	Number of control points on the time graph of the boundary condition at the node.
16-20	ITVARH(I):	Parameter indicating the time variation of the prescribed function data; = 0 for continuous variation; = 1 for discontinuous (stepped) variation.

(b) <u>Time value records</u> (8E10.3)

Number of records = NTSNDH(I)/8 = 0 or 1 (group 16a, col. 11-15).

Col. 1-10 11-20 etc.	TMHV(I,J): J=1, NTSNDH(I)	Sequential time values (T) corresponding to the control points on the time graph depicting temporal variation of the prescribed dependent variable.

(c) Functional value records (8E10.3)

Number of records = NTSNDH(I)/8 + 0 or 1 (group 15a, col. 6-10).

Col. 1-10 11-20 etc.	HVTM(K,J): J=1, NTSNDH(I)	Values of the dependent variable corresponding to TMHV(I,J).

16-II Transient flux boundary conditions

*** Omit this record if NBFVAR (group 15, col. 16-20) = 0.

Number of card sets = NBFVAR.

Each set contains the following cards:

(a) Control records (4I5)

One record.

Col. 1-5	NDFVAR(I):	Node number of a time-dependent flux boundary node.
6-10	MDEGFT(I):	Dependent variable number corresponding to the governing equation being considered.
11-15	NTSNDF(I):	Number of control points on the time graph of the flux boundary condition at the node.
16-20	ITVARF(I):	Parameter indicating the time variation of the prescribed nodal flux data; = 0 for continuous variation; = 1 for stepped variation.

(b) Time value records (E10.3)

Number of records = NTSNDF(I)/8 + 0 or 1 (group 16, col. 6-10).

Col. 1-10 11-20 etc.	TMHF(I,J): J=1, NTSNDF(I)	Sequential time values (T) corresponding to the control points on the time graph

depicting temporal variation of the flux boundary condition at the node.

(c) Flux value cards (8E10.3)

Number of records = NTSNDF(I)/8 + 0 or 1 (group 16, col. 6-10).

Col. 1-10 11-20 etc.	FVTM(I,J): J=1, NTSNDF(I)	Nodal integrated fluid flux values (for flow, L^2/T) or solute mass flux values (for transport, $M/L^3 \cdot L^2/T$) corresponding to TMHF(I,J).

(d) Fluid flux value records (8E10.3)

*** Omitted if dealing with the flow equation. (IMODL = 1) (group 3, col. 1-5).

Number of records = NTSNDF(I)/8 + 0 or 1 (group 16, col. 6-10).

Col. 1-10 11-20 etc.	QVTM(I,J): J=1, NTSNDF(I)	Volumetric fluid flux values corresponding to TMHF(I,J) (L^2/T).

17. Decaying source boundary condition data

*** Omit if IMODL = 1 or NDCS = 0.

(a) Decaying source characteristic data

Control record (I5)

Col. 1-5	NDCSRC:	Number of sources to be considered. The correct value of NDCSRC must be greater than zero and less than or equal to NDCS.

For each source, supply one record set containing the following information:

Leach time data (I5,E10.3)

Col. 1-5	ISC:	Source identification number.
6-15	TLDCS(ISC):	Leach time duration (T). For a case of continuous leaching source or step release, TLDCS(I) can be left blank or set to a very large value.

Decay coefficient data (8E10.3)

Col. 1-10 11-20 etc.	SLAMDA(ISC,: J), J=1, NSPECI)	Decay coefficients for species components 1 through NSPECI (1/T).

(b) Decaying source node data

One record set for each decaying source node. Each set contains the following information:

Control record (3I5,E10.3)

Col. 1-5	NODCS(I):	Node number.
6-10	IDCSNO(I):	Decaying source identification number.
11-15	IBDCS(I):	Boundary condition identifier; = 1 if initial species concentration values are prescribed, = 2 if initial species mass flux values are prescribed.
16-20	QFLSN(I):	Net integrated fluid flux at the source node (L^2/T).

Initial source-concentration data (8E10.3)

*** Omit if IBDCS(I) = 2.

Col. 1-10 11-20 etc.	CIDCS(I,ISP): ISP=1, NSPECI	Initial concentration values (at the source node) node for species components 1 through NSPECI (M/L^3).

Initial source-flux data (8E10.3)

*** Omit if IBDCS(I) = 1.

Col. 1-10 11-20 etc.	FMIDCS(I,ISP): ISP=1, NSPECI	Initial mass flux values (at the source node) for species components 1 through NSPECI ($M/L^3 \cdot L^2/T$).

18. Initial nodal value data of dependent variable

This option is not to be used when dealing with multi-species chained transport (ICHAIN = 1).

*** Omit if NONU (group 3, col. 41-45) = 0 or 2. Also omit if NPIN = 0.

Supply these data to the code according to one of the following formats.

(a) Format type 1 (I5, F10.5)

To be used only when NPIN (group 5, col. 11-15) is less than NP (group 3, col. 21-25).
(NOTE: NP = total number of nodes and NPIN = number of nodes for which initial nodal values are to be read).

Number of records to be supplied = NPIN (group 5, col. 11-15).

Col. 1-5	N:	Node number.
6-15	HINT(N,1):	Initial value of the first dependent variable.
16-25	HINT(N,2):	Initial value of the second dependent variable.

(b) Format type 2 (8E10.3)

To be used only for a restart run where initial values to be read correspond to the final set of nodal values obtained from a previous run. This set of nodal values can be obtained from file unit 8.

19. Default value data (5F10.6, I5)

*** Omit if only flow modeling is required (IMODL (group 3, col. 1-5)=1).

One record.

Col. 1-10	VCX:	Default value of Darcy velocity in the x-direction (L/T).
11-20	VCY:	Default value of Darcy velocity in the y-direction (L/T).
21-30	WFAC:	Upstream weighting factor for transport in x-direction. $0 \leq WFAC \leq 1$. Set to zero or leave blank for no upstream weighting.
31-40	YFAC:	Upstream weighting factor for transport in y-direction. $0 \leq YFAC \leq 1$. Set to zero or leave blank for no upstream weighting.
41-50	SWD:	Default value of initial saturation. Leave blank if not used.

51-55 IVSTED: Parameter indicating if the velocity field is steady state;
= 1 if yes,
= 0 if no.

20. Element Darcy velocity data (2(I5, 2E10.3))

*** This record type is to be omitted unless NVREAD (group 5, col. 1-5) is equal to 1.

Number of records = NE/2 + 0 or 1.

Each record contains 2 blocks of the following data:

Col. 1-5 I: Element number.

6-15 VELX(I): Value of x-component of Darcy velocity at the element centroid (L/T).

16-25 VELY(I): Value of y-component of Darcy velocity at the element centroid (L/T).

21. Element water saturation data for transport analysis (8F10.6)

*** This record type is to be omitted unless variably-saturated transport analysis is to be performed, and NVREAD (group 5, col. 1-5) is equal to 1.

Number of records = NE/8 + 0 or 1.

Col. 1-10	SWND(I):	Values of saturation at
11-20	I=1,	centroids of elements 1 through
etc.	NE	NE.

22. Initial element saturation data for hysteresis simulation

*** Omit if IHYST (group 3, col. 6-10) = 0 or NONU (group 3, col. 51-55) = 0.

(a) Number of elements (I5)

One record.

Col. 1-5 NELS: Number of elements for which initial saturation values are to be read.

(b) Saturation and hysteresis data

Format Type 1 (2I5, E10.3)

*** Use if NELS is less than NE.

Number of records = NELS.

Col. 1-5	IL:	Element number.
6-10	KHYST(IL):	Value of hysteresis index for element IL; = -1 for drying, = +1 for wetting.
11-20	SWINT(IL):	Saturation value for element IL.

Format Type 2 (16I5 and 8E10.3)

To be used only for a restart run where initial values to be read correspond to the final set of elemental values of the hysteresis index and element water content from a previous run. This data can be obtained from file unit 8. The values of the hysteresis index for all elements are read first using 16I5 format, followed by the water content values for all elements using 8E10.3 format.

23. Boundary nodal data

*** This record type is to be omitted if IOUTLT and IMBAL (group 5, col. 46-50) = 0 (flux and mass balance calculations are not required).

(a) Control record (I5)

One record.

Col. 1-5	NBOUT:	Number of nodes where nodal flux values are to be computed.

(b) Nodal numbers for flux computation (16I5)

*** Omit if NBOUT (group 21a, col. 1-5) = 0.

Number of records = NBOUT/8 + 0 or 1.

Col. 1-5 6-10 etc.	NDOUT(1): through NDOUT(NBOUT)	Node numbers of the nodes for which nodal fluid flux values are to be computed.

(c) Nodal numbers for integrated flux computation (8E10.3)

*** Omit this record set if only flow simulation is required (IMODL = 1). Also omit if NVREAD = 2.

Number of records = NBOUT/8 + 0 or 1.

Col. 1-10 11-20 etc.	QNDOUT(1): through QNDOUT(NBOUT)	Nodal values of integrated fluid flux for the outlet boundary nodes (L^2/T).

24. Evaporation and infiltration control data

*** Omit if NEIEVP (group 3, col. 71-75) = 0.

(a) Control record (4E10.3)

One record.

Col. 1-10	EIMAX:	Maximum value of potential infiltration flux per unit surface area (L/T).
11-20	PSIMIN:	Minimum value of allowable pressure head at the soil surface (L).
21-30	EVMAX:	Maximum absolute value of potential evaporation flux per unit surface area (L/T).
31-40	FRACT:	Fraction of EIMAX and EVMAX to be imposed during the first iteration. Suggested value = 0.1. Note that FRACT must be greater than 0 and less than or equal to 1.

(b) Nodal infiltration or evaporation identification numbers (16I5)

Number of records = NEIEVP/16 + 0 or 1 (group 3, col. 71-75).

Col. 1-5 6-10 etc.	IELEVP(I): I=1, NEIEVP	Sequential number of elements that are subject to infiltration or evaporation. For those elements that are subject to evaporation, attach negative sign to their sequential elements numbers.

25. Plant species data

*** Omit if NPLANT (group 3, col. 76-80) = 0.

(a) Wilting pressure head and potential transpiration (2(I5,2E10.3))

Number of records = NPLANT/2 + 1 or 0 (group 3, col. 76-80).

Col.1-5	N:	Plant species number.
6-15	PWILT(N):	Wilting pressure head for species N (L).
16-25	TPOT(N): N=1, NPLANT	Absolute value of potential transpiration rate of species N (L/T).

(b) Control record (3I5)

One record.

Col. 1-5	NZRDF:	Number of y-coordinate values for which effective root function values are specified.
6-10	NCOLPL:	Number of vertical nodal columns in the root zone.
11-15	NEROOT:	Number of finite elements in the root zone.

(c) Depth coordinate records (8E10.3)

Number of records = NZRDF/8 + 1 or 0 (group 24b, col. 1-5).

Col. 1-10 11-20 etc.	ZRDF(I): I=1, NZRDF	Values of y-coordinate for which root effectiveness function values are specified (L).

(d) Effective root function data (8E10.3)

Number of records for each plant = NZRDF/8 + 1 or 0 (group 24b, col. 1-5).

Col. 1-10 11-20 etc.	RDF(I,J): I=1, NZRDF	Values of effective root function for plant species J.

26. Root zone element and node data

*** Omit if NPLANT (group 3, col. 76-80) = 0.

(a) Root zone element data (16I5)

Number of records = NEROOT/16 + 0 or 1 (group 24b, col. 11-15).

Col. 1-5 6-10 11-15 etc.	IEROOT(I): I=1, NEROOT	Sequential numbers of the elements that lie within the root zone.

(b) Root zone nodal column data (5I5)

Number of records = NCOLPL (group 24b, col. 6-10).

Col. 1-5	I:	Nodal column number.
6-10	INDRMN(I):	Lowest nodal sequential number for column I.
11-15	INDRMX(I):	Highest nodal sequential number for column I.
16-20	INDICR(I):	Nodal number increment for column I.
21-25	IPLCOL(I):	Plant species number for column I.

Note: Elements and nodes that are at the soil surface should not be counted because they contribute only to direct evaporation and not to plant transpiration.

27. Observation node data

*** Omit if IOBSND (group 5, col. 41-45) = 0.

(a) First input option (16I5)

*** Omit if ICHAIN (group 3, col. 21-25) = 1.

Number of records = (NNOBS + 1)/16 + 0 or 1.

Col. 1-5	NNOBS:	Number of nodes for which time history of nodal values of dependent variable(s) is to be recorded.
6-10 etc.	NDOBS(I): I=1, NNOBS	Node numbers of observation nodes.

(b) Second input option

*** Omit if ICHAIN = 0.

(i) Control record (I5)

Col. 1-5	NNOBS:	Number of nodes for which time history of nodal values of dependent variables is to be recorded.

(ii) Node number records (16I5)

Number of records = NNOBS/16 + 0 or 1.

Col. 1-5 6-10 etc.	NDOBS(I),: I=1, NNOBS	Node numbers of observation nodes.

(iii) Dependent variable number records (16I5)

Col. 1-5 6-10 etc.	ISPCNO(I),: I=1, NNOBS	Species component numbers selected for the observation nodes.

28. Velocity file output time specification data (2E10.3,2I5)

*** Omit unless NVWRIT = 2.

Number of records = as many as needed.

Each record contains the following information:

Col. 1-10	TSTVOP:	Starting time value for writing the velocity output onto unit 9 (T).
11-20	DTVOP:	Time increment for velocity output (T).
21-25	NDTVOP:	Number of increments with constant value of DTVOP.
26-30	IPAUSE:	Parameter indicating if this is the last record in group 28; = 1 if yes, = 0 if no.

8.4 INPUT PREPARATION CHECKLIST

To facilitate the preparation of input data for water flow and solute transport simulations, four checklists are provided in Tables 8.1-8.4, respectively. These checklists should be used as a means for echo checking of the input data file (unit number 5).

Table 8.1. Checklist for Water Flow Simulation by VAM2D.

1. If there is only one set of material properties specified for the flow system, omit record group 8.

2. If boundary conditions are invariant with time, omit record group 16 and 17.

3. If initial conditions are uniform, omit record group 18.

4. Make sure that the setting of certain control parameters is performed as depicted in Table 8.3.

5. If time step values are to be automatically generated in VAM2D (ITSGN = 1 or 2), omit record group 6b.

Table 8.2. Checklist for Solute Transport Simulation by VAM2D.

1. Omit record group 9 and 10.

2. If there is only one set of material properties specified for the flow system, omit record group 11.

3. If boundary conditions are invariant with time, omit record group 16 and 17.

4. If initial conditions are uniform, omit record group 18.

5. Make sure that the setting of certain control parameters is performed as depicted in Table 8.4.

6. If time step values are to be automatically generated in VAM2D (ITSGN = 1 or 2), omit record group 6b.

Table 8.3. Control Parameters Used by VAM2D in Flow Simulation.

GROUP	COLUMN	VARIABLE	SET VALUE
3	1-5	IMODL	= 1
	6-10	IHYST	= 0 for non-hysteretic soil moisture properties = 1 for hysteretic soil moisture properties
	11-15	IANI	= 0 if variable anisotropy is not to be simulated = 1 if variable anisotropy is to be included in simulation
	16-20	INTSPC	= 0 (for fully-saturated flow) = 0 or 1 (for variably-saturated flow)
	26-30	ISSTA	= 0 if transient analysis is to be performed = 1 if steady state solution is desired
4	11-15	NITMAX	= 1 (for fully-saturated flow) > 1 (for variably-saturated flow)
	21-25	ILUMP	= 0 for consistent storage matrix = 1 for lumped storage matrix
	46-50	IUPSTR	= 0 if upstream weighting of relative permeability is not to be performed = 1 if upstream weighting of relative permeability is desired
5	1 - 5	NVREAD	= 0

Table 8.4. Control Parameter Values Used by VAM2D in the Transport Simulations.

GROUP	COLUMN	VARIABLE	SET VALUE
3	1-5	IMODL	= 0
	21-25	ICHAIN	= 0 if chained decay reaction do not occur = 1 if chained decay reactions are to be simulated (set ICHAIN = 0 for conservative transport simulation)
4	6-10	INEWT	= 0
	11-15	NITMAX	= 1
	16-20	IRESOL	= 0
	21-25	ILUMP	= 0
	26-35	HTOL	= 0.
5	26-30	NVPR	= 0

9 OUTPUT

9.1 GENERAL CONSIDERATIONS

Line printer output from VAM2D is organized for each problem into categories of information. These categories are summarized as follows:

- Listing of general control input data supplied to the code by the user.
- Listing of the generated mesh data or user supplied mesh data.
- Listing of boundary condition data.
- Listing of initial condition data.
- Listing of user-supplied steady-state values of element velocities and saturation.
- Listing of user-supplied data pertaining to the nonzero flux nodes and flux values.
- Listing of element numbers and centroidal coordinates.
- Listing of the input data supplied from TAPE 9 for each time step.
- Listing of information pertaining to the computation of element matrices and incorporation of boundary conditions performed by the code.
- Listing of node numbers and values of head or concentration computed by the code. This listing is given for every n-th time step, where n is the value of NSTEP.
- Listing of element numbers and water saturation values for the elements that became unsaturated. This listing is given for every n-th time step, where n is the value of NSTEP.
- Listing of element numbers and the x and y components of Darcy velocity. This listing is given for every n-th time step, where n is the value of NVPR.

9.2 OUTPUT CONTROL

Output streams are controlled by several control parameters, the values of which must be supplied to the code. Table 9.1 provides a summary of the procedures used to control various categories of output. The user should decide how much printed output is really needed for the problem simulated. For example, the mesh data and the boundary conditions are normally not needed in the restart run of the same problem.

Table 9.1. Output Control Parameters for File Number 6.

CONTROL PARAMETER	VALUE	MEANING
IPRD	3	Suppress the printout of the entire mesh data as well as the initial condition.
IPRD	2	Suppress the printout of the entire mesh data.
IPRD	1	Suppress the printout of element connectivities.
NSTEP	n	For each n-th time step, print computed values of head or concentration (as the case may be), and print computed values of element water saturation (if variably-saturated flow analysis is performed). Note: When the value of NSTEP is greater than NTS (the total number of time steps of the simulation), the mentioned printout will be suppressed.
NVPR	n	For each n-th time step, print element numbers and computed values of Darcy velocity components at the element centroids. Note: When the value of NVPR is greater than NTS, the mentioned printout will be suppressed.

NOTE: Values of IPRD, NSTEP, and NVPR are read from file number 5, described in Section 8.2.

10 INPUT AND OUTPUT FOR FOUR TEST PROBLEMS

10.1 GENERAL CONSIDERATIONS

To demonstrate the utility of the code, input data and computer output from four test problems are provided. The first problem was chosen to demonstrate a transient flow simulation. The second problem was chosen to demonstrate a transient transport simulation using the velocity file from the flow run. The third problem was chosen to demonstrate the capability of the code to perform concurrent analysis of flow and transport. The final problem was chosen to demonstrate a transient multi-component transport simulation involving a three-member chain.

10.2 PROBLEM 1: TRANSIENT UNSATURATED FLOW SIMULATION

10.2.1 <u>Input Data</u>

The input data file for this unsaturated flow problem is displayed in Table 10.1. Because the output control parameter IPRD = 0, a complete printout of mesh data, as well as initial condition data will be given as part of the printed output. Also evident in this input data is the specification of IMODL = 1. There are three layers of different soil materials. Hydraulic properties of soil and soil moisture functional parameters for each material must also be part of the input. The input data also includes sixteen prescribed head boundary conditions, as well as the node numbers of all nonzero flux boundary nodes.

Table 10.1. Input Data for the Two-Dimensional Unsaturated Flow Problem.

```
     1                                                                                   GROUP 1
 TEST PROBLEM 1    (FLOW ONLY)                                                           GROUP 2
     1     0     0     0     0     0     1     5   256   225     0     0     3     0     0     0   GROUP 3
     1     0    15     3     1          0.1         1.0     0     0     0                  GROUP 4
     0     0     0     1     1     1     1     1     1     0     0     0                   GROUP 5
       0.0         0.5         1.0         1.0                                           GROUP 6
    -100.0         0.0                                                                   GROUP 7
     1     1     1     1     1     1     1     2     2     2     2     2     2     3     3     1   GROUP 8
     1     1     1     1     1     1     2     2     2     2     2     2     3     3     1     1     ''
     1     1     1     1     1     2     2     2     2     2     2     3     3     1     1     1     ''
     1     1     1     1     2     2     2     2     2     2     3     3     1     1     1     1     ''
     1     1     1     2     2     2     2     2     2     3     3     1     1     1     1     1     ''
     1     1     2     2     2     2     2     2     3     3     1     1     1     1     1     1     ''
     1     2     2     2     2     2     2     3     3     1     1     1     1     1     1     1     ''
     2     2     2     2     2     2     3     3     1     1     1     1     1     1     1     2     ''
     2     2     2     2     2     3     3     1     1     1     1     1     1     1     2     2     ''
     2     2     2     2     3     3     1     1     1     1     1     1     1     2     2     2     ''
     2     2     2     3     3     1     1     1     1     1     1     1     2     2     2     2     ''
     2     2     3     3     1     1     1     1     1     1     1     2     2     2     2     2     ''
     2     3     3     1     1     1     1     1     1     1     2     2     2     2     2     2     ''
     3     3     1     1     1     1     1     1     1     2     2     2     2     2     2     3     ''
     3                                                                                   ''
 0.350E03  0.350E03  0.000E00  0.000E00  0.410E00  0.000E00                              GROUP 9
 2.500E01  2.500E01  0.000E00  0.000E00  0.430E00  0.000E00                              ''
 1.080E01  1.080E01  0.000E00  0.000E00  0.450E00  0.000E00                              ''
   0.0574       1.00     0.124      2.28                                                 GROUP 10
   0.0774       1.00     0.036      1.56                                                 ''
   0.0675       1.00     0.020      1.41                                                 ''
    16    16     5.0      10.0     1                                                     GROUP 12
       0.0       2.5       5.0       7.5      10.0      12.5      15.0      17.5         GROUP 13
      20.0      22.5      25.0      30.0      35.0      40.0      45.0      50.0         ''
       0.0      10.0      20.0      30.0      40.0      50.0      55.0      60.0         ''
      65.0      70.0      75.0      80.0      85.0      90.0      95.0     100.0         ''
    16     0     0    16                                                                 GROUP 15A
     1     1   -100.0                                                                    GROUP 15B
    17     1   -100.0                                                                    ''
    33     1   -100.0                                                                    ''
    49     1   -100.0                                                                    ''
    65     1   -100.0                                                                    ''
    81     1   -100.0                                                                    ''
    97     1   -100.0                                                                    ''
   113     1   -100.0                                                                    ''
   129     1   -100.0                                                                    ''
   145     1   -100.0                                                                    ''
   161     1   -100.0                                                                    ''
   177     1   -100.0                                                                    ''
   193     1   -100.0                                                                    ''
   209     1   -100.0                                                                    ''
   225     1   -100.0                                                                    ''
   241     1   -100.0                                                                    ''
    16     1     6                                                                       GROUP 16-IIA
       0.0       1.0       2.0       3.0       4.0      50.0                             ''       B
       0.0      12.5      10.0       0.0       0.0       0.0                             ''       C
    32     1     6                                                                       GROUP 16-IIA
       0.0       1.0       2.0       3.0       4.0      50.0                             ''       B
       0.0      25.0      20.0       0.0       0.0       0.0                             ''       C
    48     1     6                                                                       GROUP 16-IIA
       0.0       1.0       2.0       3.0       4.0      50.0                             ''       B
       0.0      25.0      20.0       0.0       0.0       0.0                             ''       C
    64     1     6                                                                       GROUP 16-IIA
```

```
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      25.0      20.0       0.0       0.0       0.0              ,,     C
  80    1    6                                                     GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      25.0      20.0       0.0       0.0       0.0              ,,     C
  96    1    6                                                     GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      25.0      20.0       0.0       0.0       0.0              ,,     C
 112    1    6                                                     GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      25.0      20.0       0.0       0.0       0.0              ,,     C
 128    1    6                                                     GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      25.0      20.0       0.0       0.0       0.0              ,,     C
 144    1    6                                                     GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      25.0      20.0       0.0       0.0       0.0              ,,     C
 160    1    6                                                     GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      25.0      20.0       0.0       0.0       0.0              ,,     C
 176    1    6                                                     GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      37.5      30.0       0.0       0.0       0.0              ,,     C
 192    1    6                                                     GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      50.0      40.0       0.0       0.0       0.0              ,,     C
 208    1    6                                                     GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      50.0      40.0       0.0       0.0       0.0              ,,     C
 224    1    6                                                     GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      50.0      40.0       0.0       0.0       0.0              ,,     C
 240    1    6                                                     GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      50.0      40.0       0.0       0.0       0.0              ,,     C
 256    1    6                                                     GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0              ,,     B
      0.0      25.0      20.0       0.0       0.0       0.0              ,,     C
   5   62  126  150  174  222                                      GROUP 27A
```

10.2.2 Sample Output

The output from the line printer is displayed in Table 10.2. This output, which corresponds to input data in Table 10.1, consists of the following categories of information:

1. Brief summary of control input data and material hydraulic properties
2. Mesh data
3. Prescribed boundary condition data
4. Initial condition data
5. Maximum bandwidth of the global matrix for the problem
6. Element numbers and centroidal coordinates
7. List of observation nodes
8. Time-step number
9. Print check information for convergence of the nonlinear iterations
10. Time value
11. Node numbers and nodal head values corresponding to the given time value
12. List of unsaturated elements and centroidal values of water saturation
13. List of element numbers and corresponding centroidal values of Darcy velocity components
14. Observation node information.

Note that only the results for the first and final time steps (time steps 1 and 5) are included in the sample printout to avoid lengthy presentation. Note that information in categories 8 through 13 are repeated for each time step.

Table 10.2. Output for the Two-Dimensional Unsaturated flow Problem.

```
********************************************************************************

                    THIS OUTPUT GENERATED BY VAM2D v. 5.0
                    INPUT FILE NAME = VAM2D-2F.DAT

********************************************************************************


NUMBER OF PROBLEMS TO BE SOLVED =  1


PROBLEM NUMBER:  1


PROBLEM TITLE
--------------------------------------------------------------------------------

 TEST PROBLEM 1   (FLOW ONLY)

--------------------------------------------------------------------------------



PROBLEM SPECIFICATION PARAMETERS
--------------------------------
MODEL OPTION PARAMETER ...................(IMODL) =    1
  NOTE:  IMODL = 0 FOR SOLUTE TRANSPORT ONLY
               = 1 FOR WATER FLOW ONLY
               = 2 FOR COUPLED FLOW AND TRANSPORT
HYSTERETIC SOIL MOISTURE (1=YES, 0=NO)....(IHYST) =    0
ANISOTROPIC REL. COND.(1=YES, 0=NO)........(IANI) =    0
CONVERT INITIAL HEAD VALUES(1=YES, 0=NO).(INTSPC) =    0
CHAIN-DECAY REACTIONS(1=YES, 0=NO).......(ICHAIN) =    0
STEADY STATE SIMULATION(1=YES, 0=NO)......(ISSTA) =    0
TIME STEP GENERATION INDEX (1=YES, 0=NO) .(ITSGN) =    1
NUMBER OF TIME STEPS .......................(NTS) =    5
TOTAL NUMBER OF NODES ........................(NP) =  256
TOTAL NUMBER OF ELEMENTS ....................(NE) =  225
SEQUENTIAL NUMBERING INDEX (0=Y, 1=X-DIR) (ISWAP) =    0
AXISYMMETRIC SIMULATION(1=YES, 0=NO).....(IAXSYM) =    0
NUMBER OF POROUS MATRIX MATERIALS .........(NMAT) =    3
INITIAL CONDITION NON-UNIFORMITY INDEX.....(NONU) =    0
NUMBER OF INFIL./EVAP. ELEMENTS .........(NEIEVP) =    0
NUMBER PLANT SPECIES ....................(NPLANT) =    0


TIME STEPPING AND ITERATION CONTROL PARAMETERS
----------------------------------------------
TIME STEPPING INDEX (0=CNTRL, 1=BCKWD) ...(IKALL) =    1
TYPE OF ITERATION SCHEME (1=NEWT,0=PICARD)(INEWT) =    0
MAXIMUM NON-LINEAR ITERATIONS ...........(NITMAX) =   15
MAXIMUM NUMBER OF TIME STEP REFINEMENTS .(IRESOL) =    3
LUMPING OF ELEMENT MATRIX (1=YES, 0=NO) ..(ILUMP) =    1
ITERATION TOLERANCE FOR HEAD...............(HTOL) = 0.10000E+00
UNDER RELAXATION FACTOR FOR HEAD...........(HWWT) = 0.10000E+01
REL. PERMEABILITY UPSTREAM INDEX ........(IUPSTR) =    0
```

```
NONLINEAR ITERATION SELECTION ...........(ISELSC) =    0


INPUT / OUTPUT CONTROL PARAMETERS
---------------------------------
VELOCITY/SATURATION INPUT................(NVREAD) =    0
BOUNDARY NODE DATA READ (1=YES, 0=NO)....(IOUTLT) =    0
NUMBER OF NODES FOR WHICH I.C. ARE READ....(NPIN) =    0
OUTPUT REQUIREMENT INDICATOR:
 (0=ALL DATA, 1=NO ELEMENT DATA,
  2=NO DATA, 3=NO MESH AND I.C. DATA.......(IPRD) =    1
UNIT 9 OUTPUT OF VEL / SAT (1=YES, 0=NO).(NVWRIT) =    1
VELOCITY PRINTOUT CONTROL INDEX............(NVPR) =    1
UNIT 10 OUTPUT HEAD/CONC. (0=NONE, N=NTH).(NPLOT) =    1
NODAL VALUE PRINTOUT CONTROL INDEX........(NSTEP) =    1
OBSERVATION NODE INDEX....................(IOBSND) =    1
MASS BALANCE TO BE PERFORMED (1=YES,0=NO).(IMBAL) =    0
UNIT 8 OUTPUT OF HEAD/CONC (1=YES, 0=NO).(NOWRIT) =    0
PRINT CHECK OPTION INDEX.................(IPRCHK) =    0


TEMPORAL DISCRETIZATION DATA
----------------------------
INITIAL TIME VALUE ......................... (TIMA) =  0.0000E+00
VALUE OF FIRST TIME STEP .................... (TIN) =  0.5000E+00
TIME STEP MULTIPLIER ....................... (TFAC) =  0.1000E+01
MAXIMUM TIME STEP SIZE ..................... (TMAX) =  0.1000E+01


*** LIST OF GENERATED TIME VALUES ***
-------------------------------------

0.500E+00 0.100E+01 0.150E+01 0.200E+01 0.250E+01


DEFAULT INITIAL VALUE OF PRESSURE HEAD
----------------------------------------------

         -0.1000E+03

ELEMENT PROPERTY NUMBERS
------------------------


    1    1    1    1    1    1    1    2    2    2    2    2    2    3    3    1
    1    1    1    1    1    1    2    2    2    2    2    2    3    3    1    1
    1    1    1    1    1    2    2    2    2    2    2    3    3    1    1    1
    1    1    1    1    2    2    2    2    2    2    3    3    1    1    1    1
    1    1    1    2    2    2    2    2    2    3    3    1    1    1    1    1
    1    1    2    2    2    2    2    2    3    3    1    1    1    1    1    1
    1    2    2    2    2    2    2    3    3    1    1    1    1    1    1    1
    2    2    2    2    2    2    3    3    1    1    1    1    1    1    1    2
    2    2    2    2    2    3    3    1    1    1    1    1    1    1    2    2
    2    2    2    2    3    3    1    1    1    1    1    1    1    2    2    2
    2    2    2    3    3    1    1    1    1    1    1    1    2    2    2    2
    2    2    3    3    1    1    1    1    1    1    1    2    2    2    2    2
    2    3    3    1    1    1    1    1    1    1    2    2    2    2    2    2
    3    3    1    1    1    1    1    1    1    2    2    2    2    2    2    3
    3


HYDRAULIC PROPERTIES OF POROUS MEDIA
------------------------------------
```

```
MATERIAL NUMBER:    1  (I)

X-DIRECTION HYDRAULIC CONDUCTIVITY ... (PROP(I,1)) =  0.3500E+03
Y-DIRECTION HYDRAULIC CONDUCTIVITY ... (PROP(I,2)) =  0.3500E+03
XY-DIRECTION HYDRAULIC CONDUCTIVITY .. (PROP(I,3)) =  0.0000E+00
SPECIFIC STORAGE ..................... (PROP(I,4)) =  0.0000E+00
SATURATED WATER CONTENT............... (PROP(I,5)) =  0.4100E+00
AIR-ENTRY PRESSURE HEAD VALUE ........ (PROP(I,6)) =  0.0000E+00

MATERIAL NUMBER:    2  (I)

X-DIRECTION HYDRAULIC CONDUCTIVITY ... (PROP(I,1)) =  0.2500E+02
Y-DIRECTION HYDRAULIC CONDUCTIVITY ... (PROP(I,2)) =  0.2500E+02
XY-DIRECTION HYDRAULIC CONDUCTIVITY .. (PROP(I,3)) =  0.0000E+00
SPECIFIC STORAGE ..................... (PROP(I,4)) =  0.0000E+00
SATURATED WATER CONTENT............... (PROP(I,5)) =  0.4300E+00
AIR-ENTRY PRESSURE HEAD VALUE ........ (PROP(I,6)) =  0.0000E+00

MATERIAL NUMBER:    3  (I)

X-DIRECTION HYDRAULIC CONDUCTIVITY ... (PROP(I,1)) =  0.1080E+02
Y-DIRECTION HYDRAULIC CONDUCTIVITY ... (PROP(I,2)) =  0.1080E+02
XY-DIRECTION HYDRAULIC CONDUCTIVITY .. (PROP(I,3)) =  0.0000E+00
SPECIFIC STORAGE ..................... (PROP(I,4)) =  0.0000E+00
SATURATED WATER CONTENT............... (PROP(I,5)) =  0.4500E+00
AIR-ENTRY PRESSURE HEAD VALUE ........ (PROP(I,6)) =  0.0000E+00

MATERIAL NUMBER:    1  (I)

RESIDUAL WATER SATURATION ............ (PROP(I,7)) =  0.5740E-01
POWER INDEX (N) OF K(REL) VS SAT...... (PROP(I,8)) =  0.1000E+01
 (SET N=-1 IF VAN GENUCHTEN REL. REQUIRED)
COEFF (ALPHA) OF SAT. VS CAPIL. HEAD.. (PROP(I,9)) =  0.1240E+00
POWER INDEX (BETA)      ,,      ,,     (PROP(I,10))=  0.2280E+01
POWER INDEX (GAMMA)     ,,      ,,     (PROP(I,11))=  0.5614E+00

MATERIAL NUMBER:    2  (I)

RESIDUAL WATER SATURATION ............ (PROP(I,7)) =  0.7740E-01
POWER INDEX (N) OF K(REL) VS SAT...... (PROP(I,8)) =  0.1000E+01
 (SET N=-1 IF VAN GENUCHTEN REL. REQUIRED)
COEFF (ALPHA) OF SAT. VS CAPIL. HEAD.. (PROP(I,9)) =  0.3600E-01
POWER INDEX (BETA)      ,,      ,,     (PROP(I,10))=  0.1560E+01
POWER INDEX (GAMMA)     ,,      ,,     (PROP(I,11))=  0.3590E+00

MATERIAL NUMBER:    3  (I)

RESIDUAL WATER SATURATION ............ (PROP(I,7)) =  0.6750E-01
POWER INDEX (N) OF K(REL) VS SAT...... (PROP(I,8)) =  0.1000E+01
 (SET N=-1 IF VAN GENUCHTEN REL. REQUIRED)
COEFF (ALPHA) OF SAT. VS CAPIL. HEAD.. (PROP(I,9)) =  0.2000E-01
POWER INDEX (BETA)      ,,      ,,     (PROP(I,10))=  0.1410E+01
POWER INDEX (GAMMA)     ,,      ,,     (PROP(I,11))=  0.2908E+00


X-COORDINATES OF GRID LINES
--------------------------


     0.00       2.50       5.00       7.50      10.00      12.50      15.00      17.50
    20.00      22.50      25.00      30.00      35.00      40.00      45.00      50.00


Y-COORDINATES OF GRID LINES
--------------------------
```

0.00	10.00	20.00	30.00	40.00	50.00	55.00	60.00
65.00	70.00	75.00	80.00	85.00	90.00	95.00	100.00

*** NODAL COORDINATES ***

NODE	X-COOR.	Y-COOR.	NODE	X-COOR.	Y-COOR.	NODE	X-COOR.	Y-COOR.
1	0.00	0.00	2	0.00	10.00	3	0.00	20.00
4	0.00	30.00	5	0.00	40.00	6	0.00	50.00
7	0.00	55.00	8	0.00	60.00	9	0.00	65.00
10	0.00	70.00	11	0.00	75.00	12	0.00	80.00
13	0.00	85.00	14	0.00	90.00	15	0.00	95.00
16	0.00	100.00	17	2.50	0.00	18	2.50	10.00
19	2.50	20.00	20	2.50	30.00	21	2.50	40.00
22	2.50	50.00	23	2.50	55.00	24	2.50	60.00
25	2.50	65.00	26	2.50	70.00	27	2.50	75.00
28	2.50	80.00	29	2.50	85.00	30	2.50	90.00
31	2.50	95.00	32	2.50	100.00	33	5.00	0.00
34	5.00	10.00	35	5.00	20.00	36	5.00	30.00
37	5.00	40.00	38	5.00	50.00	39	5.00	55.00
40	5.00	60.00	41	5.00	65.00	42	5.00	70.00
43	5.00	75.00	44	5.00	80.00	45	5.00	85.00
46	5.00	90.00	47	5.00	95.00	48	5.00	100.00
49	7.50	0.00	50	7.50	10.00	51	7.50	20.00
52	7.50	30.00	53	7.50	40.00	54	7.50	50.00
55	7.50	55.00	56	7.50	60.00	57	7.50	65.00
58	7.50	70.00	59	7.50	75.00	60	7.50	80.00
61	7.50	85.00	62	7.50	90.00	63	7.50	95.00
64	7.50	100.00	65	10.00	0.00	66	10.00	10.00
67	10.00	20.00	68	10.00	30.00	69	10.00	40.00
70	10.00	50.00	71	10.00	55.00	72	10.00	60.00
73	10.00	65.00	74	10.00	70.00	75	10.00	75.00
76	10.00	80.00	77	10.00	85.00	78	10.00	90.00
79	10.00	95.00	80	10.00	100.00	81	12.50	0.00
82	12.50	10.00	83	12.50	20.00	84	12.50	30.00
85	12.50	40.00	86	12.50	50.00	87	12.50	55.00
88	12.50	60.00	89	12.50	65.00	90	12.50	70.00
91	12.50	75.00	92	12.50	80.00	93	12.50	85.00
94	12.50	90.00	95	12.50	95.00	96	12.50	100.00
97	15.00	0.00	98	15.00	10.00	99	15.00	20.00
100	15.00	30.00	101	15.00	40.00	102	15.00	50.00
103	15.00	55.00	104	15.00	60.00	105	15.00	65.00
106	15.00	70.00	107	15.00	75.00	108	15.00	80.00
109	15.00	85.00	110	15.00	90.00	111	15.00	95.00
112	15.00	100.00	113	17.50	0.00	114	17.50	10.00
115	17.50	20.00	116	17.50	30.00	117	17.50	40.00
118	17.50	50.00	119	17.50	55.00	120	17.50	60.00
121	17.50	65.00	122	17.50	70.00	123	17.50	75.00
124	17.50	80.00	125	17.50	85.00	126	17.50	90.00
127	17.50	95.00	128	17.50	100.00	129	20.00	0.00
130	20.00	10.00	131	20.00	20.00	132	20.00	30.00
133	20.00	40.00	134	20.00	50.00	135	20.00	55.00
136	20.00	60.00	137	20.00	65.00	138	20.00	70.00
139	20.00	75.00	140	20.00	80.00	141	20.00	85.00
142	20.00	90.00	143	20.00	95.00	144	20.00	100.00
145	22.50	0.00	146	22.50	10.00	147	22.50	20.00
148	22.50	30.00	149	22.50	40.00	150	22.50	50.00
151	22.50	55.00	152	22.50	60.00	153	22.50	65.00
154	22.50	70.00	155	22.50	75.00	156	22.50	80.00

157	22.50	85.00	158	22.50	90.00	159	22.50	95.00
160	22.50	100.00	161	25.00	0.00	162	25.00	10.00
163	25.00	20.00	164	25.00	30.00	165	25.00	40.00
166	25.00	50.00	167	25.00	55.00	168	25.00	60.00
169	25.00	65.00	170	25.00	70.00	171	25.00	75.00
172	25.00	80.00	173	25.00	85.00	174	25.00	90.00
175	25.00	95.00	176	25.00	100.00	177	30.00	0.00
178	30.00	10.00	179	30.00	20.00	180	30.00	30.00
181	30.00	40.00	182	30.00	50.00	183	30.00	55.00
184	30.00	60.00	185	30.00	65.00	186	30.00	70.00
187	30.00	75.00	188	30.00	80.00	189	30.00	85.00
190	30.00	90.00	191	30.00	95.00	192	30.00	100.00
193	35.00	0.00	194	35.00	10.00	195	35.00	20.00
196	35.00	30.00	197	35.00	40.00	198	35.00	50.00
199	35.00	55.00	200	35.00	60.00	201	35.00	65.00
202	35.00	70.00	203	35.00	75.00	204	35.00	80.00
205	35.00	85.00	206	35.00	90.00	207	35.00	95.00
208	35.00	100.00	209	40.00	0.00	210	40.00	10.00
211	40.00	20.00	212	40.00	30.00	213	40.00	40.00
214	40.00	50.00	215	40.00	55.00	216	40.00	60.00
217	40.00	65.00	218	40.00	70.00	219	40.00	75.00
220	40.00	80.00	221	40.00	85.00	222	40.00	90.00
223	40.00	95.00	224	40.00	100.00	225	45.00	0.00
226	45.00	10.00	227	45.00	20.00	228	45.00	30.00
229	45.00	40.00	230	45.00	50.00	231	45.00	55.00
232	45.00	60.00	233	45.00	65.00	234	45.00	70.00
235	45.00	75.00	236	45.00	80.00	237	45.00	85.00
238	45.00	90.00	239	45.00	95.00	240	45.00	100.00
241	50.00	0.00	242	50.00	10.00	243	50.00	20.00
244	50.00	30.00	245	50.00	40.00	246	50.00	50.00
247	50.00	55.00	248	50.00	60.00	249	50.00	65.00
250	50.00	70.00	251	50.00	75.00	252	50.00	80.00
253	50.00	85.00	254	50.00	90.00	255	50.00	95.00
256	50.00	100.00						

BOUNDARY CONDITION DATA

NUMBER OF STEADY DIRICHLET BOUNDARIES .... (NBTO) = 16
NUMBER OF STEADY FLUX BOUNDARIES .... (NDFLUX) = 0
NUMBER OF TRANSIENT DIRICHLET BOUNDARIES.... (NBHVAR) = 0
NUMBER OF TRANSIENT FLUX BOUNDARIES.... .... (NBFVAR) = 16

DIRICHLET BOUNDARY CONDITION DATA

INDEX	NODE NUMBER	DEP. VAR. #	PRESCRIBED VALUE
1	1	1	-100.0
2	17	1	-100.0
3	33	1	-100.0
4	49	1	-100.0
5	65	1	-100.0
6	81	1	-100.0
7	97	1	-100.0
8	113	1	-100.0
9	129	1	-100.0
10	145	1	-100.0
11	161	1	-100.0
12	177	1	-100.0
13	193	1	-100.0
14	209	1	-100.0

15	225	1	-100.0
16	241	1	-100.0

TIME DEPENDENT FLUX B. C. FOR
NODE # 16 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	12.50	2.000	10.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 32 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 48 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 64 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0

FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 80 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 96 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 112 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 128 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 144 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 160 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 176 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	37.50	2.000	30.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 192 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	50.00	2.000	40.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 208 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	50.00	2.000	40.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 224 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	50.00	2.000	40.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 240 DEPENDENT VARIABLE # 1

```
NUMBER OF CONTROL POINTS IN THE TIME GRAPH =    6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP)  =    0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) =    0
FLUX DATA REPETITION INDEX (0=NO, 1=YES)   =    0
```

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	50.00	2.000	40.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

```
TIME DEPENDENT FLUX B. C. FOR
 NODE #   256     DEPENDENT VARIABLE #     1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH =    6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP)  =    0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) =    0
FLUX DATA REPETITION INDEX (0=NO, 1=YES)   =    0
```

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

------- ACTUAL HALF BAND WIDTH =   17   FULL BANDWIDTH =   35 -------

LIST OF OBSERVATION NODES

62 126 150 174 222

+++++++++ BEGIN TRANSIENT CALCULATIONS ++++++++

**** ELAPSED SIMULATION TIME : 0.5000   TIME STEP NUMBER :   1   TIME STEP SIZE: 0.500E+00 ****

ITERATION	NUMBER OF NON-CONVERGENT NODES	MAXIMUM ERROR	NODE NUMBER	RELAXATION FACTOR
1	240	-42.40	64	1.00
2	176	4.444	256	0.932
3	0	0.2075	199	1.00

*** NODAL HEAD VALUES ***

NODE	HEAD VALUE	NODE	HEAD VALUE	NODE	HEAD VALUE	NODE	HEAD VALUE	NODE	HEAD VALUE
1	-100.0	2	-104.7	3	-109.1	4	-113.3	5	-117.2
6	-120.9	7	-122.6	8	-124.4	9	-126.1	10	-127.9
11	-129.8	12	-131.7	13	-133.8	14	-136.0	15	-137.0
16	-138.1	17	-100.0	18	-104.7	19	-109.1	20	-113.3
21	-117.2	22	-120.9	23	-122.6	24	-124.4	25	-126.1
26	-127.9	27	-129.8	28	-131.7	29	-133.8	30	-136.0
31	-137.0	32	-138.1	33	-100.0	34	-104.7	35	-109.1
36	-113.3	37	-117.2	38	-120.9	39	-122.6	40	-124.4
41	-126.1	42	-127.9	43	-129.8	44	-131.7	45	-133.8
46	-136.0	47	-137.0	48	-138.1	49	-100.0	50	-104.7
51	-109.1	52	-113.3	53	-117.2	54	-120.9	55	-122.6
56	-124.4	57	-126.1	58	-127.9	59	-129.8	60	-131.7
61	-133.8	62	-136.0	63	-137.0	64	-138.1	65	-100.0
66	-104.7	67	-109.1	68	-113.3	69	-117.2	70	-120.9
71	-122.6	72	-124.4	73	-126.1	74	-127.9	75	-129.8
76	-131.7	77	-133.8	78	-136.0	79	-137.0	80	-138.1
81	-100.0	82	-104.7	83	-109.1	84	-113.3	85	-117.2
86	-120.9	87	-122.6	88	-124.4	89	-126.1	90	-127.9
91	-129.8	92	-131.7	93	-133.8	94	-136.0	95	-137.0
96	-138.1	97	-100.0	98	-104.7	99	-109.1	100	-113.3
101	-117.2	102	-120.9	103	-122.6	104	-124.4	105	-126.1
106	-127.9	107	-129.8	108	-131.7	109	-133.8	110	-136.0
111	-137.0	112	-138.1	113	-100.0	114	-104.7	115	-109.1
116	-113.3	117	-117.2	118	-120.9	119	-122.6	120	-124.4
121	-126.1	122	-127.9	123	-129.8	124	-131.7	125	-133.8
126	-136.0	127	-137.0	128	-138.1	129	-100.0	130	-104.7
131	-109.1	132	-113.3	133	-117.2	134	-120.9	135	-122.6
136	-124.4	137	-126.1	138	-127.9	139	-129.8	140	-131.7
141	-133.8	142	-136.0	143	-137.0	144	-138.1	145	-100.0
146	-104.7	147	-109.1	148	-113.3	149	-117.2	150	-120.9
151	-122.6	152	-124.4	153	-126.1	154	-127.9	155	-129.8
156	-131.7	157	-133.8	158	-136.0	159	-137.0	160	-138.1
161	-100.0	162	-104.7	163	-109.1	164	-113.3	165	-117.2
166	-120.9	167	-122.6	168	-124.4	169	-126.1	170	-127.9
171	-129.8	172	-131.7	173	-133.8	174	-136.0	175	-137.0
176	-138.1	177	-100.0	178	-104.7	179	-109.1	180	-113.3
181	-117.2	182	-120.9	183	-122.6	184	-124.4	185	-126.1
186	-127.9	187	-129.8	188	-131.7	189	-133.8	190	-136.0
191	-137.0	192	-138.1	193	-100.0	194	-104.7	195	-109.1
196	-113.3	197	-117.2	198	-120.9	199	-122.6	200	-124.4
201	-126.1	202	-127.9	203	-129.8	204	-131.7	205	-133.8
206	-136.0	207	-137.0	208	-138.1	209	-100.0	210	-104.7
211	-109.1	212	-113.3	213	-117.2	214	-120.9	215	-122.6
216	-124.4	217	-126.1	218	-127.9	219	-129.8	220	-131.7
221	-133.8	222	-136.0	223	-137.0	224	-138.1	225	-100.0
226	-104.7	227	-109.1	228	-113.3	229	-117.2	230	-120.9
231	-122.6	232	-124.4	233	-126.1	234	-127.9	235	-129.8
236	-131.7	237	-133.8	238	-136.0	239	-137.0	240	-138.1
241	-100.0	242	-104.7	243	-109.1	244	-113.3	245	-117.2
246	-120.9	247	-122.6	248	-124.4	249	-126.1	250	-127.9
251	-129.8	252	-131.7	253	-133.8	254	-136.0	255	-137.0
256	-138.1								

*** LIST OF PARTIALLY SATURATED ELEMENTS ***

ELEM.	SAT. VALUE	ELEM.	SAT. VALUE	ELEM.	SAT. VALUE	ELEM.	SAT. VALUE	ELEM.	SAT. VALUE
1	0.0938	2	0.0918	3	0.0901	4	0.0887	5	0.0874
6	0.0866	7	0.0860	8	0.4616	9	0.4588	10	0.4560
11	0.4532	12	0.4502	13	0.4472	14	0.6475	15	0.6460
16	0.0938	17	0.0918	18	0.0901	19	0.0887	20	0.0874
21	0.0866	22	0.0860	23	0.4616	24	0.4588	25	0.4560
26	0.4532	27	0.4502	28	0.4472	29	0.6475	30	0.6460
31	0.0938	32	0.0918	33	0.0901	34	0.0887	35	0.0874
36	0.0866	37	0.0860	38	0.4616	39	0.4588	40	0.4560
41	0.4532	42	0.4502	43	0.4472	44	0.6475	45	0.6460
46	0.0938	47	0.0918	48	0.0901	49	0.0887	50	0.0874
51	0.0866	52	0.0860	53	0.4616	54	0.4588	55	0.4560
56	0.4532	57	0.4502	58	0.4472	59	0.6475	60	0.6460
61	0.0938	62	0.0918	63	0.0901	64	0.0887	65	0.0874
66	0.0866	67	0.0860	68	0.4616	69	0.4588	70	0.4560
71	0.4532	72	0.4502	73	0.4472	74	0.6475	75	0.6460
76	0.0938	77	0.0918	78	0.0901	79	0.0887	80	0.0874
81	0.0866	82	0.0860	83	0.4616	84	0.4588	85	0.4560
86	0.4532	87	0.4502	88	0.4472	89	0.6475	90	0.6460
91	0.0938	92	0.0918	93	0.0901	94	0.0887	95	0.0874
96	0.0866	97	0.0860	98	0.4616	99	0.4588	100	0.4560
101	0.4532	102	0.4502	103	0.4472	104	0.6475	105	0.6460
106	0.0938	107	0.0918	108	0.0901	109	0.0887	110	0.0874
111	0.0866	112	0.0860	113	0.4616	114	0.4588	115	0.4560
116	0.4532	117	0.4502	118	0.4472	119	0.6475	120	0.6460
121	0.0938	122	0.0918	123	0.0901	124	0.0887	125	0.0874
126	0.0866	127	0.0860	128	0.4616	129	0.4588	130	0.4560
131	0.4532	132	0.4502	133	0.4472	134	0.6475	135	0.6460
136	0.0938	137	0.0918	138	0.0901	139	0.0887	140	0.0874
141	0.0866	142	0.0860	143	0.4616	144	0.4588	145	0.4560
146	0.4532	147	0.4502	148	0.4472	149	0.6475	150	0.6460
151	0.0938	152	0.0918	153	0.0901	154	0.0887	155	0.0874
156	0.0866	157	0.0860	158	0.4616	159	0.4588	160	0.4560
161	0.4532	162	0.4502	163	0.4472	164	0.6475	165	0.6460
166	0.0938	167	0.0918	168	0.0901	169	0.0887	170	0.0874
171	0.0866	172	0.0860	173	0.4616	174	0.4588	175	0.4560
176	0.4532	177	0.4502	178	0.4472	179	0.6475	180	0.6460
181	0.0938	182	0.0918	183	0.0901	184	0.0887	185	0.0874
186	0.0866	187	0.0860	188	0.4616	189	0.4588	190	0.4560
191	0.4532	192	0.4502	193	0.4472	194	0.6475	195	0.6460
196	0.0938	197	0.0918	198	0.0901	199	0.0887	200	0.0874
201	0.0866	202	0.0860	203	0.4616	204	0.4588	205	0.4560
206	0.4532	207	0.4502	208	0.4472	209	0.6475	210	0.6460
211	0.0938	212	0.0918	213	0.0901	214	0.0887	215	0.0874
216	0.0866	217	0.0860	218	0.4616	219	0.4588	220	0.4560
221	0.4532	222	0.4502	223	0.4472	224	0.6475	225	0.6460

*** ELEMENTAL FLUID VELOCITY ***

ELEMENT	X-VELOCITY	Y-VELOCITY	ELEMENT	X-VELOCITY	Y-VELOCITY	ELEMENT	X-VELOCITY	Y-VELOCITY
1	9.834E-12	-7.16	2	1.395E-11	-7.15	3	1.327E-11	-7.12
4	1.268E-11	-7.08	5	1.622E-11	-7.03	6	1.970E-11	-6.98
7	1.934E-11	-6.94	8	1.515E-11	-6.82	9	1.316E-11	-6.62
10	1.680E-11	-6.40	11	1.852E-11	-6.17	12	1.103E-11	-5.93
13	1.458E-11	-5.68	14	1.222E-11	-5.41	15	1.219E-11	-5.14
16	9.834E-12	-7.16	17	1.860E-11	-7.15	18	0.000E+00	-7.12
19	-1.268E-11	-7.08	20	4.056E-12	-7.03	21	1.576E-11	-6.98

22	1.160E-11	-6.94	23	3.787E-12	-6.82	24	-5.640E-12	-6.62
25	-1.866E-12	-6.40	26	0.000E+00	-6.17	27	7.351E-12	-5.93
28	1.094E-11	-5.68	29	1.222E-11	-5.41	30	1.950E-11	-5.14
31	9.834E-12	-7.16	32	4.651E-12	-7.15	33	-1.770E-11	-7.12
34	-1.691E-11	-7.08	35	-4.056E-12	-7.03	36	-3.939E-12	-6.98
37	-1.160E-11	-6.94	38	-2.462E-11	-6.82	39	-3.008E-11	-6.62
40	-2.053E-11	-6.40	41	-7.409E-12	-6.17	42	-7.351E-12	-5.93
43	-7.291E-12	-5.68	44	0.000E+00	-5.41	45	7.312E-12	-5.14
46	0.000E+00	-7.16	47	-9.302E-12	-7.15	48	-3.097E-11	-7.12
49	-3.382E-11	-7.08	50	-2.839E-11	-7.03	51	-3.152E-11	-6.98
52	-3.094E-11	-6.94	53	-3.409E-11	-6.82	54	-3.384E-11	-6.62
55	-3.546E-11	-6.40	56	-3.704E-11	-6.17	57	-4.043E-11	-5.93
58	-3.645E-11	-5.68	59	-1.222E-11	-5.41	60	-2.437E-12	-5.14
61	-4.917E-12	-7.16	62	-2.791E-11	-7.15	63	-5.751E-11	-7.12
64	-5.918E-11	-7.08	65	-4.867E-11	-7.03	66	-5.121E-11	-6.98
67	-5.415E-11	-6.94	68	-5.492E-11	-6.82	69	-6.016E-11	-6.62
70	-6.346E-11	-6.40	71	-6.297E-11	-6.17	72	-5.513E-11	-5.93
73	-5.833E-11	-5.68	74	-3.177E-11	-5.41	75	-2.681E-11	-5.14
76	-1.475E-11	-7.16	77	-4.186E-11	-7.15	78	-7.078E-11	-7.12
79	-8.455E-11	-7.08	80	-7.706E-11	-7.03	81	-7.879E-11	-6.98
82	-8.897E-11	-6.94	83	-8.711E-11	-6.82	84	-7.333E-11	-6.62
85	-7.279E-11	-6.40	86	-7.779E-11	-6.17	87	-7.351E-11	-5.93
88	-7.291E-11	-5.68	89	-4.643E-11	-5.41	90	-4.875E-11	-5.14
91	-2.950E-11	-7.16	92	-6.046E-11	-7.15	93	-8.405E-11	-7.12
94	-1.015E-10	-7.08	95	-1.095E-10	-7.03	96	-1.103E-10	-6.98
97	-1.083E-10	-6.94	98	-1.098E-10	-6.82	99	-1.034E-10	-6.62
100	-9.518E-11	-6.40	101	-9.261E-11	-6.17	102	-9.556E-11	-5.93
103	-9.478E-11	-5.68	104	-7.087E-11	-5.41	105	-7.312E-11	-5.14
106	-2.950E-11	-7.16	107	-8.837E-11	-7.15	108	-1.106E-10	-7.12
109	-1.268E-10	-7.08	110	-1.419E-10	-7.03	111	-1.339E-10	-6.98
112	-1.354E-10	-6.94	113	-1.288E-10	-6.82	114	-1.335E-10	-6.62
115	-1.325E-10	-6.40	116	-1.185E-10	-6.17	117	-1.139E-10	-5.93
118	-1.203E-10	-5.68	119	-8.798E-11	-5.41	120	-8.531E-11	-5.14
121	-4.425E-11	-7.16	122	-1.209E-10	-7.15	123	-1.504E-10	-7.12
124	-1.606E-10	-7.08	125	-1.784E-10	-7.03	126	-1.773E-10	-6.98
127	-1.547E-10	-6.94	128	-1.534E-10	-6.82	129	-1.561E-10	-6.62
130	-1.512E-10	-6.40	131	-1.519E-10	-6.17	132	-1.544E-10	-5.93
133	-1.531E-10	-5.68	134	-1.026E-10	-5.41	135	-1.146E-10	-5.14
136	-5.900E-11	-7.16	137	-1.349E-10	-7.15	138	-1.814E-10	-7.12
139	-2.029E-10	-7.08	140	-2.149E-10	-7.03	141	-2.049E-10	-6.98
142	-1.779E-10	-6.94	143	-1.629E-10	-6.82	144	-1.617E-10	-6.62
145	-1.642E-10	-6.40	146	-1.667E-10	-6.17	147	-1.691E-10	-5.93
148	-1.640E-10	-5.68	149	-1.197E-10	-5.41	150	-1.365E-10	-5.14
151	-4.671E-11	-7.16	152	-1.209E-10	-7.15	153	-1.637E-10	-7.12
154	-1.860E-10	-7.08	155	-1.926E-10	-7.03	156	-1.871E-10	-6.98
157	-1.818E-10	-6.94	158	-1.742E-10	-6.82	159	-1.702E-10	-6.62
160	-1.708E-10	-6.40	161	-1.741E-10	-6.17	162	-1.764E-10	-5.93
163	-1.732E-10	-5.68	164	-1.185E-10	-5.41	165	-1.182E-10	-5.14
166	-3.442E-11	-7.16	167	-9.070E-11	-7.15	168	-1.217E-10	-7.12
169	-1.395E-10	-7.08	170	-1.480E-10	-7.03	171	-1.477E-10	-6.98
172	-1.431E-10	-6.94	173	-1.392E-10	-6.82	174	-1.401E-10	-6.62
175	-1.418E-10	-6.40	176	-1.408E-10	-6.17	177	-1.341E-10	-5.93
178	-1.349E-10	-5.68	179	-9.164E-11	-5.41	180	-8.775E-11	-5.14
181	-2.950E-11	-7.16	182	-6.279E-11	-7.15	183	-8.405E-11	-7.12
184	-9.723E-11	-7.08	185	-9.733E-11	-7.03	186	-9.849E-11	-6.98
187	-1.006E-10	-6.94	188	-9.942E-11	-6.82	189	-1.015E-10	-6.62
190	-1.026E-10	-6.40	191	-1.000E-10	-6.17	192	-9.556E-11	-5.93
193	-9.114E-11	-5.68	194	-5.987E-11	-5.41	195	-5.850E-11	-5.14
196	-1.229E-11	-7.16	197	-3.721E-11	-7.15	198	-4.866E-11	-7.12
199	-5.496E-11	-7.08	200	-6.083E-11	-7.03	201	-6.106E-11	-6.98
202	-6.189E-11	-6.94	203	-6.344E-11	-6.82	204	-6.205E-11	-6.62
205	-5.599E-11	-6.40	206	-5.927E-11	-6.17	207	-6.432E-11	-5.93
208	-6.380E-11	-5.68	209	-4.032E-11	-5.41	210	-3.900E-11	-5.14
211	-9.834E-12	-7.16	212	-1.860E-11	-7.15	213	-1.991E-11	-7.12
214	-1.691E-11	-7.08	215	-2.231E-11	-7.03	216	-2.758E-11	-6.98

217	-2.708E-11	-6.94	218	-2.651E-11	-6.82	219	-2.726E-11	-6.62
220	-2.706E-11	-6.40	221	-2.593E-11	-6.17	222	-3.124E-11	-5.93
223	-3.281E-11	-5.68	224	-2.444E-11	-5.41	225	-2.559E-11	-5.14

SOLUTION IS NOW COMPLETE FOR TARGET TIME STEP NO. 1 NUMBER OF COMPUTATIONAL TIME STEPS PERFORMED = 1

**** ELAPSED SIMULATION TIME : 2.500 TIME STEP NUMBER : 5 TIME STEP SIZE: 0.500E+00 ****

ITERATION	NUMBER OF NON-CONVERGENT NODES	MAXIMUM ERROR	NODE NUMBER	RELAXATION FACTOR
1	240	-24.66	192	1.00
2	144	1.712	240	0.955
3	0	3.9058E-02	86	1.00

*** NODAL HEAD VALUES ***

NODE	HEAD VALUE	NODE	HEAD VALUE	NODE	HEAD VALUE	NODE	HEAD VALUE	NODE	HEAD VALUE
1	-100.0	2	-106.2	3	-112.1	4	-117.7	5	-123.1
6	-128.3	7	-130.8	8	-133.2	9	-135.7	10	-138.3
11	-140.9	12	-143.5	13	-146.2	14	-148.9	15	-150.6
16	-152.5	17	-100.0	18	-106.2	19	-112.1	20	-117.7
21	-123.1	22	-128.3	23	-130.8	24	-133.2	25	-135.7
26	-138.3	27	-140.9	28	-143.5	29	-146.2	30	-148.9
31	-150.6	32	-152.5	33	-100.0	34	-106.2	35	-112.1
36	-117.7	37	-123.1	38	-128.3	39	-130.8	40	-133.2
41	-135.7	42	-138.3	43	-140.9	44	-143.5	45	-146.2
46	-148.9	47	-150.6	48	-152.5	49	-100.0	50	-106.2
51	-112.1	52	-117.7	53	-123.1	54	-128.3	55	-130.8
56	-133.2	57	-135.7	58	-138.3	59	-140.9	60	-143.5
61	-146.2	62	-148.9	63	-150.6	64	-152.5	65	-100.0
66	-106.2	67	-112.1	68	-117.7	69	-123.1	70	-128.3
71	-130.8	72	-133.2	73	-135.7	74	-138.3	75	-140.9
76	-143.5	77	-146.2	78	-148.9	79	-150.6	80	-152.5
81	-100.0	82	-106.2	83	-112.1	84	-117.7	85	-123.1
86	-128.3	87	-130.8	88	-133.2	89	-135.7	90	-138.3
91	-140.9	92	-143.5	93	-146.2	94	-148.9	95	-150.6
96	-152.5	97	-100.0	98	-106.2	99	-112.1	100	-117.7
101	-123.1	102	-128.3	103	-130.8	104	-133.2	105	-135.7
106	-138.3	107	-140.9	108	-143.5	109	-146.2	110	-148.9
111	-150.6	112	-152.5	113	-100.0	114	-106.2	115	-112.1
116	-117.7	117	-123.1	118	-128.3	119	-130.8	120	-133.2
121	-135.7	122	-138.3	123	-140.9	124	-143.5	125	-146.2
126	-148.9	127	-150.6	128	-152.5	129	-100.0	130	-106.2
131	-112.1	132	-117.7	133	-123.1	134	-128.3	135	-130.8
136	-133.2	137	-135.7	138	-138.3	139	-140.9	140	-143.5
141	-146.2	142	-148.9	143	-150.6	144	-152.5	145	-100.0
146	-106.2	147	-112.1	148	-117.7	149	-123.1	150	-128.3
151	-130.8	152	-133.2	153	-135.7	154	-138.3	155	-140.9
156	-143.5	157	-146.2	158	-148.9	159	-150.6	160	-152.5

161	-100.0	162	-106.2	163	-112.1	164	-117.7	165	-123.1
166	-128.3	167	-130.8	168	-133.2	169	-135.7	170	-138.3
171	-140.9	172	-143.5	173	-146.2	174	-148.9	175	-150.6
176	-152.5	177	-100.0	178	-106.2	179	-112.1	180	-117.7
181	-123.1	182	-128.3	183	-130.8	184	-133.2	185	-135.7
186	-138.3	187	-140.9	188	-143.5	189	-146.2	190	-148.9
191	-150.6	192	-152.5	193	-100.0	194	-106.2	195	-112.1
196	-117.7	197	-123.1	198	-128.3	199	-130.8	200	-133.2
201	-135.7	202	-138.3	203	-140.9	204	-143.5	205	-146.2
206	-148.9	207	-150.6	208	-152.5	209	-100.0	210	-106.2
211	-112.1	212	-117.7	213	-123.1	214	-128.3	215	-130.8
216	-133.2	217	-135.7	218	-138.3	219	-140.9	220	-143.5
221	-146.2	222	-148.9	223	-150.6	224	-152.5	225	-100.0
226	-106.2	227	-112.1	228	-117.7	229	-123.1	230	-128.3
231	-130.8	232	-133.2	233	-135.7	234	-138.3	235	-140.9
236	-143.5	237	-146.2	238	-148.9	239	-150.6	240	-152.5
241	-100.0	242	-106.2	243	-112.1	244	-117.7	245	-123.1
246	-128.3	247	-130.8	248	-133.2	249	-135.7	250	-138.3
251	-140.9	252	-143.5	253	-146.2	254	-148.9	255	-150.6
256	-152.5								

*** LIST OF PARTIALLY SATURATED ELEMENTS ***

ELEM.	SAT. VALUE	ELEM.	SAT. VALUE	ELEM.	SAT. VALUE	ELEM.	SAT. VALUE	ELEM.	SAT. VALUE
1	0.0935	2	0.0909	3	0.0888	4	0.0870	5	0.0854
6	0.0843	7	0.0837	8	0.4478	9	0.4442	10	0.4407
11	0.4372	12	0.4338	13	0.4304	14	0.6298	15	0.6275
16	0.0935	17	0.0909	18	0.0888	19	0.0870	20	0.0854
21	0.0843	22	0.0837	23	0.4478	24	0.4442	25	0.4407
26	0.4372	27	0.4338	28	0.4304	29	0.6298	30	0.6275
31	0.0935	32	0.0909	33	0.0888	34	0.0870	35	0.0854
36	0.0843	37	0.0837	38	0.4478	39	0.4442	40	0.4407
41	0.4372	42	0.4338	43	0.4304	44	0.6298	45	0.6275
46	0.0935	47	0.0909	48	0.0888	49	0.0870	50	0.0854
51	0.0843	52	0.0837	53	0.4478	54	0.4442	55	0.4407
56	0.4372	57	0.4338	58	0.4304	59	0.6298	60	0.6275
61	0.0935	62	0.0909	63	0.0888	64	0.0870	65	0.0854
66	0.0843	67	0.0837	68	0.4478	69	0.4442	70	0.4407
71	0.4372	72	0.4338	73	0.4304	74	0.6298	75	0.6275
76	0.0935	77	0.0909	78	0.0888	79	0.0870	80	0.0854
81	0.0843	82	0.0837	83	0.4478	84	0.4442	85	0.4407
86	0.4372	87	0.4338	88	0.4304	89	0.6298	90	0.6275
91	0.0935	92	0.0909	93	0.0888	94	0.0870	95	0.0854
96	0.0843	97	0.0837	98	0.4478	99	0.4442	100	0.4407
101	0.4372	102	0.4338	103	0.4304	104	0.6298	105	0.6275
106	0.0935	107	0.0909	108	0.0888	109	0.0870	110	0.0854
111	0.0843	112	0.0837	113	0.4478	114	0.4442	115	0.4407
116	0.4372	117	0.4338	118	0.4304	119	0.6298	120	0.6275
121	0.0935	122	0.0909	123	0.0888	124	0.0870	125	0.0854
126	0.0843	127	0.0837	128	0.4478	129	0.4442	130	0.4407
131	0.4372	132	0.4338	133	0.4304	134	0.6298	135	0.6275
136	0.0935	137	0.0909	138	0.0888	139	0.0870	140	0.0854
141	0.0843	142	0.0837	143	0.4478	144	0.4442	145	0.4407
146	0.4372	147	0.4338	148	0.4304	149	0.6298	150	0.6275
151	0.0935	152	0.0909	153	0.0888	154	0.0870	155	0.0854
156	0.0843	157	0.0837	158	0.4478	159	0.4442	160	0.4407
161	0.4372	162	0.4338	163	0.4304	164	0.6298	165	0.6275
166	0.0935	167	0.0909	168	0.0888	169	0.0870	170	0.0854
171	0.0843	172	0.0837	173	0.4478	174	0.4442	175	0.4407
176	0.4372	177	0.4338	178	0.4304	179	0.6298	180	0.6275

181	0.0935	182	0.0909	183	0.0888	184	0.0870	185	0.0854
186	0.0843	187	0.0837	188	0.4478	189	0.4442	190	0.4407
191	0.4372	192	0.4338	193	0.4304	194	0.6298	195	0.6275
196	0.0935	197	0.0909	198	0.0888	199	0.0870	200	0.0854
201	0.0843	202	0.0837	203	0.4478	204	0.4442	205	0.4407
206	0.4372	207	0.4338	208	0.4304	209	0.6298	210	0.6275
211	0.0935	212	0.0909	213	0.0888	214	0.0870	215	0.0854
216	0.0843	217	0.0837	218	0.4478	219	0.4442	220	0.4407
221	0.4372	222	0.4338	223	0.4304	224	0.6298	225	0.6275

*** ELEMENTAL FLUID VELOCITY ***

ELEMENT	X-VELOCITY	Y-VELOCITY	ELEMENT	X-VELOCITY	Y-VELOCITY	ELEMENT	X-VELOCITY	Y-VELOCITY
1	9.743E-12	-5.10	2	1.812E-11	-5.10	3	1.696E-11	-5.08
4	1.997E-11	-5.06	5	1.891E-11	-5.04	6	1.456E-11	-5.02
7	1.777E-11	-5.01	8	2.191E-11	-4.95	9	2.170E-11	-4.85
10	2.149E-11	-4.75	11	2.483E-11	-4.63	12	2.108E-11	-4.51
13	1.392E-11	-4.38	14	1.185E-11	-4.25	15	1.180E-11	-4.09
16	1.461E-11	-5.10	17	1.359E-11	-5.10	18	8.482E-12	-5.08
19	7.989E-12	-5.06	20	1.135E-11	-5.04	21	1.456E-11	-5.02
22	1.066E-11	-5.01	23	1.095E-11	-4.95	24	7.232E-12	-4.85
25	1.791E-11	-4.75	26	1.774E-11	-4.63	27	1.405E-11	-4.51
28	1.740E-11	-4.38	29	1.421E-11	-4.25	30	1.888E-11	-4.09
31	4.872E-12	-5.10	32	1.359E-11	-5.10	33	8.482E-12	-5.08
34	0.000E+00	-5.06	35	-3.782E-12	-5.04	36	-7.280E-12	-5.02
37	-1.777E-11	-5.01	38	-1.095E-11	-4.95	39	3.616E-12	-4.85
40	3.582E-12	-4.75	41	0.000E+00	-4.63	42	0.000E+00	-4.51
43	0.000E+00	-4.38	44	4.738E-12	-4.25	45	1.180E-11	-4.09
46	4.872E-12	-5.10	47	0.000E+00	-5.10	48	-8.482E-12	-5.08
49	-2.796E-11	-5.06	50	-3.026E-11	-5.04	51	-2.548E-11	-5.02
52	-2.487E-11	-5.01	53	-2.191E-11	-4.95	54	-1.808E-11	-4.85
55	-2.149E-11	-4.75	56	-3.193E-11	-4.63	57	-3.162E-11	-4.51
58	-1.392E-11	-4.38	59	0.000E+00	-4.25	60	-2.360E-12	-4.09
61	4.872E-12	-5.10	62	-1.359E-11	-5.10	63	-4.241E-11	-5.08
64	-3.995E-11	-5.06	65	-3.782E-11	-5.04	66	-5.096E-11	-5.02
67	-5.330E-11	-5.01	68	-5.112E-11	-4.95	69	-5.424E-11	-4.85
70	-6.089E-11	-4.75	71	-6.385E-11	-4.63	72	-5.622E-11	-4.51
73	-4.176E-11	-4.38	74	-2.606E-11	-4.25	75	-3.067E-11	-4.09
76	-9.743E-12	-5.10	77	-2.718E-11	-5.10	78	-5.938E-11	-5.08
79	-6.791E-11	-5.06	80	-6.808E-11	-5.04	81	-6.552E-11	-5.02
82	-7.462E-11	-5.01	83	-9.129E-11	-4.95	84	-9.402E-11	-4.85
85	-9.312E-11	-4.75	86	-8.159E-11	-4.63	87	-7.730E-11	-4.51
88	-6.960E-11	-4.38	89	-4.738E-11	-4.25	90	-5.191E-11	-4.09
91	-1.461E-11	-5.10	92	-4.983E-11	-5.10	93	-8.482E-11	-5.08
94	-9.987E-11	-5.06	95	-9.833E-11	-5.04	96	-1.019E-10	-5.02
97	-9.950E-11	-5.01	98	-1.132E-10	-4.95	99	-1.193E-10	-4.85
100	-1.182E-10	-4.75	101	-1.135E-10	-4.63	102	-1.019E-10	-4.51
103	-1.044E-10	-4.38	104	-7.344E-11	-4.25	105	-7.551E-11	-4.09
106	-2.923E-11	-5.10	107	-7.700E-11	-5.10	108	-1.060E-10	-5.08
109	-1.238E-10	-5.06	110	-1.286E-10	-5.04	111	-1.274E-10	-5.02
112	-1.315E-10	-5.01	113	-1.424E-10	-4.95	114	-1.410E-10	-4.85
115	-1.397E-10	-4.75	116	-1.419E-10	-4.63	117	-1.405E-10	-4.51
118	-1.392E-10	-4.38	119	-9.239E-11	-4.25	120	-9.438E-11	-4.09
121	-4.384E-11	-5.10	122	-1.042E-10	-5.10	123	-1.400E-10	-5.08
124	-1.518E-10	-5.06	125	-1.551E-10	-5.04	126	-1.529E-10	-5.02
127	-1.492E-10	-5.01	128	-1.534E-10	-4.95	129	-1.591E-10	-4.85
130	-1.576E-10	-4.75	131	-1.561E-10	-4.63	132	-1.651E-10	-4.51
133	-1.705E-10	-4.38	134	-1.208E-10	-4.25	135	-1.251E-10	-4.09
136	-5.359E-11	-5.10	137	-1.314E-10	-5.10	138	-1.654E-10	-5.08
139	-1.798E-10	-5.06	140	-1.891E-10	-5.04	141	-1.820E-10	-5.02

142	-1.706E-10	-5.01	143	-1.789E-10	-4.95	144	-1.808E-10	-4.85
145	-1.862E-10	-4.75	146	-1.880E-10	-4.63	147	-1.862E-10	-4.51
148	-1.879E-10	-4.38	149	-1.469E-10	-4.25	150	-1.534E-10	-4.09
151	-4.141E-11	-5.10	152	-1.087E-10	-5.10	153	-1.484E-10	-5.08
154	-1.638E-10	-5.06	155	-1.740E-10	-5.04	156	-1.802E-10	-5.02
157	-1.741E-10	-5.01	158	-1.753E-10	-4.95	159	-1.790E-10	-4.85
160	-1.827E-10	-4.75	161	-1.845E-10	-4.63	162	-1.915E-10	-4.51
163	-2.018E-10	-4.38	164	-1.398E-10	-4.25	165	-1.380E-10	-4.09
166	-3.167E-11	-5.10	167	-7.700E-11	-5.10	168	-1.060E-10	-5.08
169	-1.278E-10	-5.06	170	-1.380E-10	-5.04	171	-1.383E-10	-5.02
172	-1.386E-10	-5.01	173	-1.479E-10	-4.95	174	-1.501E-10	-4.85
175	-1.540E-10	-4.75	176	-1.561E-10	-4.63	177	-1.581E-10	-4.51
178	-1.566E-10	-4.38	179	-1.054E-10	-4.25	180	-1.050E-10	-4.09
181	-1.949E-11	-5.10	182	-5.209E-11	-5.10	183	-7.846E-11	-5.08
184	-9.388E-11	-5.06	185	-1.040E-10	-5.04	186	-1.074E-10	-5.02
187	-1.048E-10	-5.01	188	-1.114E-10	-4.95	189	-1.121E-10	-4.85
190	-1.110E-10	-4.75	191	-1.117E-10	-4.63	192	-1.107E-10	-4.51
193	-1.096E-10	-4.38	194	-7.107E-11	-4.25	195	-6.489E-11	-4.09
196	-1.705E-11	-5.10	197	-4.303E-11	-5.10	198	-5.301E-11	-5.08
199	-5.792E-11	-5.06	200	-6.429E-11	-5.04	201	-7.098E-11	-5.02
202	-7.107E-11	-5.01	203	-6.938E-11	-4.95	204	-6.690E-11	-4.85
205	-6.447E-11	-4.75	206	-6.740E-11	-4.63	207	-7.027E-11	-4.51
208	-6.612E-11	-4.38	209	-4.501E-11	-4.25	210	-4.247E-11	-4.09
211	-1.218E-11	-5.10	212	-2.265E-11	-5.10	213	-1.909E-11	-5.08
214	-1.598E-11	-5.06	215	-2.269E-11	-5.04	216	-2.730E-11	-5.02
217	-2.665E-11	-5.01	218	-2.556E-11	-4.95	219	-2.531E-11	-4.85
220	-2.686E-11	-4.75	221	-2.483E-11	-4.63	222	-2.284E-11	-4.51
223	-2.610E-11	-4.38	224	-1.895E-11	-4.25	225	-1.770E-11	-4.09

SOLUTION IS NOW COMPLETE FOR TARGET TIME STEP NO. 5 NUMBER OF COMPUTATIONAL TIME STEPS PERFORMED = 1

*** OBSERVATION NODE INFORMATION ***

NODAL VALUES OF DEPENDENT VARIABLE OVER TIME

OBSERVED NODE NUMBER: 62

TIME	HEAD VALUE	TIME	HEAD VALUE	TIME	HEAD VALUE	TIME	HEAD VALUE
0.5000E+00	-0.1360E+03	0.1000E+01	-0.1195E+03	0.1500E+01	-0.1210E+03	0.2000E+01	-0.1262E+03
0.2500E+01	-0.1489E+03						

OBSERVED NODE NUMBER: 126

TIME	HEAD VALUE	TIME	HEAD VALUE	TIME	HEAD VALUE	TIME	HEAD VALUE
0.5000E+00	-0.1360E+03	0.1000E+01	-0.1195E+03	0.1500E+01	-0.1210E+03	0.2000E+01	-0.1262E+03
0.2500E+01	-0.1489E+03						

OBSERVED NODE NUMBER: 150

TIME	HEAD VALUE	TIME	HEAD VALUE	TIME	HEAD VALUE	TIME	HEAD VALUE
0.5000E+00	-0.1209E+03	0.1000E+01	-0.1139E+03	0.1500E+01	-0.1142E+03	0.2000E+01	-0.1168E+03
0.2500E+01	-0.1283E+03						

OBSERVED NODE NUMBER: 174

```
TIME      HEAD VALUE      TIME      HEAD VALUE      TIME      HEAD VALUE      TIME      HEAD VALUE
----      ----------      ----      ----------      ----      ----------      ----      ----------

0.5000E+00   -0.1360E+03     0.1000E+01   -0.1195E+03     0.1500E+01   -0.1210E+03     0.2000E+01   -0.1262E+03
0.2500E+01   -0.1489E+03

              OBSERVED NODE NUMBER:    222

TIME      HEAD VALUE      TIME      HEAD VALUE      TIME      HEAD VALUE      TIME      HEAD VALUE
----      ----------      ----      ----------      ----      ----------      ----      ----------

0.5000E+00   -0.1360E+03     0.1000E+01   -0.1195E+03     0.1500E+01   -0.1210E+03     0.2000E+01   -0.1262E+03
0.2500E+01   -0.1489E+03


              *****  VAM2D HAS FULLY EXCECUTED  *****
```

10.3 PROBLEM 2: TRANSIENT TRANSPORT SIMULATION

10.3.1 Input Data

The input data file for this sample transport problem is presented in Table 10.3. Note that the modeling option parameter IMODL = 0. Because the output control parameter IPRD is set equal to 0, the mesh data and initial condition data will appear in the printed output. Also evident in the depicted input data is the specification of NVREAD = 2. This means that data pertaining to Darcy velocity and water saturation values must be supplied to the code from a separate data file in TAPE9, which was written during the solution of the previous flow problem. Finally, the input data shown in Table 10.3 also contains sixteen prescribed concentration boundary conditions, as well as node numbers of all non-zero flux boundary nodes.

10.3.2 Sample Output

Output of the transport calculation is displayed in Table 10.4. This output consists of the following categories of information:

1. Brief summary of control input data and material transport properties
2. Mesh data
3. Prescribed boundary condition data
4. Default value of velocities and upstream weighting factors
5. Maximum bandwidth of the global matrix
6. Element centroidal coordinates
7. List of observation nodes
8. Time step number
9. Element velocities, water saturation, nodal storage, and flux values that were read from file number 9
10. Node numbers and concentration values corresponding to the given time value
11. Observation node information.

Note that information in categories 9 through 11 is repeated for each time step. The given printout only contain results for the first and final time steps.

Table 10.3. Input Data for the Two-Dimensional Solute Transport Problem.

```
   1                                                                       GROUP 1
TEST PROBLEM 2      (TRANSPORT ONLY)                                       GROUP 2
   0   0   0   0   0   0   1   5 256 225   0   0   3   0   0   0           GROUP 3
   1   0  10   1   1     0.1     1.0                                       GROUP 4
   2   0   0   2   0   1   1   1   1   0   0   0                           GROUP 5
      0.0       0.5       1.0       1.0                                    GROUP 6
   -100.0       0.0                                                        GROUP 7
   1   1   1   1   1   1   1   2   2   2   2   2   2   3   3   1           GROUP 8
   1   1   1   1   1   1   2   2   2   2   2   2   3   3   1   1             ,,
   1   1   1   1   1   2   2   2   2   2   2   3   3   1   1   1             ,,
   1   1   1   1   2   2   2   2   2   2   3   3   1   1   1   1             ,,
   1   1   1   2   2   2   2   2   2   3   3   1   1   1   1   1             ,,
   1   1   2   2   2   2   2   2   3   3   1   1   1   1   1   1             ,,
   1   2   2   2   2   2   2   3   3   1   1   1   1   1   1   1             ,,
   2   2   2   2   2   2   3   3   1   1   1   1   1   1   1   2             ,,
   2   2   2   2   2   3   3   1   1   1   1   1   1   1   2   2             ,,
   2   2   2   2   3   3   1   1   1   1   1   1   1   2   2   2             ,,
   2   2   2   3   3   1   1   1   1   1   1   1   2   2   2   2             ,,
   2   2   3   3   1   1   1   1   1   1   1   2   2   2   2   2             ,,
   2   3   3   1   1   1   1   1   1   1   2   2   2   2   2   2             ,,
   3   3   1   1   1   1   1   1   1   2   2   2   2   2   2   3             ,,
   3                                                                         ,,
      2.0       2.0       0.0       0.0       0.41      1.65               GROUP 11A
      2.0       2.0       0.0       0.0       0.43      1.55                 ,,
      2.0       2.0       0.0       0.0       0.45      1.50                 ,,
      0.0       0.0                                                        GROUP 11B
      0.0       0.0                                                          ,,
      0.0       0.0                                                          ,,
  16  16        5.0      10.0   1                                          GROUP 12
      0.0       2.5       5.0       7.5      10.0      12.5      15.0      17.5  GROUP 13
     20.0      22.5      25.0      30.0      35.0      40.0      45.0      50.0    ,,
      0.0      10.0      20.0      30.0      40.0      50.0      55.0      60.0    ,,
     65.0      70.0      75.0      80.0      85.0      90.0      95.0     100.0    ,,
  16   0   0  16                                                           GROUP 15A
  16   1        1.0                                                        GROUP 15B
  32   1        1.0                                                          ,,
  48   1        1.0                                                          ,,
  64   1        1.0                                                          ,,
  80   1        1.0                                                          ,,
  96   1        1.0                                                          ,,
 112   1        1.0                                                          ,,
 128   1        1.0                                                          ,,
 144   1        1.0                                                          ,,
 160   1        1.0                                                          ,,
 176   1        1.0                                                          ,,
 192   1        1.0                                                          ,,
 208   1        1.0                                                          ,,
 224   1        1.0                                                          ,,
 240   1        1.0                                                          ,,
 256   1        1.0                                                          ,,
  16   1   6                                                               GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0                  ,,      B
      0.0      12.5      10.0       0.0       0.0       0.0                  ,,      C
      0.0      12.5      10.0       0.0       0.0       0.0                  ,,      D
  32   1   6                                                               GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0                  ,,      B
      0.0      25.0      20.0       0.0       0.0       0.0                  ,,      C
      0.0      25.0      20.0       0.0       0.0       0.0                  ,,      D
  48   1   6                                                               GROUP 16-IIA
      0.0       1.0       2.0       3.0       4.0      50.0                  ,,      B
```

```
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     C
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     D
  64    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     C
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     D
  80    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     C
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     D
  96    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     C
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     D
 112    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     C
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     D
 128    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     C
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     D
 144    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     C
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     D
 160    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     C
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     D
 176    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      37.5      30.0      0.0      0.0      0.0              ,,     C
       0.0      37.5      30.0      0.0      0.0      0.0              ,,     D
 192    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      50.0      40.0      0.0      0.0      0.0              ,,     C
       0.0      50.0      40.0      0.0      0.0      0.0              ,,     D
 208    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      50.0      40.0      0.0      0.0      0.0              ,,     C
       0.0      50.0      40.0      0.0      0.0      0.0              ,,     D
 224    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      50.0      40.0      0.0      0.0      0.0              ,,     C
       0.0      50.0      40.0      0.0      0.0      0.0              ,,     D
 240    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      50.0      40.0      0.0      0.0      0.0              ,,     C
       0.0      50.0      40.0      0.0      0.0      0.0              ,,     D
 256    1    6                                                         GROUP 16-IIA
       0.0       1.0       2.0      3.0      4.0     50.0              ,,     B
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     C
       0.0      25.0      20.0      0.0      0.0      0.0              ,,     D
       0.0       0.0       0.0      0.0      0.0    0                  GROUP 19
   5   62  126  150  174  222                                          GROUP 27A
```

Table 10.4. Output for the Two-Dimensional Solute Transport Problem.

```
********************************************************************************

                        THIS OUTPUT GENERATED BY VAM2D v. 5.0
                        INPUT FILE NAME = VAM2D-2T.DAT

********************************************************************************


NUMBER OF PROBLEMS TO BE SOLVED =  1


PROBLEM NUMBER:  1


PROBLEM TITLE
--------------------------------------------------------------------------------

TEST PROBLEM 2      (TRANSPORT ONLY)

--------------------------------------------------------------------------------



PROBLEM SPECIFICATION PARAMETERS
--------------------------------
MODEL OPTION PARAMETER ...................(IMODL) =    0
  NOTE:  IMODL = 0 FOR SOLUTE TRANSPORT ONLY
               = 1 FOR WATER FLOW ONLY
               = 2 FOR COUPLED FLOW AND TRANSPORT
HYSTERETIC SOIL MOISTURE (1=YES, 0=NO)....(IHYST) =    0
ANISOTROPIC REL. COND.(1=YES, 0=NO)........(IANI) =    0
CONVERT INITIAL HEAD VALUES(1=YES, 0=NO).(INTSPC) =    0
CHAIN-DECAY REACTIONS(1=YES, 0=NO).......(ICHAIN) =    0
STEADY STATE SIMULATION(1=YES, 0=NO)......(ISSTA) =    0
TIME STEP GENERATION INDEX (1=YES, 0=NO) .(ITSGN) =    1
NUMBER OF TIME STEPS .......................(NTS) =    5
TOTAL NUMBER OF NODES .......................(NP) =  256
TOTAL NUMBER OF ELEMENTS ....................(NE) =  225
SEQUENTIAL NUMBERING INDEX (0=Y, 1=X-DIR) (ISWAP) =    0
AXISYMMETRIC SIMULATION(1=YES, 0=NO).....(IAXSYM) =    0
NUMBER OF POROUS MATRIX MATERIALS .........(NMAT) =    3
INITIAL CONDITION NON-UNIFORMITY INDEX.....(NONU) =    0
NUMBER OF INFIL./EVAP. ELEMENTS .........(NEIEVP) =    0
NUMBER PLANT SPECIES ....................(NPLANT) =    0


TIME STEPPING AND ITERATION CONTROL PARAMETERS
----------------------------------------------
TIME STEPPING INDEX (0=CNTRL, 1=BCKWD) ...(IKALL) =    1
TYPE OF ITERATION SCHEME (1=NEWT,0=PICARD)(INEWT) =    0
MAXIMUM NON-LINEAR ITERATIONS ...........(NITMAX) =    1
MAXIMUM NUMBER OF TIME STEP REFINEMENTS .(IRESOL) =    3
LUMPING OF ELEMENT MATRIX (1=YES, 0=NO) ..(ILUMP) =    0
```

```
INPUT / OUTPUT CONTROL PARAMETERS
---------------------------------
VELOCITY/SATURATION INPUT................(NVREAD) =    2
BOUNDARY NODE DATA READ (1=YES, 0=NO)....(IOUTLT) =    0
NUMBER OF NODES FOR WHICH I.C. ARE READ....(NPIN) =    0
OUTPUT REQUIREMENT INDICATOR:
 (0=ALL DATA, 1=NO ELEMENT DATA,
  2=NO DATA, 3=NO MESH AND I.C. DATA.......(IPRD) =    2
UNIT 9 OUTPUT OF VEL / SAT (1=YES, 0=NO).(NVWRIT) =    0
VELOCITY PRINTOUT CONTROL INDEX............(NVPR) =    1
UNIT 10 OUTPUT HEAD/CONC. (0=NONE, N=NTH).(NPLOT) =    1
NODAL VALUE PRINTOUT CONTROL INDEX........(NSTEP) =    1
OBSERVATION NODE INDEX...................(IOBSND) =    1
MASS BALANCE TO BE PERFORMED (1=YES,0=NO).(IMBAL) =    0
UNIT 8 OUTPUT OF HEAD/CONC (1=YES, 0=NO).(NOWRIT) =    0
PRINT CHECK OPTION INDEX.................(IPRCHK) =    0


TEMPORAL DISCRETIZATION DATA
----------------------------
INITIAL TIME VALUE ........................ (TIMA) =  0.0000E+00
VALUE OF FIRST TIME STEP ................... (TIN) =  0.5000E+00
TIME STEP MULTIPLIER ...................... (TFAC) =  0.1000E+01
MAXIMUM TIME STEP SIZE .................... (TMAX) =  0.1000E+01


*** LIST OF GENERATED TIME VALUES ***
-------------------------------------

0.500E+00 0.100E+01 0.150E+01 0.200E+01 0.250E+01

DEFAULT INITIAL CONCENTRATION VALUE
-----------------------------------

         0.0000E+00

ELEMENT PROPERTY NUMBERS
------------------------


    1    1    1    1    1    1    1    2    2    2    2    2    2    3    3    1
    1    1    1    1    1    1    2    2    2    2    2    2    3    3    1    1
    1    1    1    1    1    2    2    2    2    2    2    3    3    1    1    1
    1    1    1    1    2    2    2    2    2    2    3    3    1    1    1    1
    1    1    1    2    2    2    2    2    2    3    3    1    1    1    1    1
    1    1    2    2    2    2    2    2    3    3    1    1    1    1    1    1
    1    2    2    2    2    2    2    3    3    1    1    1    1    1    1    1
    2    2    2    2    2    2    3    3    1    1    1    1    1    1    1    2
    2    2    2    2    2    3    3    1    1    1    1    1    1    1    2    2
    2    2    2    2    3    3    1    1    1    1    1    1    1    2    2    2
    2    2    2    3    3    1    1    1    1    1    1    1    2    2    2    2
    2    2    3    3    1    1    1    1    1    1    1    2    2    2    2    2
    2    3    3    1    1    1    1    1    1    1    2    2    2    2    2    2
    3    3    1    1    1    1    1    1    1    2    2    2    2    2    2    3
    3


TRANSPORT PROPERTIES OF POROUS MEDIA
------------------------------------


MATERIAL NUMBER:    1  (I)

LONGITUDINAL DISPERSIVITY ALPHA-L ....(PROPJ(I,1)) =  0.2000E+01
TRANSVERSE DISPERSIVITY ALPHA-T ......(PROPJ(I,2)) =  0.2000E+01
```

```
MOLECULAR DIFFUSION COMPONENT D-XX....(PROPJ(I,3)) =  0.0000E+00
MOLECULAR DIFFUSION COMPONENT D-YY....(PROPJ(I,4)) =  0.0000E+00
EFFECTIVE POROSITY(0 FOR STEADY STATE)(PROPJ(I,5)) =  0.4100E+00
BULK DENSITY (g/cm**2) ...............(PROPJ(I,6)) =  0.1650E+01

MATERIAL NUMBER:    2  (I)

LONGITUDINAL DISPERSIVITY ALPHA-L ....(PROPJ(I,1)) =  0.2000E+01
TRANSVERSE DISPERSIVITY ALPHA-T ......(PROPJ(I,2)) =  0.2000E+01
MOLECULAR DIFFUSION COMPONENT D-XX....(PROPJ(I,3)) =  0.0000E+00
MOLECULAR DIFFUSION COMPONENT D-YY....(PROPJ(I,4)) =  0.0000E+00
EFFECTIVE POROSITY(0 FOR STEADY STATE)(PROPJ(I,5)) =  0.4300E+00
BULK DENSITY (g/cm**2) ...............(PROPJ(I,6)) =  0.1550E+01

MATERIAL NUMBER:    3  (I)

LONGITUDINAL DISPERSIVITY ALPHA-L ....(PROPJ(I,1)) =  0.2000E+01
TRANSVERSE DISPERSIVITY ALPHA-T ......(PROPJ(I,2)) =  0.2000E+01
MOLECULAR DIFFUSION COMPONENT D-XX....(PROPJ(I,3)) =  0.0000E+00
MOLECULAR DIFFUSION COMPONENT D-YY....(PROPJ(I,4)) =  0.0000E+00
EFFECTIVE POROSITY(0 FOR STEADY STATE)(PROPJ(I,5)) =  0.4500E+00
BULK DENSITY (g/cm**2) ...............(PROPJ(I,6)) =  0.1500E+01


SOLUTE PROPERTIES
-----------------

MATERIAL NUMBER:    1  (I)
DECAY COEFFICIENT ................... (RPROP(I,1)) =  0.0000E+00
DISTRIBUTION COEFFICIENT (cm**3/g)... (RPROP(I,2)) =  0.0000E+00

MATERIAL NUMBER:    2  (I)
DECAY COEFFICIENT ................... (RPROP(I,1)) =  0.0000E+00
DISTRIBUTION COEFFICIENT (cm**3/g)... (RPROP(I,2)) =  0.0000E+00

MATERIAL NUMBER:    3  (I)
DECAY COEFFICIENT ................... (RPROP(I,1)) =  0.0000E+00
DISTRIBUTION COEFFICIENT (cm**3/g)... (RPROP(I,2)) =  0.0000E+00


X-COORDINATES OF GRID LINES
--------------------------


       0.00       2.50       5.00       7.50      10.00      12.50      15.00      17.50
      20.00      22.50      25.00      30.00      35.00      40.00      45.00      50.00


Y-COORDINATES OF GRID LINES
--------------------------


       0.00      10.00      20.00      30.00      40.00      50.00      55.00      60.00
      65.00      70.00      75.00      80.00      85.00      90.00      95.00     100.00


BOUNDARY CONDITION DATA
-----------------------------------

NUMBER OF STEADY DIRICHLET BOUNDARIES ........ (NBTO) =   16
NUMBER OF STEADY FLUX BOUNDARIES ........... (NDFLUX) =    0
NUMBER OF TRANSIENT DIRICHLET BOUNDARIES.... (NBHVAR) =    0
NUMBER OF TRANSIENT FLUX BOUNDARIES.... .... (NBFVAR) =   16
```

DIRICHLET BOUNDARY CONDITION DATA

INDEX	NODE NUMBER	DEP. VAR. #	PRESCRIBED VALUE
1	16	1	1.000
2	32	1	1.000
3	48	1	1.000
4	64	1	1.000
5	80	1	1.000
6	96	1	1.000
7	112	1	1.000
8	128	1	1.000
9	144	1	1.000
10	160	1	1.000
11	176	1	1.000
12	192	1	1.000
13	208	1	1.000
14	224	1	1.000
15	240	1	1.000
16	256	1	1.000

TIME DEPENDENT FLUX B. C. FOR
NODE # 16 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	12.50	12.50
2.000	10.00	10.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 32 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	25.00	25.00
2.000	20.00	20.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 48 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6

TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	25.00	25.00
2.000	20.00	20.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 64 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	25.00	25.00
2.000	20.00	20.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 80 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	25.00	25.00
2.000	20.00	20.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 96 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	25.00	25.00
2.000	20.00	20.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 112 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	25.00	25.00
2.000	20.00	20.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 128 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	25.00	25.00
2.000	20.00	20.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 144 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	25.00	25.00
2.000	20.00	20.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 160 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	25.00	25.00
2.000	20.00	20.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 176 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	37.50	37.50
2.000	30.00	30.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 192 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	50.00	50.00
2.000	40.00	40.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 208 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	50.00	50.00
2.000	40.00	40.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR

NODE # 224 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	50.00	50.00
2.000	40.00	40.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 240 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	50.00	50.00
2.000	40.00	40.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 256 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED SOLUTE MASS AND WATER AND WATER VOLUMETRIC FLUXES

0.0000E+00	0.0000E+00	0.0000E+00	1.000	25.00	25.00
2.000	20.00	20.00	3.000	0.0000E+00	0.0000E+00
4.000	0.0000E+00	0.0000E+00	50.00	0.0000E+00	0.0000E+00

DEFAULT VALUES AND WEIGHTING FACTORS

DEFAULT VALUE OF X-VELOCITY ....(VCX) = 0.0000E+00
DEFAULT VALUE OF Y-VELOCITY ....(VCY) = 0.0000E+00
X-DIRECTION UPSTREAM WEIGHTING FACTOR ......(WFAC) = 0.0000E+00
Y-DIRECTION UPSTREAM WEIGHTING FACTOR ......(YFAC) = 0.0000E+00
DEFAULT WATER SATURATION ....(SWD) = 0.0000E+00
STEADY-STATE VELOCITY FIELD (0=NO, 1=YES).(IVSTED) = 0

------- ACTUAL HALF BAND WIDTH = 17 FULL BANDWIDTH = 35 -------

LIST OF OBSERVATION NODES

62 126 150 174 222

+++++++++ BEGIN TRANSIENT CALCULATIONS ++++++++

**** ELAPSED SIMULATION TIME : 0.5000 TIME STEP NUMBER : 1 TIME STEP SIZE: 0.500E+00 ****

*** ELEMENTAL FLUID VELOCITY FROM TAPE 9 ***

ELEMENT	X-VELOCITY	Y-VELOCITY	ELEMENT	X-VELOCITY	Y-VELOCITY	ELEMENT	X-VELOCITY	Y-VELOCITY
1	9.834E-12	-7.16	2	1.395E-11	-7.15	3	1.327E-11	-7.12
4	1.268E-11	-7.08	5	1.622E-11	-7.03	6	1.970E-11	-6.98
7	1.934E-11	-6.94	8	1.515E-11	-6.82	9	1.316E-11	-6.62
10	1.680E-11	-6.40	11	1.852E-11	-6.17	12	1.103E-11	-5.93
13	1.458E-11	-5.68	14	1.222E-11	-5.41	15	1.219E-11	-5.14
16	9.834E-12	-7.16	17	1.860E-11	-7.15	18	0.000E+00	-7.12
19	-1.268E-11	-7.08	20	4.056E-12	-7.03	21	1.576E-11	-6.98
22	1.160E-11	-6.94	23	3.787E-12	-6.82	24	-5.640E-12	-6.62
25	-1.866E-12	-6.40	26	0.000E+00	-6.17	27	7.351E-12	-5.93
28	1.094E-11	-5.68	29	1.222E-11	-5.41	30	1.950E-11	-5.14
31	9.834E-12	-7.16	32	4.651E-12	-7.15	33	-1.770E-11	-7.12
34	-1.691E-11	-7.08	35	-4.056E-12	-7.03	36	-3.939E-12	-6.98
37	-1.160E-11	-6.94	38	-2.462E-11	-6.82	39	-3.008E-11	-6.62
40	-2.053E-11	-6.40	41	-7.409E-12	-6.17	42	-7.351E-12	-5.93
43	-7.291E-12	-5.68	44	0.000E+00	-5.41	45	7.312E-12	-5.14
46	0.000E+00	-7.16	47	-9.302E-12	-7.15	48	-3.097E-11	-7.12
49	-3.382E-11	-7.08	50	-2.839E-11	-7.03	51	-3.152E-11	-6.98
52	-3.094E-11	-6.94	53	-3.409E-11	-6.82	54	-3.384E-11	-6.62
55	-3.546E-11	-6.40	56	-3.704E-11	-6.17	57	-4.043E-11	-5.93
58	-3.645E-11	-5.68	59	-1.222E-11	-5.41	60	-2.437E-12	-5.14
61	-4.917E-12	-7.16	62	-2.791E-11	-7.15	63	-5.751E-11	-7.12
64	-5.918E-11	-7.08	65	-4.867E-11	-7.03	66	-5.121E-11	-6.98
67	-5.415E-11	-6.94	68	-5.492E-11	-6.82	69	-6.016E-11	-6.62
70	-6.346E-11	-6.40	71	-6.297E-11	-6.17	72	-5.513E-11	-5.93
73	-5.833E-11	-5.68	74	-3.177E-11	-5.41	75	-2.681E-11	-5.14
76	-1.475E-11	-7.16	77	-4.186E-11	-7.15	78	-7.078E-11	-7.12
79	-8.455E-11	-7.08	80	-7.706E-11	-7.03	81	-7.879E-11	-6.98
82	-8.897E-11	-6.94	83	-8.711E-11	-6.82	84	-7.333E-11	-6.62
85	-7.279E-11	-6.40	86	-7.779E-11	-6.17	87	-7.351E-11	-5.93
88	-7.291E-11	-5.68	89	-4.643E-11	-5.41	90	-4.875E-11	-5.14
91	-2.950E-11	-7.16	92	-6.046E-11	-7.15	93	-8.405E-11	-7.12
94	-1.015E-10	-7.08	95	-1.095E-10	-7.03	96	-1.103E-10	-6.98
97	-1.083E-10	-6.94	98	-1.098E-10	-6.82	99	-1.034E-10	-6.62
100	-9.518E-11	-6.40	101	-9.261E-11	-6.17	102	-9.556E-11	-5.93
103	-9.478E-11	-5.68	104	-7.087E-11	-5.41	105	-7.312E-11	-5.14

106	-2.950E-11	-7.16	107	-8.837E-11	-7.15	108	-1.106E-10	-7.12
109	-1.268E-10	-7.08	110	-1.419E-10	-7.03	111	-1.339E-10	-6.98
112	-1.354E-10	-6.94	113	-1.288E-10	-6.82	114	-1.335E-10	-6.62
115	-1.325E-10	-6.40	116	-1.185E-10	-6.17	117	-1.139E-10	-5.93
118	-1.203E-10	-5.68	119	-8.798E-11	-5.41	120	-8.531E-11	-5.14
121	-4.425E-11	-7.16	122	-1.209E-10	-7.15	123	-1.504E-10	-7.12
124	-1.606E-10	-7.08	125	-1.784E-10	-7.03	126	-1.773E-10	-6.98
127	-1.547E-10	-6.94	128	-1.534E-10	-6.82	129	-1.561E-10	-6.62
130	-1.512E-10	-6.40	131	-1.519E-10	-6.17	132	-1.544E-10	-5.93
133	-1.531E-10	-5.68	134	-1.026E-10	-5.41	135	-1.146E-10	-5.14
136	-5.900E-11	-7.16	137	-1.349E-10	-7.15	138	-1.814E-10	-7.12
139	-2.029E-10	-7.08	140	-2.149E-10	-7.03	141	-2.049E-10	-6.98
142	-1.779E-10	-6.94	143	-1.629E-10	-6.82	144	-1.617E-10	-6.62
145	-1.642E-10	-6.40	146	-1.667E-10	-6.17	147	-1.691E-10	-5.93
148	-1.640E-10	-5.68	149	-1.197E-10	-5.41	150	-1.365E-10	-5.14
151	-4.671E-11	-7.16	152	-1.209E-10	-7.15	153	-1.637E-10	-7.12
154	-1.860E-10	-7.08	155	-1.926E-10	-7.03	156	-1.871E-10	-6.98
157	-1.818E-10	-6.94	158	-1.742E-10	-6.82	159	-1.702E-10	-6.62
160	-1.708E-10	-6.40	161	-1.741E-10	-6.17	162	-1.764E-10	-5.93
163	-1.732E-10	-5.68	164	-1.185E-10	-5.41	165	-1.182E-10	-5.14
166	-3.442E-11	-7.16	167	-9.070E-11	-7.15	168	-1.217E-10	-7.12
169	-1.395E-10	-7.08	170	-1.480E-10	-7.03	171	-1.477E-10	-6.98
172	-1.431E-10	-6.94	173	-1.392E-10	-6.82	174	-1.401E-10	-6.62
175	-1.418E-10	-6.40	176	-1.408E-10	-6.17	177	-1.341E-10	-5.93
178	-1.349E-10	-5.68	179	-9.164E-11	-5.41	180	-8.775E-11	-5.14
181	-2.950E-11	-7.16	182	-6.279E-11	-7.15	183	-8.405E-11	-7.12
184	-9.723E-11	-7.08	185	-9.733E-11	-7.03	186	-9.849E-11	-6.98
187	-1.006E-10	-6.94	188	-9.942E-11	-6.82	189	-1.015E-10	-6.62
190	-1.026E-10	-6.40	191	-1.000E-10	-6.17	192	-9.556E-11	-5.93
193	-9.114E-11	-5.68	194	-5.987E-11	-5.41	195	-5.850E-11	-5.14
196	-1.229E-11	-7.16	197	-3.721E-11	-7.15	198	-4.866E-11	-7.12
199	-5.496E-11	-7.08	200	-6.083E-11	-7.03	201	-6.106E-11	-6.98
202	-6.189E-11	-6.94	203	-6.344E-11	-6.82	204	-6.205E-11	-6.62
205	-5.599E-11	-6.40	206	-5.927E-11	-6.17	207	-6.432E-11	-5.93
208	-6.380E-11	-5.68	209	-4.032E-11	-5.41	210	-3.900E-11	-5.14
211	-9.834E-12	-7.16	212	-1.860E-11	-7.15	213	-1.991E-11	-7.12
214	-1.691E-11	-7.08	215	-2.231E-11	-7.03	216	-2.758E-11	-6.98
217	-2.708E-11	-6.94	218	-2.651E-11	-6.82	219	-2.726E-11	-6.62
220	-2.706E-11	-6.40	221	-2.593E-11	-6.17	222	-3.124E-11	-5.93
223	-3.281E-11	-5.68	224	-2.444E-11	-5.41	225	-2.559E-11	-5.14

ELEMENT SATURATION VALUES FROM TAPE 9

ELEMENT	SAT. VALUE	ELEMENT	SAT. VALUE	ELEMENT	SAT. VALUE	ELEMENT	SAT. VALUE	ELEMENT	SAT. VALUE
1	9.3799E-02	2	9.1831E-02	3	9.0149E-02	4	8.8694E-02	5	8.7423E-02
6	8.6563E-02	7	8.6035E-02	8	0.4616	9	0.4588	10	0.4560
11	0.4532	12	0.4502	13	0.4472	14	0.6475	15	0.6460
16	9.3799E-02	17	9.1831E-02	18	9.0149E-02	19	8.8694E-02	20	8.7423E-02
21	8.6563E-02	22	8.6035E-02	23	0.4616	24	0.4588	25	0.4560
26	0.4532	27	0.4502	28	0.4472	29	0.6475	30	0.6460
31	9.3799E-02	32	9.1831E-02	33	9.0149E-02	34	8.8694E-02	35	8.7423E-02
36	8.6563E-02	37	8.6035E-02	38	0.4616	39	0.4588	40	0.4560
41	0.4532	42	0.4502	43	0.4472	44	0.6475	45	0.6460
46	9.3799E-02	47	9.1831E-02	48	9.0149E-02	49	8.8694E-02	50	8.7423E-02
51	8.6563E-02	52	8.6035E-02	53	0.4616	54	0.4588	55	0.4560
56	0.4532	57	0.4502	58	0.4472	59	0.6475	60	0.6460
61	9.3799E-02	62	9.1831E-02	63	9.0149E-02	64	8.8694E-02	65	8.7423E-02
66	8.6563E-02	67	8.6035E-02	68	0.4616	69	0.4588	70	0.4560
71	0.4532	72	0.4502	73	0.4472	74	0.6475	75	0.6460
76	9.3799E-02	77	9.1831E-02	78	9.0149E-02	79	8.8694E-02	80	8.7423E-02
81	8.6563E-02	82	8.6035E-02	83	0.4616	84	0.4588	85	0.4560

86	0.4532	87	0.4502	88	0.4472	89	0.6475	90	0.6460
91	9.3799E-02	92	9.1831E-02	93	9.0149E-02	94	8.8694E-02	95	8.7423E-02
96	8.6563E-02	97	8.6035E-02	98	0.4616	99	0.4588	100	0.4560
101	0.4532	102	0.4502	103	0.4472	104	0.6475	105	0.6460
106	9.3799E-02	107	9.1831E-02	108	9.0149E-02	109	8.8694E-02	110	8.7423E-02
111	8.6563E-02	112	8.6035E-02	113	0.4616	114	0.4588	115	0.4560
116	0.4532	117	0.4502	118	0.4472	119	0.6475	120	0.6460
121	9.3799E-02	122	9.1831E-02	123	9.0149E-02	124	8.8694E-02	125	8.7423E-02
126	8.6563E-02	127	8.6035E-02	128	0.4616	129	0.4588	130	0.4560
131	0.4532	132	0.4502	133	0.4472	134	0.6475	135	0.6460
136	9.3799E-02	137	9.1831E-02	138	9.0149E-02	139	8.8694E-02	140	8.7423E-02
141	8.6563E-02	142	8.6035E-02	143	0.4616	144	0.4588	145	0.4560
146	0.4532	147	0.4502	148	0.4472	149	0.6475	150	0.6460
151	9.3799E-02	152	9.1831E-02	153	9.0149E-02	154	8.8694E-02	155	8.7423E-02
156	8.6563E-02	157	8.6035E-02	158	0.4616	159	0.4588	160	0.4560
161	0.4532	162	0.4502	163	0.4472	164	0.6475	165	0.6460
166	9.3799E-02	167	9.1831E-02	168	9.0149E-02	169	8.8694E-02	170	8.7423E-02
171	8.6563E-02	172	8.6035E-02	173	0.4616	174	0.4588	175	0.4560
176	0.4532	177	0.4502	178	0.4472	179	0.6475	180	0.6460
181	9.3799E-02	182	9.1831E-02	183	9.0149E-02	184	8.8694E-02	185	8.7423E-02
186	8.6563E-02	187	8.6035E-02	188	0.4616	189	0.4588	190	0.4560
191	0.4532	192	0.4502	193	0.4472	194	0.6475	195	0.6460
196	9.3799E-02	197	9.1831E-02	198	9.0149E-02	199	8.8694E-02	200	8.7423E-02
201	8.6563E-02	202	8.6035E-02	203	0.4616	204	0.4588	205	0.4560
206	0.4532	207	0.4502	208	0.4472	209	0.6475	210	0.6460
211	9.3799E-02	212	9.1831E-02	213	9.0149E-02	214	8.8694E-02	215	8.7423E-02
216	8.6563E-02	217	8.6035E-02	218	0.4616	219	0.4588	220	0.4560
221	0.4532	222	0.4502	223	0.4472	224	0.6475	225	0.6460

*** NODAL CONCENTRATION VALUES ***

NODE	CONC. VALUE	NODE	CONC. VALUE	NODE	CONC. VALUE	NODE	CONC. VALUE	NODE	CONC. VALUE
1	4.5372E-02	2	4.8945E-02	3	5.4916E-02	4	6.0558E-02	5	6.7108E-02
6	7.4142E-02	7	7.8010E-02	8	8.1996E-02	9	9.7980E-02	10	0.1296
11	0.1707	12	0.2269	13	0.3042	14	0.4119	15	0.6172
16	1.000	17	4.5372E-02	18	4.8945E-02	19	5.4916E-02	20	6.0558E-02
21	6.7108E-02	22	7.4142E-02	23	7.8010E-02	24	8.1996E-02	25	9.7980E-02
26	0.1296	27	0.1707	28	0.2269	29	0.3042	30	0.4119
31	0.6172	32	1.000	33	4.5372E-02	34	4.8945E-02	35	5.4916E-02
36	6.0558E-02	37	6.7108E-02	38	7.4142E-02	39	7.8010E-02	40	8.1996E-02
41	9.7980E-02	42	0.1296	43	0.1707	44	0.2269	45	0.3042
46	0.4119	47	0.6172	48	1.000	49	4.5372E-02	50	4.8945E-02
51	5.4916E-02	52	6.0558E-02	53	6.7108E-02	54	7.4142E-02	55	7.8010E-02
56	8.1996E-02	57	9.7980E-02	58	0.1296	59	0.1707	60	0.2269
61	0.3042	62	0.4119	63	0.6172	64	1.000	65	4.5372E-02
66	4.8945E-02	67	5.4916E-02	68	6.0558E-02	69	6.7108E-02	70	7.4142E-02
71	7.8010E-02	72	8.1996E-02	73	9.7980E-02	74	0.1296	75	0.1707
76	0.2269	77	0.3042	78	0.4119	79	0.6172	80	1.000
81	4.5372E-02	82	4.8945E-02	83	5.4916E-02	84	6.0558E-02	85	6.7108E-02
86	7.4142E-02	87	7.8010E-02	88	8.1996E-02	89	9.7980E-02	90	0.1296
91	0.1707	92	0.2269	93	0.3042	94	0.4119	95	0.6172
96	1.000	97	4.5372E-02	98	4.8945E-02	99	5.4916E-02	100	6.0558E-02
101	6.7108E-02	102	7.4142E-02	103	7.8010E-02	104	8.1996E-02	105	9.7980E-02
106	0.1296	107	0.1707	108	0.2269	109	0.3042	110	0.4119
111	0.6172	112	1.000	113	4.5372E-02	114	4.8945E-02	115	5.4916E-02
116	6.0558E-02	117	6.7108E-02	118	7.4142E-02	119	7.8010E-02	120	8.1996E-02
121	9.7980E-02	122	0.1296	123	0.1707	124	0.2269	125	0.3042
126	0.4119	127	0.6172	128	1.000	129	4.5372E-02	130	4.8945E-02
131	5.4916E-02	132	6.0558E-02	133	6.7108E-02	134	7.4142E-02	135	7.8010E-02
136	8.1996E-02	137	9.7980E-02	138	0.1296	139	0.1707	140	0.2269

141	0.3042	142	0.4119	143	0.6172	144	1.000	145	4.5372E-02
146	4.8945E-02	147	5.4916E-02	148	6.0558E-02	149	6.7108E-02	150	7.4142E-02
151	7.8010E-02	152	8.1996E-02	153	9.7980E-02	154	0.1296	155	0.1707
156	0.2269	157	0.3042	158	0.4119	159	0.6172	160	1.000
161	4.5372E-02	162	4.8945E-02	163	5.4916E-02	164	6.0558E-02	165	6.7108E-02
166	7.4142E-02	167	7.8010E-02	168	8.1996E-02	169	9.7980E-02	170	0.1296
171	0.1707	172	0.2269	173	0.3042	174	0.4119	175	0.6172
176	1.000	177	4.5372E-02	178	4.8945E-02	179	5.4916E-02	180	6.0558E-02
181	6.7108E-02	182	7.4142E-02	183	7.8010E-02	184	8.1996E-02	185	9.7980E-02
186	0.1296	187	0.1707	188	0.2269	189	0.3042	190	0.4119
191	0.6172	192	1.000	193	4.5372E-02	194	4.8945E-02	195	5.4916E-02
196	6.0558E-02	197	6.7108E-02	198	7.4142E-02	199	7.8010E-02	200	8.1996E-02
201	9.7980E-02	202	0.1296	203	0.1707	204	0.2269	205	0.3042
206	0.4119	207	0.6172	208	1.000	209	4.5372E-02	210	4.8945E-02
211	5.4916E-02	212	6.0558E-02	213	6.7108E-02	214	7.4142E-02	215	7.8010E-02
216	8.1996E-02	217	9.7980E-02	218	0.1296	219	0.1707	220	0.2269
221	0.3042	222	0.4119	223	0.6172	224	1.000	225	4.5372E-02
226	4.8945E-02	227	5.4916E-02	228	6.0558E-02	229	6.7108E-02	230	7.4142E-02
231	7.8010E-02	232	8.1996E-02	233	9.7980E-02	234	0.1296	235	0.1707
236	0.2269	237	0.3042	238	0.4119	239	0.6172	240	1.000
241	4.5372E-02	242	4.8945E-02	243	5.4916E-02	244	6.0558E-02	245	6.7108E-02
246	7.4142E-02	247	7.8010E-02	248	8.1996E-02	249	9.7980E-02	250	0.1296
251	0.1707	252	0.2269	253	0.3042	254	0.4119	255	0.6172
256	1.000								

**** ELAPSED SIMULATION TIME : 2.500 TIME STEP NUMBER : 5 TIME STEP SIZE: 0.500E+00 ****

*** ELEMENTAL FLUID VELOCITY FROM TAPE 9 ***

ELEMENT	X-VELOCITY	Y-VELOCITY	ELEMENT	X-VELOCITY	Y-VELOCITY	ELEMENT	X-VELOCITY	Y-VELOCITY
1	9.743E-12	-5.10	2	1.812E-11	-5.10	3	1.696E-11	-5.08
4	1.997E-11	-5.06	5	1.891E-11	-5.04	6	1.456E-11	-5.02
7	1.777E-11	-5.01	8	2.191E-11	-4.95	9	2.170E-11	-4.85
10	2.149E-11	-4.75	11	2.483E-11	-4.63	12	2.108E-11	-4.51
13	1.392E-11	-4.38	14	1.185E-11	-4.25	15	1.180E-11	-4.09
16	1.461E-11	-5.10	17	1.359E-11	-5.10	18	8.482E-12	-5.08
19	7.989E-12	-5.06	20	1.135E-11	-5.04	21	1.456E-11	-5.02
22	1.066E-11	-5.01	23	1.095E-11	-4.95	24	7.232E-12	-4.85
25	1.791E-11	-4.75	26	1.774E-11	-4.63	27	1.405E-11	-4.51
28	1.740E-11	-4.38	29	1.421E-11	-4.25	30	1.888E-11	-4.09
31	4.872E-12	-5.10	32	1.359E-11	-5.10	33	8.482E-12	-5.08
34	0.000E+00	-5.06	35	-3.782E-12	-5.04	36	-7.280E-12	-5.02
37	-1.777E-11	-5.01	38	-1.095E-11	-4.95	39	3.616E-12	-4.85
40	3.582E-12	-4.75	41	0.000E+00	-4.63	42	0.000E+00	-4.51
43	0.000E+00	-4.38	44	4.738E-12	-4.25	45	1.180E-11	-4.09
46	4.872E-12	-5.10	47	0.000E+00	-5.10	48	-8.482E-12	-5.08
49	-2.796E-11	-5.06	50	-3.026E-11	-5.04	51	-2.548E-11	-5.02
52	-2.487E-11	-5.01	53	-2.191E-11	-4.95	54	-1.808E-11	-4.85
55	-2.149E-11	-4.75	56	-3.193E-11	-4.63	57	-3.162E-11	-4.51
58	-1.392E-11	-4.38	59	0.000E+00	-4.25	60	-2.360E-12	-4.09
61	4.872E-12	-5.10	62	-1.359E-11	-5.10	63	-4.241E-11	-5.08
64	-3.995E-11	-5.06	65	-3.782E-11	-5.04	66	-5.096E-11	-5.02
67	-5.330E-11	-5.01	68	-5.112E-11	-4.95	69	-5.424E-11	-4.85

70	-6.089E-11	-4.75	71	-6.385E-11	-4.63	72	-5.622E-11	-4.51
73	-4.176E-11	-4.38	74	-2.606E-11	-4.25	75	-3.067E-11	-4.09
76	-9.743E-12	-5.10	77	-2.718E-11	-5.10	78	-5.938E-11	-5.08
79	-6.791E-11	-5.06	80	-6.808E-11	-5.04	81	-6.552E-11	-5.02
82	-7.462E-11	-5.01	83	-9.129E-11	-4.95	84	-9.402E-11	-4.85
85	-9.312E-11	-4.75	86	-8.159E-11	-4.63	87	-7.730E-11	-4.51
88	-6.960E-11	-4.38	89	-4.738E-11	-4.25	90	-5.191E-11	-4.09
91	-1.461E-11	-5.10	92	-4.983E-11	-5.10	93	-8.482E-11	-5.08
94	-9.987E-11	-5.06	95	-9.833E-11	-5.04	96	-1.019E-10	-5.02
97	-9.950E-11	-5.01	98	-1.132E-10	-4.95	99	-1.193E-10	-4.85
100	-1.182E-10	-4.75	101	-1.135E-10	-4.63	102	-1.019E-10	-4.51
103	-1.044E-10	-4.38	104	-7.344E-11	-4.25	105	-7.551E-11	-4.09
106	-2.923E-11	-5.10	107	-7.700E-11	-5.10	108	-1.060E-10	-5.08
109	-1.238E-10	-5.06	110	-1.286E-10	-5.04	111	-1.274E-10	-5.02
112	-1.315E-10	-5.01	113	-1.424E-10	-4.95	114	-1.410E-10	-4.85
115	-1.397E-10	-4.75	116	-1.419E-10	-4.63	117	-1.405E-10	-4.51
118	-1.392E-10	-4.38	119	-9.239E-11	-4.25	120	-9.438E-11	-4.09
121	-4.384E-11	-5.10	122	-1.042E-10	-5.10	123	-1.400E-10	-5.08
124	-1.518E-10	-5.06	125	-1.551E-10	-5.04	126	-1.529E-10	-5.02
127	-1.492E-10	-5.01	128	-1.534E-10	-4.95	129	-1.591E-10	-4.85
130	-1.576E-10	-4.75	131	-1.561E-10	-4.63	132	-1.651E-10	-4.51
133	-1.705E-10	-4.38	134	-1.208E-10	-4.25	135	-1.251E-10	-4.09
136	-5.359E-11	-5.10	137	-1.314E-10	-5.10	138	-1.654E-10	-5.08
139	-1.798E-10	-5.06	140	-1.891E-10	-5.04	141	-1.820E-10	-5.02
142	-1.706E-10	-5.01	143	-1.789E-10	-4.95	144	-1.808E-10	-4.85
145	-1.862E-10	-4.75	146	-1.880E-10	-4.63	147	-1.862E-10	-4.51
148	-1.879E-10	-4.38	149	-1.469E-10	-4.25	150	-1.534E-10	-4.09
151	-4.141E-11	-5.10	152	-1.087E-10	-5.10	153	-1.484E-10	-5.08
154	-1.638E-10	-5.06	155	-1.740E-10	-5.04	156	-1.802E-10	-5.02
157	-1.741E-10	-5.01	158	-1.753E-10	-4.95	159	-1.790E-10	-4.85
160	-1.827E-10	-4.75	161	-1.845E-10	-4.63	162	-1.915E-10	-4.51
163	-2.018E-10	-4.38	164	-1.398E-10	-4.25	165	-1.380E-10	-4.09
166	-3.167E-11	-5.10	167	-7.700E-11	-5.10	168	-1.060E-10	-5.08
169	-1.278E-10	-5.06	170	-1.380E-10	-5.04	171	-1.383E-10	-5.02
172	-1.386E-10	-5.01	173	-1.479E-10	-4.95	174	-1.501E-10	-4.85
175	-1.540E-10	-4.75	176	-1.561E-10	-4.63	177	-1.581E-10	-4.51
178	-1.566E-10	-4.38	179	-1.054E-10	-4.25	180	-1.050E-10	-4.09
181	-1.949E-11	-5.10	182	-5.209E-11	-5.10	183	-7.846E-11	-5.08
184	-9.388E-11	-5.06	185	-1.040E-10	-5.04	186	-1.074E-10	-5.02
187	-1.048E-10	-5.01	188	-1.114E-10	-4.95	189	-1.121E-10	-4.85
190	-1.110E-10	-4.75	191	-1.117E-10	-4.63	192	-1.107E-10	-4.51
193	-1.096E-10	-4.38	194	-7.107E-11	-4.25	195	-6.489E-11	-4.09
196	-1.705E-11	-5.10	197	-4.303E-11	-5.10	198	-5.301E-11	-5.08
199	-5.792E-11	-5.06	200	-6.429E-11	-5.04	201	-7.098E-11	-5.02
202	-7.107E-11	-5.01	203	-6.938E-11	-4.95	204	-6.690E-11	-4.85
205	-6.447E-11	-4.75	206	-6.740E-11	-4.63	207	-7.027E-11	-4.51
208	-6.612E-11	-4.38	209	-4.501E-11	-4.25	210	-4.247E-11	-4.09
211	-1.218E-11	-5.10	212	-2.265E-11	-5.10	213	-1.909E-11	-5.08
214	-1.598E-11	-5.06	215	-2.269E-11	-5.04	216	-2.730E-11	-5.02
217	-2.665E-11	-5.01	218	-2.556E-11	-4.95	219	-2.531E-11	-4.85
220	-2.686E-11	-4.75	221	-2.483E-11	-4.63	222	-2.284E-11	-4.51
223	-2.610E-11	-4.38	224	-1.895E-11	-4.25	225	-1.770E-11	-4.09

ELEMENT SATURATION VALUES FROM TAPE 9

ELEMENT	SAT. VALUE	ELEMENT	SAT. VALUE	ELEMENT	SAT. VALUE	ELEMENT	SAT. VALUE	ELEMENT	SAT. VALUE
1	9.3464E-02	2	9.0933E-02	3	8.8797E-02	4	8.6972E-02	5	8.5398E-02
6	8.4347E-02	7	8.3706E-02	8	0.4478	9	0.4442	10	0.4407
11	0.4372	12	0.4338	13	0.4304	14	0.6298	15	0.6275
16	9.3464E-02	17	9.0933E-02	18	8.8797E-02	19	8.6972E-02	20	8.5398E-02
21	8.4347E-02	22	8.3706E-02	23	0.4478	24	0.4442	25	0.4407

26	0.4372	27	0.4338	28	0.4304	29	0.6298	30	0.6275
31	9.3464E-02	32	9.0933E-02	33	8.8797E-02	34	8.6972E-02	35	8.5398E-02
36	8.4347E-02	37	8.3706E-02	38	0.4478	39	0.4442	40	0.4407
41	0.4372	42	0.4338	43	0.4304	44	0.6298	45	0.6275
46	9.3464E-02	47	9.0933E-02	48	8.8797E-02	49	8.6972E-02	50	8.5398E-02
51	8.4347E-02	52	8.3706E-02	53	0.4478	54	0.4442	55	0.4407
56	0.4372	57	0.4338	58	0.4304	59	0.6298	60	0.6275
61	9.3464E-02	62	9.0933E-02	63	8.8797E-02	64	8.6972E-02	65	8.5398E-02
66	8.4347E-02	67	8.3706E-02	68	0.4478	69	0.4442	70	0.4407
71	0.4372	72	0.4338	73	0.4304	74	0.6298	75	0.6275
76	9.3464E-02	77	9.0933E-02	78	8.8797E-02	79	8.6972E-02	80	8.5398E-02
81	8.4347E-02	82	8.3706E-02	83	0.4478	84	0.4442	85	0.4407
86	0.4372	87	0.4338	88	0.4304	89	0.6298	90	0.6275
91	9.3464E-02	92	9.0933E-02	93	8.8797E-02	94	8.6972E-02	95	8.5398E-02
96	8.4347E-02	97	8.3706E-02	98	0.4478	99	0.4442	100	0.4407
101	0.4372	102	0.4338	103	0.4304	104	0.6298	105	0.6275
106	9.3464E-02	107	9.0933E-02	108	8.8797E-02	109	8.6972E-02	110	8.5398E-02
111	8.4347E-02	112	8.3706E-02	113	0.4478	114	0.4442	115	0.4407
116	0.4372	117	0.4338	118	0.4304	119	0.6298	120	0.6275
121	9.3464E-02	122	9.0933E-02	123	8.8797E-02	124	8.6972E-02	125	8.5398E-02
126	8.4347E-02	127	8.3706E-02	128	0.4478	129	0.4442	130	0.4407
131	0.4372	132	0.4338	133	0.4304	134	0.6298	135	0.6275
136	9.3464E-02	137	9.0933E-02	138	8.8797E-02	139	8.6972E-02	140	8.5398E-02
141	8.4347E-02	142	8.3706E-02	143	0.4478	144	0.4442	145	0.4407
146	0.4372	147	0.4338	148	0.4304	149	0.6298	150	0.6275
151	9.3464E-02	152	9.0933E-02	153	8.8797E-02	154	8.6972E-02	155	8.5398E-02
156	8.4347E-02	157	8.3706E-02	158	0.4478	159	0.4442	160	0.4407
161	0.4372	162	0.4338	163	0.4304	164	0.6298	165	0.6275
166	9.3464E-02	167	9.0933E-02	168	8.8797E-02	169	8.6972E-02	170	8.5398E-02
171	8.4347E-02	172	8.3706E-02	173	0.4478	174	0.4442	175	0.4407
176	0.4372	177	0.4338	178	0.4304	179	0.6298	180	0.6275
181	9.3464E-02	182	9.0933E-02	183	8.8797E-02	184	8.6972E-02	185	8.5398E-02
186	8.4347E-02	187	8.3706E-02	188	0.4478	189	0.4442	190	0.4407
191	0.4372	192	0.4338	193	0.4304	194	0.6298	195	0.6275
196	9.3464E-02	197	9.0933E-02	198	8.8797E-02	199	8.6972E-02	200	8.5398E-02
201	8.4347E-02	202	8.3706E-02	203	0.4478	204	0.4442	205	0.4407
206	0.4372	207	0.4338	208	0.4304	209	0.6298	210	0.6275
211	9.3464E-02	212	9.0933E-02	213	8.8797E-02	214	8.6972E-02	215	8.5398E-02
216	8.4347E-02	217	8.3706E-02	218	0.4478	219	0.4442	220	0.4407
221	0.4372	222	0.4338	223	0.4304	224	0.6298	225	0.6275

*** NODAL CONCENTRATION VALUES ***

NODE	CONC. VALUE	NODE	CONC. VALUE	NODE	CONC. VALUE	NODE	CONC. VALUE	NODE	CONC. VALUE
1	0.8203	2	0.8311	3	0.8473	4	0.8598	5	0.8726
6	0.8841	7	0.8897	8	0.8950	9	0.9130	10	0.9398
11	0.9601	12	0.9755	13	0.9863	14	0.9931	15	0.9978
16	1.000	17	0.8203	18	0.8311	19	0.8473	20	0.8598
21	0.8726	22	0.8841	23	0.8897	24	0.8950	25	0.9130
26	0.9398	27	0.9601	28	0.9755	29	0.9863	30	0.9931
31	0.9978	32	1.000	33	0.8203	34	0.8311	35	0.8473
36	0.8598	37	0.8726	38	0.8841	39	0.8897	40	0.8950
41	0.9130	42	0.9398	43	0.9601	44	0.9755	45	0.9863
46	0.9931	47	0.9978	48	1.000	49	0.8203	50	0.8311
51	0.8473	52	0.8598	53	0.8726	54	0.8841	55	0.8897
56	0.8950	57	0.9130	58	0.9398	59	0.9601	60	0.9755
61	0.9863	62	0.9931	63	0.9978	64	1.000	65	0.8203
66	0.8311	67	0.8473	68	0.8598	69	0.8726	70	0.8841
71	0.8897	72	0.8950	73	0.9130	74	0.9398	75	0.9601
76	0.9755	77	0.9863	78	0.9931	79	0.9978	80	1.000

81	0.8203	82	0.8311	83	0.8473	84	0.8598	85	0.8726
86	0.8841	87	0.8897	88	0.8950	89	0.9130	90	0.9398
91	0.9601	92	0.9755	93	0.9863	94	0.9931	95	0.9978
96	1.000	97	0.8203	98	0.8311	99	0.8473	100	0.8598
101	0.8726	102	0.8841	103	0.8897	104	0.8950	105	0.9130
106	0.9398	107	0.9601	108	0.9755	109	0.9863	110	0.9931
111	0.9978	112	1.000	113	0.8203	114	0.8311	115	0.8473
116	0.8598	117	0.8726	118	0.8841	119	0.8897	120	0.8950
121	0.9130	122	0.9398	123	0.9601	124	0.9755	125	0.9863
126	0.9931	127	0.9978	128	1.000	129	0.8203	130	0.8311
131	0.8473	132	0.8598	133	0.8726	134	0.8841	135	0.8897
136	0.8950	137	0.9130	138	0.9398	139	0.9601	140	0.9755
141	0.9863	142	0.9931	143	0.9978	144	1.000	145	0.8203
146	0.8311	147	0.8473	148	0.8598	149	0.8726	150	0.8841
151	0.8897	152	0.8950	153	0.9130	154	0.9398	155	0.9601
156	0.9755	157	0.9863	158	0.9931	159	0.9978	160	1.000
161	0.8203	162	0.8311	163	0.8473	164	0.8598	165	0.8726
166	0.8841	167	0.8897	168	0.8950	169	0.9130	170	0.9398
171	0.9601	172	0.9755	173	0.9863	174	0.9931	175	0.9978
176	1.000	177	0.8203	178	0.8311	179	0.8473	180	0.8598
181	0.8726	182	0.8841	183	0.8897	184	0.8950	185	0.9130
186	0.9398	187	0.9601	188	0.9755	189	0.9863	190	0.9931
191	0.9978	192	1.000	193	0.8203	194	0.8311	195	0.8473
196	0.8598	197	0.8726	198	0.8841	199	0.8897	200	0.8950
201	0.9130	202	0.9398	203	0.9601	204	0.9755	205	0.9863
206	0.9931	207	0.9978	208	1.000	209	0.8203	210	0.8311
211	0.8473	212	0.8598	213	0.8726	214	0.8841	215	0.8897
216	0.8950	217	0.9130	218	0.9398	219	0.9601	220	0.9755
221	0.9863	222	0.9931	223	0.9978	224	1.000	225	0.8203
226	0.8311	227	0.8473	228	0.8598	229	0.8726	230	0.8841
231	0.8897	232	0.8950	233	0.9130	234	0.9398	235	0.9601
236	0.9755	237	0.9863	238	0.9931	239	0.9978	240	1.000
241	0.8203	242	0.8311	243	0.8473	244	0.8598	245	0.8726
246	0.8841	247	0.8897	248	0.8950	249	0.9130	250	0.9398
251	0.9601	252	0.9755	253	0.9863	254	0.9931	255	0.9978
256	1.000								

*** OBSERVATION NODE INFORMATION ***

NODAL VALUES OF DEPENDENT VARIABLE OVER TIME

OBSERVED NODE NUMBER: 62

TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION		
0.5000E+00	0.4119E+00	0.1000E+01	0.8179E+00	0.1500E+01	0.9470E+00	0.2000E+01	0.9841E+00		
0.2500E+01	0.9931E+00								

OBSERVED NODE NUMBER: 126

TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION		
0.5000E+00	0.4119E+00	0.1000E+01	0.8179E+00	0.1500E+01	0.9470E+00	0.2000E+01	0.9841E+00		
0.2500E+01	0.9931E+00								

OBSERVED NODE NUMBER: 150

TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION		
0.5000E+00	0.7414E-01	0.1000E+01	0.3465E+00	0.1500E+01	0.6217E+00	0.2000E+01	0.8039E+00		

0.2500E+01	0.8841E+00

OBSERVED NODE NUMBER: 174

TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION
0.5000E+00	0.4119E+00	0.1000E+01	0.8179E+00	0.1500E+01	0.9470E+00	0.2000E+01	0.9841E+00
0.2500E+01	0.9931E+00						

OBSERVED NODE NUMBER: 222

TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION
0.5000E+00	0.4119E+00	0.1000E+01	0.8179E+00	0.1500E+01	0.9470E+00	0.2000E+01	0.9841E+00
0.2500E+01	0.9931E+00						

***** VAM2D HAS FULLY EXCECUTED *****

10.4 PROBLEM 3: CONCURRENT SIMULATION OF FLOW AND TRANSPORT

10.4.1 Input Data

The input data file for this sample flow and transport problem is presented in Table 10.5. Note that the modeling parameter option IMODL is now set equal to 2. Because the output control parameter IPRD is set equal to 0, the mesh data and initial condition data will appear in the printed output. Also evident in the depicted input data is the specification of NVREAD = 0. The use of IMODL = 2 means that the flow and transport equations will be solved concurrently. Hence there is no need to supply a velocity file. The input data shown in Table 10.5 also contains sixteen prescribed concentration boundary conditions, as well as node numbers of all non-zero flux boundary nodes.

Table 10.5. Input Data for the Concurrent Simulation of Unsaturated Flow and Solute Transport Problems.

```
      1                                                                                               GROUP 1
 TEST PROBLEM 2        (FLOW AND TRANSPORT SIMULTANEOUSLY)                                            GROUP 2
    2     0     0     0     0     0     1     5   256   225     0     0     3     0     0     0      GROUP 3
    1     0    10     3     1         0.1         1.0     0     0                                   GROUP 4
    0     0     0     2     0     1     1     1     1     0     0     0                             GROUP 5
        0.0         0.5         1.0         1.0                                                       GROUP 6
     -100.0         0.0                                                                               GROUP 7
    1     1     1     1     1     1     1     2     2     2     2     2     2     3     3     1      GROUP 8
    1     1     1     1     1     1     2     2     2     2     2     2     3     3     1     1        ''
    1     1     1     1     1     2     2     2     2     2     2     3     3     1     1     1        ''
    1     1     1     1     2     2     2     2     2     2     3     3     1     1     1     1        ''
    1     1     1     2     2     2     2     2     2     3     3     1     1     1     1     1        ''
    1     1     2     2     2     2     2     2     3     3     1     1     1     1     1     1        ''
    1     2     2     2     2     2     2     3     3     1     1     1     1     1     1     1        ''
    2     2     2     2     2     2     3     3     1     1     1     1     1     1     1     2        ''
    2     2     2     2     2     3     3     1     1     1     1     1     1     1     2     2        ''
    2     2     2     2     3     3     1     1     1     1     1     1     1     2     2     2        ''
    2     2     2     3     3     1     1     1     1     1     1     1     2     2     2     2        ''
    2     2     3     3     1     1     1     1     1     1     1     2     2     2     2     2        ''
    2     3     3     1     1     1     1     1     1     1     2     2     2     2     2     2        ''
    3     3     1     1     1     1     1     1     1     2     2     2     2     2     2     3        ''
    3                                                                                                 ''
 0.350E03  0.350E03  0.000E00  0.000E00  0.410E00  0.000E00                                           GROUP 9
 2.500E01  2.500E01  0.000E00  0.000E00  0.430E00  0.000E00                                             ''
 1.080E01  1.080E01  0.000E00  0.000E00  0.450E00  0.000E00                                             ''
   0.0574      1.00     0.124      2.28                                                               GROUP 10
   0.0774      1.00     0.036      1.56                                                                 ''
   0.0675      1.00     0.020      1.41                                                                 ''
       2.0        2.0       0.0       0.0       0.41       1.65                                       GROUP 11A
       2.0        2.0       0.0       0.0       0.43       1.55                                         ''
       2.0        2.0       0.0       0.0       0.45       1.50                                         ''
       0.0        0.0                                                                                 GROUP 11B
       0.0        0.0                                                                                   ''
       0.0        0.0                                                                                   ''
   16   16        5.0      10.0     1                                                                 GROUP 12
       0.0        2.5       5.0       7.5       10.0       12.5       15.0       17.5                 GROUP 13
      20.0       22.5      25.0      30.0       35.0       40.0       45.0       50.0                   ''
       0.0       10.0      20.0      30.0       40.0       50.0       55.0       60.0                   ''
      65.0       70.0      75.0      80.0       85.0       90.0       95.0      100.0                   ''
   32    0    0   16                                                                                  GROUP 15A
    1    1   -100.0                                                                                   GROUP 15B
   17    1   -100.0                                                                                     ''
   33    1   -100.0                                                                                     ''
   49    1   -100.0                                                                                     ''
   65    1   -100.0                                                                                     ''
   81    1   -100.0                                                                                     ''
   97    1   -100.0                                                                                     ''
  113    1   -100.0                                                                                     ''
  129    1   -100.0                                                                                     ''
  145    1   -100.0                                                                                     ''
  161    1   -100.0                                                                                     ''
  177    1   -100.0                                                                                     ''
  193    1   -100.0                                                                                     ''
  209    1   -100.0                                                                                     ''
  225    1   -100.0                                                                                     ''
  241    1   -100.0                                                                                     ''
   16    2      1.0                                                                                     ''
   32    2      1.0                                                                                     ''
   48    2      1.0                                                                                     ''
   64    2      1.0                                                                                     ''
   80    2      1.0                                                                                     ''
```

```
 96    2         1.0                                                                 ,,
112    2         1.0                                                                 ,,
128    2         1.0                                                                 ,,
144    2         1.0                                                                 ,,
160    2         1.0                                                                 ,,
176    2         1.0                                                                 ,,
192    2         1.0                                                                 ,,
208    2         1.0                                                                 ,,
224    2         1.0                                                                 ,,
240    2         1.0                                                                 ,,
256    2         1.0                                                                 ,,
 16    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       12.5      10.0       0.0       0.0        0.0                        ,,        C
 32    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       25.0      20.0       0.0       0.0        0.0                        ,,        C
 48    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       25.0      20.0       0.0       0.0        0.0                        ,,        C
 64    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       25.0      20.0       0.0       0.0        0.0                        ,,        C
 80    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       25.0      20.0       0.0       0.0        0.0                        ,,        C
 96    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       25.0      20.0       0.0       0.0        0.0                        ,,        C
112    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       25.0      20.0       0.0       0.0        0.0                        ,,        C
128    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       25.0      20.0       0.0       0.0        0.0                        ,,        C
144    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       25.0      20.0       0.0       0.0        0.0                        ,,        C
160    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       25.0      20.0       0.0       0.0        0.0                        ,,        C
176    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       37.5      30.0       0.0       0.0        0.0                        ,,        C
192    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       50.0      40.0       0.0       0.0        0.0                        ,,        C
208    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       50.0      40.0       0.0       0.0        0.0                        ,,        C
224    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       50.0      40.0       0.0       0.0        0.0                        ,,        C
240    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       50.0      40.0       0.0       0.0        0.0                        ,,        C
256    1    6                                                                        GROUP 16-IIA
      0.0        1.0       2.0       3.0       4.0       50.0                        ,,        B
      0.0       25.0      20.0       0.0       0.0        0.0                        ,,        C
      0.0        0.0       0.0       0.0       0.0    0                                GROUP 19
  5   62   126   150  174  222                                                       GROUP 27A
```

10.4.2 <u>Sample Output</u>

Output of the flow and transport calculation is displayed in Table 10.6. This output consists of the following catagories of information:

1. Brief summary of control input data and material hydraulic properties
2. Mesh data
3. Prescribed boundary condition data
4. Initial condition data
5. Maximum bandwidth of the global matrix for the problem
6. Element numbers and centroidal coordinates
7. List of observation nodes
8. Time-step number
9. Print check information for the convergence of the nonlinear iterations
10. Time value
11. Node numbers and nodal head values corresponding to the given time value
12. List of unsaturated elements and centroidal values of water saturation
13. List of element numbers and corresponding centroidal values of Darcy velocity components
14. Node numbers and concentration values corresponding to the given time value
15. Observation node information.

Note that information in categories 8-14 are repeated for each time step, and only result for time step 1 is included in the given printout.

Table 10.6. Output for the Concurrent Simulation Run.

```
********************************************************************************

                         THIS OUTPUT GENERATED BY VAM2D v. 5.0
                         INPUT FILE NAME = VAM2D-2FT.DAT

********************************************************************************


NUMBER OF PROBLEMS TO BE SOLVED =  1


PROBLEM NUMBER:  1


PROBLEM TITLE
--------------------------------------------------------------------------------

TEST PROBLEM 2      (FLOW AND TRANSPORT SIMULTANEOUSLY)

--------------------------------------------------------------------------------



PROBLEM SPECIFICATION PARAMETERS
--------------------------------
MODEL OPTION PARAMETER ....................(IMODL) =    2
  NOTE:  IMODL = 0 FOR SOLUTE TRANSPORT ONLY
               = 1 FOR WATER FLOW ONLY
               = 2 FOR COUPLED FLOW AND TRANSPORT
HYSTERETIC SOIL MOISTURE (1=YES, 0=NO)....(IHYST) =    0
ANISOTROPIC REL. COND.(1=YES, 0=NO)........(IANI) =    0
CONVERT INITIAL HEAD VALUES(1=YES, 0=NO).(INTSPC) =    0
CHAIN-DECAY REACTIONS(1=YES, 0=NO).......(ICHAIN) =    0
STEADY STATE SIMULATION(1=YES, 0=NO)......(ISSTA) =    0
TIME STEP GENERATION INDEX (1=YES, 0=NO) .(ITSGN) =    1
NUMBER OF TIME STEPS ........................(NTS) =    5
TOTAL NUMBER OF NODES ........................(NP) =  256
TOTAL NUMBER OF ELEMENTS .....................(NE) =  225
SEQUENTIAL NUMBERING INDEX (0=Y, 1=X-DIR) (ISWAP) =    0
AXISYMMETRIC SIMULATION(1=YES, 0=NO).....(IAXSYM) =    0
NUMBER OF POROUS MATRIX MATERIALS .........(NMAT) =    3
INITIAL CONDITION NON-UNIFORMITY INDEX.....(NONU) =    0
NUMBER OF INFIL./EVAP. ELEMENTS .........(NEIEVP) =    0
NUMBER PLANT SPECIES .....................(NPLANT) =    0


TIME STEPPING AND ITERATION CONTROL PARAMETERS
----------------------------------------------
TIME STEPPING INDEX (0=CNTRL, 1=BCKWD) ...(IKALL) =    1
TYPE OF ITERATION SCHEME (1=NEWT,0=PICARD)(INEWT) =    0
MAXIMUM NON-LINEAR ITERATIONS ...........(NITMAX) =   10
MAXIMUM NUMBER OF TIME STEP REFINEMENTS .(IRESOL) =    3
LUMPING OF ELEMENT MATRIX (1=YES, 0=NO) ..(ILUMP) =    1


INPUT / OUTPUT CONTROL PARAMETERS
---------------------------------
VELOCITY/SATURATION INPUT................(NVREAD) =    0
```

```
BOUNDARY NODE DATA READ (1=YES, 0=NO)....(IOUTLT) =    0
NUMBER OF NODES FOR WHICH I.C. ARE READ....(NPIN) =    0
OUTPUT REQUIREMENT INDICATOR:
 (0=ALL DATA, 1=NO ELEMENT DATA,
  2=NO DATA, 3=NO MESH AND I.C. DATA.......(IPRD) =    2
UNIT 9 OUTPUT OF VEL / SAT (1=YES, 0=NO).(NVWRIT) =    0
VELOCITY PRINTOUT CONTROL INDEX............(NVPR) =    1
UNIT 10 OUTPUT HEAD/CONC. (0=NONE, N=NTH).(NPLOT) =    1
NODAL VALUE PRINTOUT CONTROL INDEX........(NSTEP) =    1
OBSERVATION NODE INDEX...................(IOBSND) =    1
MASS BALANCE TO BE PERFORMED (1=YES,0=NO).(IMBAL) =    0
UNIT 8 OUTPUT OF HEAD/CONC (1=YES, 0=NO).(NOWRIT) =    0
PRINT CHECK OPTION INDEX.................(IPRCHK) =    0
```

TEMPORAL DISCRETIZATION DATA

```
INITIAL TIME VALUE ........................ (TIMA) =  0.0000E+00
VALUE OF FIRST TIME STEP ................... (TIN) =  0.5000E+00
TIME STEP MULTIPLIER ...................... (TFAC) =  0.1000E+01
MAXIMUM TIME STEP SIZE .................... (TMAX) =  0.1000E+01
```

*** LIST OF GENERATED TIME VALUES ***

0.500E+00 0.100E+01 0.150E+01 0.200E+01 0.250E+01

DEFAULT INITIAL VALUE OF PRESSURE HEAD

-0.1000E+03

DEFAULT INITIAL CONCENTRATION VALUE

0.0000E+00

ELEMENT PROPERTY NUMBERS

1	1	1	1	1	1	1	2	2	2	2	2	2	3	3	1
1	1	1	1	1	1	2	2	2	2	2	2	3	3	1	1
1	1	1	1	1	2	2	2	2	2	2	3	3	1	1	1
1	1	1	1	2	2	2	2	2	2	3	3	1	1	1	1
1	1	1	2	2	2	2	2	2	3	3	1	1	1	1	1
1	1	2	2	2	2	2	2	3	3	1	1	1	1	1	1
1	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1
2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	2
2	2	2	2	2	3	3	1	1	1	1	1	1	1	2	2
2	2	2	2	3	3	1	1	1	1	1	1	1	2	2	2
2	2	2	3	3	1	1	1	1	1	1	1	2	2	2	2
2	2	3	3	1	1	1	1	1	1	1	2	2	2	2	2
2	3	3	1	1	1	1	1	1	1	2	2	2	2	2	2
3	3	1	1	1	1	1	1	1	2	2	2	2	2	2	3
3															

HYDRAULIC PROPERTIES OF POROUS MEDIA

MATERIAL NUMBER: 1 (I)

```
X-DIRECTION HYDRAULIC CONDUCTIVITY ... (PROP(I,1)) =  0.3500E+03
Y-DIRECTION HYDRAULIC CONDUCTIVITY ... (PROP(I,2)) =  0.3500E+03
XY-DIRECTION HYDRAULIC CONDUCTIVITY .. (PROP(I,3)) =  0.0000E+00
SPECIFIC STORAGE ..................... (PROP(I,4)) =  0.0000E+00
SATURATED WATER CONTENT............... (PROP(I,5)) =  0.4100E+00
AIR-ENTRY PRESSURE HEAD VALUE ........ (PROP(I,6)) =  0.0000E+00

MATERIAL NUMBER:    2  (I)

X-DIRECTION HYDRAULIC CONDUCTIVITY ... (PROP(I,1)) =  0.2500E+02
Y-DIRECTION HYDRAULIC CONDUCTIVITY ... (PROP(I,2)) =  0.2500E+02
XY-DIRECTION HYDRAULIC CONDUCTIVITY .. (PROP(I,3)) =  0.0000E+00
SPECIFIC STORAGE ..................... (PROP(I,4)) =  0.0000E+00
SATURATED WATER CONTENT............... (PROP(I,5)) =  0.4300E+00
AIR-ENTRY PRESSURE HEAD VALUE ........ (PROP(I,6)) =  0.0000E+00

MATERIAL NUMBER:    3  (I)

X-DIRECTION HYDRAULIC CONDUCTIVITY ... (PROP(I,1)) =  0.1080E+02
Y-DIRECTION HYDRAULIC CONDUCTIVITY ... (PROP(I,2)) =  0.1080E+02
XY-DIRECTION HYDRAULIC CONDUCTIVITY .. (PROP(I,3)) =  0.0000E+00
SPECIFIC STORAGE ..................... (PROP(I,4)) =  0.0000E+00
SATURATED WATER CONTENT............... (PROP(I,5)) =  0.4500E+00
AIR-ENTRY PRESSURE HEAD VALUE ........ (PROP(I,6)) =  0.0000E+00

MATERIAL NUMBER:    1  (I)

RESIDUAL WATER SATURATION ............ (PROP(I,7)) =  0.5740E-01
POWER INDEX (N) OF K(REL) VS SAT...... (PROP(I,8)) =  0.1000E+01
 (SET N=-1 IF VAN GENUCHTEN REL. REQUIRED)
COEFF (ALPHA) OF SAT. VS CAPIL. HEAD.. (PROP(I,9)) =  0.1240E+00
POWER INDEX (BETA)      ,,       ,,    (PROP(I,10))=  0.2280E+01
POWER INDEX (GAMMA)     ,,       ,,    (PROP(I,11))=  0.5614E+00

MATERIAL NUMBER:    2  (I)

RESIDUAL WATER SATURATION ............ (PROP(I,7)) =  0.7740E-01
POWER INDEX (N) OF K(REL) VS SAT...... (PROP(I,8)) =  0.1000E+01
 (SET N=-1 IF VAN GENUCHTEN REL. REQUIRED)
COEFF (ALPHA) OF SAT. VS CAPIL. HEAD.. (PROP(I,9)) =  0.3600E-01
POWER INDEX (BETA)      ,,       ,,    (PROP(I,10))=  0.1560E+01
POWER INDEX (GAMMA)     ,,       ,,    (PROP(I,11))=  0.3590E+00

MATERIAL NUMBER:    3  (I)

RESIDUAL WATER SATURATION ............ (PROP(I,7)) =  0.6750E-01
POWER INDEX (N) OF K(REL) VS SAT...... (PROP(I,8)) =  0.1000E+01
 (SET N=-1 IF VAN GENUCHTEN REL. REQUIRED)
COEFF (ALPHA) OF SAT. VS CAPIL. HEAD.. (PROP(I,9)) =  0.2000E-01
POWER INDEX (BETA)      ,,       ,,    (PROP(I,10))=  0.1410E+01
POWER INDEX (GAMMA)     ,,       ,,    (PROP(I,11))=  0.2908E+00


TRANSPORT PROPERTIES OF POROUS MEDIA
-----------------------------------


MATERIAL NUMBER:    1  (I)

LONGITUDINAL DISPERSIVITY ALPHA-L ....(PROPJ(I,1)) =  0.2000E+01
TRANSVERSE DISPERSIVITY ALPHA-T ......(PROPJ(I,2)) =  0.2000E+01
MOLECULAR DIFFUSION COMPONENT D-XX....(PROPJ(I,3)) =  0.0000E+00
MOLECULAR DIFFUSION COMPONENT D-YY....(PROPJ(I,4)) =  0.0000E+00
EFFECTIVE POROSITY(0 FOR STEADY STATE)(PROPJ(I,5)) =  0.4100E+00
```

```
BULK DENSITY (g/cm**2) ...............(PROPJ(I,6)) =  0.1650E+01

MATERIAL NUMBER:    2  (I)

LONGITUDINAL DISPERSIVITY ALPHA-L ....(PROPJ(I,1)) =  0.2000E+01
TRANSVERSE DISPERSIVITY ALPHA-T ......(PROPJ(I,2)) =  0.2000E+01
MOLECULAR DIFFUSION COMPONENT D-XX....(PROPJ(I,3)) =  0.0000E+00
MOLECULAR DIFFUSION COMPONENT D-YY....(PROPJ(I,4)) =  0.0000E+00
EFFECTIVE POROSITY(0 FOR STEADY STATE)(PROPJ(I,5)) =  0.4300E+00
BULK DENSITY (g/cm**2) ...............(PROPJ(I,6)) =  0.1550E+01

MATERIAL NUMBER:    3  (I)

LONGITUDINAL DISPERSIVITY ALPHA-L ....(PROPJ(I,1)) =  0.2000E+01
TRANSVERSE DISPERSIVITY ALPHA-T ......(PROPJ(I,2)) =  0.2000E+01
MOLECULAR DIFFUSION COMPONENT D-XX....(PROPJ(I,3)) =  0.0000E+00
MOLECULAR DIFFUSION COMPONENT D-YY....(PROPJ(I,4)) =  0.0000E+00
EFFECTIVE POROSITY(0 FOR STEADY STATE)(PROPJ(I,5)) =  0.4500E+00
BULK DENSITY (g/cm**2) ...............(PROPJ(I,6)) =  0.1500E+01


SOLUTE PROPERTIES
-----------------

MATERIAL NUMBER:    1  (I)
DECAY COEFFICIENT ................... (RPROP(I,1)) =  0.0000E+00
DISTRIBUTION COEFFICIENT (cm**3/g)... (RPROP(I,2)) =  0.0000E+00

MATERIAL NUMBER:    2  (I)
DECAY COEFFICIENT ................... (RPROP(I,1)) =  0.0000E+00
DISTRIBUTION COEFFICIENT (cm**3/g)... (RPROP(I,2)) =  0.0000E+00

MATERIAL NUMBER:    3  (I)
DECAY COEFFICIENT ................... (RPROP(I,1)) =  0.0000E+00
DISTRIBUTION COEFFICIENT (cm**3/g)... (RPROP(I,2)) =  0.0000E+00


X-COORDINATES OF GRID LINES
--------------------------


        0.00       2.50       5.00       7.50      10.00      12.50      15.00      17.50
       20.00      22.50      25.00      30.00      35.00      40.00      45.00      50.00


Y-COORDINATES OF GRID LINES
--------------------------


        0.00      10.00      20.00      30.00      40.00      50.00      55.00      60.00
       65.00      70.00      75.00      80.00      85.00      90.00      95.00     100.00


BOUNDARY CONDITION DATA
-----------------------------------


NUMBER OF STEADY DIRICHLET BOUNDARIES ........ (NBTO) =   32
NUMBER OF STEADY FLUX BOUNDARIES ........... (NDFLUX) =    0
NUMBER OF TRANSIENT DIRICHLET BOUNDARIES.... (NBHVAR) =    0
NUMBER OF TRANSIENT FLUX BOUNDARIES.... .... (NBFVAR) =   16


DIRICHLET BOUNDARY CONDITION DATA
--------------------------------
```

INDEX	NODE NUMBER	DEP. VAR. #	PRESCRIBED VALUE
1	1	1	-100.0
2	17	1	-100.0
3	33	1	-100.0
4	49	1	-100.0
5	65	1	-100.0
6	81	1	-100.0
7	97	1	-100.0
8	113	1	-100.0
9	129	1	-100.0
10	145	1	-100.0
11	161	1	-100.0
12	177	1	-100.0
13	193	1	-100.0
14	209	1	-100.0
15	225	1	-100.0
16	241	1	-100.0
17	16	2	1.000
18	32	2	1.000
19	48	2	1.000
20	64	2	1.000
21	80	2	1.000
22	96	2	1.000
23	112	2	1.000
24	128	2	1.000
25	144	2	1.000
26	160	2	1.000
27	176	2	1.000
28	192	2	1.000
29	208	2	1.000
30	224	2	1.000
31	240	2	1.000
32	256	2	1.000

TIME DEPENDENT FLUX B. C. FOR
NODE # 16 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	12.50	2.000	10.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 32 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 48 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 64 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 80 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 96 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 112 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 128 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 144 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 160 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 176 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	37.50	2.000	30.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 192 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	50.00	2.000	40.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 208 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0

FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	50.00	2.000	40.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 224 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	50.00	2.000	40.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 240 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	50.00	2.000	40.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

TIME DEPENDENT FLUX B. C. FOR
NODE # 256 DEPENDENT VARIABLE # 1

NUMBER OF CONTROL POINTS IN THE TIME GRAPH = 6
TEMPORAL VARIATION (0=CONTINUOUS, 1=STEP) = 0
NODAL FLUX INTEGRATION INDEX (0=NO, 1=YES) = 0
FLUX DATA REPETITION INDEX (0=NO, 1=YES) = 0

TIME VERSUS PRESCRIBED WATER FLUXES

0.0000E+00	0.0000E+00	1.000	25.00	2.000	20.00
3.000	0.0000E+00	4.000	0.0000E+00	50.00	0.0000E+00

DEFAULT VALUES AND WEIGHTING FACTORS

```
DEFAULT VALUE OF X-VELOCITY .................(VCX) =  0.0000E+00
DEFAULT VALUE OF Y-VELOCITY .................(VCY) =  0.0000E+00
X-DIRECTION UPSTREAM WEIGHTING FACTOR ......(WFAC) =  0.0000E+00
Y-DIRECTION UPSTREAM WEIGHTING FACTOR ......(YFAC) =  0.0000E+00
DEFAULT WATER SATURATION ....................(SWD) =  0.0000E+00
STEADY-STATE VELOCITY FIELD (0=NO, 1=YES).(IVSTED) =    0
```

------- ACTUAL HALF BAND WIDTH = 17 FULL BANDWIDTH = 35 -------

LIST OF OBSERVATION NODES

62 126 150 174 222

+++++++++ BEGIN TRANSIENT CALCULATIONS ++++++++

**** ELAPSED SIMULATION TIME : 0.5000 TIME STEP NUMBER : 1 TIME STEP SIZE: 0.500E+00 ****

ITERATION	NUMBER OF NON-CONVERGENT NODES	MAXIMUM ERROR	NODE NUMBER	RELAXATION FACTOR
1	240	-42.40	64	1.00
2	176	4.444	256	0.932
3	0	0.2075	199	1.00

*** NODAL HEAD VALUES ***

NODE	HEAD VALUE	NODE	HEAD VALUE	NODE	HEAD VALUE	NODE	HEAD VALUE	NODE	HEAD VALUE
1	-100.0	2	-104.7	3	-109.1	4	-113.3	5	-117.2
6	-120.9	7	-122.6	8	-124.4	9	-126.1	10	-127.9
11	-129.8	12	-131.7	13	-133.8	14	-136.0	15	-137.0
16	-138.1	17	-100.0	18	-104.7	19	-109.1	20	-113.3
21	-117.2	22	-120.9	23	-122.6	24	-124.4	25	-126.1
26	-127.9	27	-129.8	28	-131.7	29	-133.8	30	-136.0
31	-137.0	32	-138.1	33	-100.0	34	-104.7	35	-109.1
36	-113.3	37	-117.2	38	-120.9	39	-122.6	40	-124.4
41	-126.1	42	-127.9	43	-129.8	44	-131.7	45	-133.8
46	-136.0	47	-137.0	48	-138.1	49	-100.0	50	-104.7

51	-109.1	52	-113.3	53	-117.2	54	-120.9	55	-122.6
56	-124.4	57	-126.1	58	-127.9	59	-129.8	60	-131.7
61	-133.8	62	-136.0	63	-137.0	64	-138.1	65	-100.0
66	-104.7	67	-109.1	68	-113.3	69	-117.2	70	-120.9
71	-122.6	72	-124.4	73	-126.1	74	-127.9	75	-129.8
76	-131.7	77	-133.8	78	-136.0	79	-137.0	80	-138.1
81	-100.0	82	-104.7	83	-109.1	84	-113.3	85	-117.2
86	-120.9	87	-122.6	88	-124.4	89	-126.1	90	-127.9
91	-129.8	92	-131.7	93	-133.8	94	-136.0	95	-137.0
96	-138.1	97	-100.0	98	-104.7	99	-109.1	100	-113.3
101	-117.2	102	-120.9	103	-122.6	104	-124.4	105	-126.1
106	-127.9	107	-129.8	108	-131.7	109	-133.8	110	-136.0
111	-137.0	112	-138.1	113	-100.0	114	-104.7	115	-109.1
116	-113.3	117	-117.2	118	-120.9	119	-122.6	120	-124.4
121	-126.1	122	-127.9	123	-129.8	124	-131.7	125	-133.8
126	-136.0	127	-137.0	128	-138.1	129	-100.0	130	-104.7
131	-109.1	132	-113.3	133	-117.2	134	-120.9	135	-122.6
136	-124.4	137	-126.1	138	-127.9	139	-129.8	140	-131.7
141	-133.8	142	-136.0	143	-137.0	144	-138.1	145	-100.0
146	-104.7	147	-109.1	148	-113.3	149	-117.2	150	-120.9
151	-122.6	152	-124.4	153	-126.1	154	-127.9	155	-129.8
156	-131.7	157	-133.8	158	-136.0	159	-137.0	160	-138.1
161	-100.0	162	-104.7	163	-109.1	164	-113.3	165	-117.2
166	-120.9	167	-122.6	168	-124.4	169	-126.1	170	-127.9
171	-129.8	172	-131.7	173	-133.8	174	-136.0	175	-137.0
176	-138.1	177	-100.0	178	-104.7	179	-109.1	180	-113.3
181	-117.2	182	-120.9	183	-122.6	184	-124.4	185	-126.1
186	-127.9	187	-129.8	188	-131.7	189	-133.8	190	-136.0
191	-137.0	192	-138.1	193	-100.0	194	-104.7	195	-109.1
196	-113.3	197	-117.2	198	-120.9	199	-122.6	200	-124.4
201	-126.1	202	-127.9	203	-129.8	204	-131.7	205	-133.8
206	-136.0	207	-137.0	208	-138.1	209	-100.0	210	-104.7
211	-109.1	212	-113.3	213	-117.2	214	-120.9	215	-122.6
216	-124.4	217	-126.1	218	-127.9	219	-129.8	220	-131.7
221	-133.8	222	-136.0	223	-137.0	224	-138.1	225	-100.0
226	-104.7	227	-109.1	228	-113.3	229	-117.2	230	-120.9
231	-122.6	232	-124.4	233	-126.1	234	-127.9	235	-129.8
236	-131.7	237	-133.8	238	-136.0	239	-137.0	240	-138.1
241	-100.0	242	-104.7	243	-109.1	244	-113.3	245	-117.2
246	-120.9	247	-122.6	248	-124.4	249	-126.1	250	-127.9
251	-129.8	252	-131.7	253	-133.8	254	-136.0	255	-137.0
256	-138.1								

*** LIST OF PARTIALLY SATURATED ELEMENTS ***

ELEM.	SAT. VALUE	ELEM.	SAT. VALUE	ELEM.	SAT. VALUE	ELEM.	SAT. VALUE	ELEM.	SAT. VALUE
1	0.0938	2	0.0918	3	0.0901	4	0.0887	5	0.0874
6	0.0866	7	0.0860	8	0.4616	9	0.4588	10	0.4560
11	0.4532	12	0.4502	13	0.4472	14	0.6475	15	0.6460
16	0.0938	17	0.0918	18	0.0901	19	0.0887	20	0.0874
21	0.0866	22	0.0860	23	0.4616	24	0.4588	25	0.4560
26	0.4532	27	0.4502	28	0.4472	29	0.6475	30	0.6460
31	0.0938	32	0.0918	33	0.0901	34	0.0887	35	0.0874
36	0.0866	37	0.0860	38	0.4616	39	0.4588	40	0.4560
41	0.4532	42	0.4502	43	0.4472	44	0.6475	45	0.6460
46	0.0938	47	0.0918	48	0.0901	49	0.0887	50	0.0874
51	0.0866	52	0.0860	53	0.4616	54	0.4588	55	0.4560
56	0.4532	57	0.4502	58	0.4472	59	0.6475	60	0.6460
61	0.0938	62	0.0918	63	0.0901	64	0.0887	65	0.0874
66	0.0866	67	0.0860	68	0.4616	69	0.4588	70	0.4560

71	0.4532	72	0.4502	73	0.4472	74	0.6475	75	0.6460
76	0.0938	77	0.0918	78	0.0901	79	0.0887	80	0.0874
81	0.0866	82	0.0860	83	0.4616	84	0.4588	85	0.4560
86	0.4532	87	0.4502	88	0.4472	89	0.6475	90	0.6460
91	0.0938	92	0.0918	93	0.0901	94	0.0887	95	0.0874
96	0.0866	97	0.0860	98	0.4616	99	0.4588	100	0.4560
101	0.4532	102	0.4502	103	0.4472	104	0.6475	105	0.6460
106	0.0938	107	0.0918	108	0.0901	109	0.0887	110	0.0874
111	0.0866	112	0.0860	113	0.4616	114	0.4588	115	0.4560
116	0.4532	117	0.4502	118	0.4472	119	0.6475	120	0.6460
121	0.0938	122	0.0918	123	0.0901	124	0.0887	125	0.0874
126	0.0866	127	0.0860	128	0.4616	129	0.4588	130	0.4560
131	0.4532	132	0.4502	133	0.4472	134	0.6475	135	0.6460
136	0.0938	137	0.0918	138	0.0901	139	0.0887	140	0.0874
141	0.0866	142	0.0860	143	0.4616	144	0.4588	145	0.4560
146	0.4532	147	0.4502	148	0.4472	149	0.6475	150	0.6460
151	0.0938	152	0.0918	153	0.0901	154	0.0887	155	0.0874
156	0.0866	157	0.0860	158	0.4616	159	0.4588	160	0.4560
161	0.4532	162	0.4502	163	0.4472	164	0.6475	165	0.6460
166	0.0938	167	0.0918	168	0.0901	169	0.0887	170	0.0874
171	0.0866	172	0.0860	173	0.4616	174	0.4588	175	0.4560
176	0.4532	177	0.4502	178	0.4472	179	0.6475	180	0.6460
181	0.0938	182	0.0918	183	0.0901	184	0.0887	185	0.0874
186	0.0866	187	0.0860	188	0.4616	189	0.4588	190	0.4560
191	0.4532	192	0.4502	193	0.4472	194	0.6475	195	0.6460
196	0.0938	197	0.0918	198	0.0901	199	0.0887	200	0.0874
201	0.0866	202	0.0860	203	0.4616	204	0.4588	205	0.4560
206	0.4532	207	0.4502	208	0.4472	209	0.6475	210	0.6460
211	0.0938	212	0.0918	213	0.0901	214	0.0887	215	0.0874
216	0.0866	217	0.0860	218	0.4616	219	0.4588	220	0.4560
221	0.4532	222	0.4502	223	0.4472	224	0.6475	225	0.6460

*** ELEMENTAL FLUID VELOCITY ***

ELEMENT	X-VELOCITY	Y-VELOCITY	ELEMENT	X-VELOCITY	Y-VELOCITY	ELEMENT	X-VELOCITY	Y-VELOCITY
1	9.834E-12	-7.16	2	1.395E-11	-7.15	3	1.327E-11	-7.12
4	1.268E-11	-7.08	5	1.622E-11	-7.03	6	1.970E-11	-6.98
7	1.934E-11	-6.94	8	1.515E-11	-6.82	9	1.316E-11	-6.62
10	1.680E-11	-6.40	11	1.852E-11	-6.17	12	1.103E-11	-5.93
13	1.458E-11	-5.68	14	1.222E-11	-5.41	15	1.219E-11	-5.14
16	9.834E-12	-7.16	17	1.860E-11	-7.15	18	0.000E+00	-7.12
19	-1.268E-11	-7.08	20	4.056E-12	-7.03	21	1.576E-11	-6.98
22	1.160E-11	-6.94	23	3.787E-12	-6.82	24	-5.640E-12	-6.62
25	-1.866E-12	-6.40	26	0.000E+00	-6.17	27	7.351E-12	-5.93
28	1.094E-11	-5.68	29	1.222E-11	-5.41	30	1.950E-11	-5.14
31	9.834E-12	-7.16	32	4.651E-12	-7.15	33	-1.770E-11	-7.12
34	-1.691E-11	-7.08	35	-4.056E-12	-7.03	36	-3.939E-12	-6.98
37	-1.160E-11	-6.94	38	-2.462E-11	-6.82	39	-3.008E-11	-6.62
40	-2.053E-11	-6.40	41	-7.409E-12	-6.17	42	-7.351E-12	-5.93
43	-7.291E-12	-5.68	44	0.000E+00	-5.41	45	7.312E-12	-5.14
46	0.000E+00	-7.16	47	-9.302E-12	-7.15	48	-3.097E-11	-7.12
49	-3.382E-11	-7.08	50	-2.839E-11	-7.03	51	-3.152E-11	-6.98
52	-3.094E-11	-6.94	53	-3.409E-11	-6.82	54	-3.384E-11	-6.62
55	-3.546E-11	-6.40	56	-3.704E-11	-6.17	57	-4.043E-11	-5.93
58	-3.645E-11	-5.68	59	-1.222E-11	-5.41	60	-2.437E-12	-5.14
61	-4.917E-12	-7.16	62	-2.791E-11	-7.15	63	-5.751E-11	-7.12
64	-5.918E-11	-7.08	65	-4.867E-11	-7.03	66	-5.121E-11	-6.98
67	-5.415E-11	-6.94	68	-5.492E-11	-6.82	69	-6.016E-11	-6.62
70	-6.346E-11	-6.40	71	-6.297E-11	-6.17	72	-5.513E-11	-5.93
73	-5.833E-11	-5.68	74	-3.177E-11	-5.41	75	-2.681E-11	-5.14

76	-1.475E-11	-7.16	77	-4.186E-11	-7.15	78	-7.078E-11	-7.12
79	-8.455E-11	-7.08	80	-7.706E-11	-7.03	81	-7.879E-11	-6.98
82	-8.897E-11	-6.94	83	-8.711E-11	-6.82	84	-7.333E-11	-6.62
85	-7.279E-11	-6.40	86	-7.779E-11	-6.17	87	-7.351E-11	-5.93
88	-7.291E-11	-5.68	89	-4.643E-11	-5.41	90	-4.875E-11	-5.14
91	-2.950E-11	-7.16	92	-6.046E-11	-7.15	93	-8.405E-11	-7.12
94	-1.015E-10	-7.08	95	-1.095E-10	-7.03	96	-1.103E-10	-6.98
97	-1.083E-10	-6.94	98	-1.098E-10	-6.82	99	-1.034E-10	-6.62
100	-9.518E-11	-6.40	101	-9.261E-11	-6.17	102	-9.556E-11	-5.93
103	-9.478E-11	-5.68	104	-7.087E-11	-5.41	105	-7.312E-11	-5.14
106	-2.950E-11	-7.16	107	-8.837E-11	-7.15	108	-1.106E-10	-7.12
109	-1.268E-10	-7.08	110	-1.419E-10	-7.03	111	-1.339E-10	-6.98
112	-1.354E-10	-6.94	113	-1.288E-10	-6.82	114	-1.335E-10	-6.62
115	-1.325E-10	-6.40	116	-1.185E-10	-6.17	117	-1.139E-10	-5.93
118	-1.203E-10	-5.68	119	-8.798E-11	-5.41	120	-8.531E-11	-5.14
121	-4.425E-11	-7.16	122	-1.209E-10	-7.15	123	-1.504E-10	-7.12
124	-1.606E-10	-7.08	125	-1.784E-10	-7.03	126	-1.773E-10	-6.98
127	-1.547E-10	-6.94	128	-1.534E-10	-6.82	129	-1.561E-10	-6.62
130	-1.512E-10	-6.40	131	-1.519E-10	-6.17	132	-1.544E-10	-5.93
133	-1.531E-10	-5.68	134	-1.026E-10	-5.41	135	-1.146E-10	-5.14
136	-5.900E-11	-7.16	137	-1.349E-10	-7.15	138	-1.814E-10	-7.12
139	-2.029E-10	-7.08	140	-2.149E-10	-7.03	141	-2.049E-10	-6.98
142	-1.779E-10	-6.94	143	-1.629E-10	-6.82	144	-1.617E-10	-6.62
145	-1.642E-10	-6.40	146	-1.667E-10	-6.17	147	-1.691E-10	-5.93
148	-1.640E-10	-5.68	149	-1.197E-10	-5.41	150	-1.365E-10	-5.14
151	-4.671E-11	-7.16	152	-1.209E-10	-7.15	153	-1.637E-10	-7.12
154	-1.860E-10	-7.08	155	-1.926E-10	-7.03	156	-1.871E-10	-6.98
157	-1.818E-10	-6.94	158	-1.742E-10	-6.82	159	-1.702E-10	-6.62
160	-1.708E-10	-6.40	161	-1.741E-10	-6.17	162	-1.764E-10	-5.93
163	-1.732E-10	-5.68	164	-1.185E-10	-5.41	165	-1.182E-10	-5.14
166	-3.442E-11	-7.16	167	-9.070E-11	-7.15	168	-1.217E-10	-7.12
169	-1.395E-10	-7.08	170	-1.480E-10	-7.03	171	-1.477E-10	-6.98
172	-1.431E-10	-6.94	173	-1.392E-10	-6.82	174	-1.401E-10	-6.62
175	-1.418E-10	-6.40	176	-1.408E-10	-6.17	177	-1.341E-10	-5.93
178	-1.349E-10	-5.68	179	-9.164E-11	-5.41	180	-8.775E-11	-5.14
181	-2.950E-11	-7.16	182	-6.279E-11	-7.15	183	-8.405E-11	-7.12
184	-9.723E-11	-7.08	185	-9.733E-11	-7.03	186	-9.849E-11	-6.98
187	-1.006E-10	-6.94	188	-9.942E-11	-6.82	189	-1.015E-10	-6.62
190	-1.026E-10	-6.40	191	-1.000E-10	-6.17	192	-9.556E-11	-5.93
193	-9.114E-11	-5.68	194	-5.987E-11	-5.41	195	-5.850E-11	-5.14
196	-1.229E-11	-7.16	197	-3.721E-11	-7.15	198	-4.866E-11	-7.12
199	-5.496E-11	-7.08	200	-6.083E-11	-7.03	201	-6.106E-11	-6.98
202	-6.189E-11	-6.94	203	-6.344E-11	-6.82	204	-6.205E-11	-6.62
205	-5.599E-11	-6.40	206	-5.927E-11	-6.17	207	-6.432E-11	-5.93
208	-6.380E-11	-5.68	209	-4.032E-11	-5.41	210	-3.900E-11	-5.14
211	-9.834E-12	-7.16	212	-1.860E-11	-7.15	213	-1.991E-11	-7.12
214	-1.691E-11	-7.08	215	-2.231E-11	-7.03	216	-2.758E-11	-6.98
217	-2.708E-11	-6.94	218	-2.651E-11	-6.82	219	-2.726E-11	-6.62
220	-2.706E-11	-6.40	221	-2.593E-11	-6.17	222	-3.124E-11	-5.93
223	-3.281E-11	-5.68	224	-2.444E-11	-5.41	225	-2.559E-11	-5.14

FLOW ANALYSIS IS COMPLETED FOR TARGET TIME STEP NO. 1 NUMBER OF COMPUTATIONAL TIME STEPS PERFORMED = 1

**** ELAPSED SIMULATION TIME : 0.5000 TIME STEP NUMBER : 1 TIME STEP SIZE: 0.500E+00 ****

***** NODAL CONCENTRATION VALUES *****

NODE	CONC. VALUE	NODE	CONC. VALUE	NODE	CONC. VALUE	NODE	CONC. VALUE	NODE	CONC. VALUE
1	4.5372E-02	2	4.8945E-02	3	5.4916E-02	4	6.0558E-02	5	6.7108E-02
6	7.4142E-02	7	7.8010E-02	8	8.1996E-02	9	9.7980E-02	10	0.1296
11	0.1707	12	0.2269	13	0.3042	14	0.4119	15	0.6172
16	1.000	17	4.5372E-02	18	4.8945E-02	19	5.4916E-02	20	6.0558E-02
21	6.7108E-02	22	7.4142E-02	23	7.8010E-02	24	8.1996E-02	25	9.7980E-02
26	0.1296	27	0.1707	28	0.2269	29	0.3042	30	0.4119
31	0.6172	32	1.000	33	4.5372E-02	34	4.8945E-02	35	5.4916E-02
36	6.0558E-02	37	6.7108E-02	38	7.4142E-02	39	7.8010E-02	40	8.1996E-02
41	9.7980E-02	42	0.1296	43	0.1707	44	0.2269	45	0.3042
46	0.4119	47	0.6172	48	1.000	49	4.5372E-02	50	4.8945E-02
51	5.4916E-02	52	6.0558E-02	53	6.7108E-02	54	7.4142E-02	55	7.8010E-02
56	8.1996E-02	57	9.7980E-02	58	0.1296	59	0.1707	60	0.2269
61	0.3042	62	0.4119	63	0.6172	64	1.000	65	4.5372E-02
66	4.8945E-02	67	5.4916E-02	68	6.0558E-02	69	6.7108E-02	70	7.4142E-02
71	7.8010E-02	72	8.1996E-02	73	9.7980E-02	74	0.1296	75	0.1707
76	0.2269	77	0.3042	78	0.4119	79	0.6172	80	1.000
81	4.5372E-02	82	4.8945E-02	83	5.4916E-02	84	6.0558E-02	85	6.7108E-02
86	7.4142E-02	87	7.8010E-02	88	8.1996E-02	89	9.7980E-02	90	0.1296
91	0.1707	92	0.2269	93	0.3042	94	0.4119	95	0.6172
96	1.000	97	4.5372E-02	98	4.8945E-02	99	5.4916E-02	100	6.0558E-02
101	6.7108E-02	102	7.4142E-02	103	7.8010E-02	104	8.1996E-02	105	9.7980E-02
106	0.1296	107	0.1707	108	0.2269	109	0.3042	110	0.4119
111	0.6172	112	1.000	113	4.5372E-02	114	4.8945E-02	115	5.4916E-02
116	6.0558E-02	117	6.7108E-02	118	7.4142E-02	119	7.8010E-02	120	8.1996E-02
121	9.7980E-02	122	0.1296	123	0.1707	124	0.2269	125	0.3042
126	0.4119	127	0.6172	128	1.000	129	4.5372E-02	130	4.8945E-02
131	5.4916E-02	132	6.0558E-02	133	6.7108E-02	134	7.4142E-02	135	7.8010E-02
136	8.1996E-02	137	9.7980E-02	138	0.1296	139	0.1707	140	0.2269
141	0.3042	142	0.4119	143	0.6172	144	1.000	145	4.5372E-02
146	4.8945E-02	147	5.4916E-02	148	6.0558E-02	149	6.7108E-02	150	7.4142E-02
151	7.8010E-02	152	8.1996E-02	153	9.7980E-02	154	0.1296	155	0.1707
156	0.2269	157	0.3042	158	0.4119	159	0.6172	160	1.000
161	4.5372E-02	162	4.8945E-02	163	5.4916E-02	164	6.0558E-02	165	6.7108E-02
166	7.4142E-02	167	7.8010E-02	168	8.1996E-02	169	9.7980E-02	170	0.1296
171	0.1707	172	0.2269	173	0.3042	174	0.4119	175	0.6172
176	1.000	177	4.5372E-02	178	4.8945E-02	179	5.4916E-02	180	6.0558E-02
181	6.7108E-02	182	7.4142E-02	183	7.8010E-02	184	8.1996E-02	185	9.7980E-02
186	0.1296	187	0.1707	188	0.2269	189	0.3042	190	0.4119
191	0.6172	192	1.000	193	4.5372E-02	194	4.8945E-02	195	5.4916E-02
196	6.0558E-02	197	6.7108E-02	198	7.4142E-02	199	7.8010E-02	200	8.1996E-02
201	9.7980E-02	202	0.1296	203	0.1707	204	0.2269	205	0.3042
206	0.4119	207	0.6172	208	1.000	209	4.5372E-02	210	4.8945E-02
211	5.4916E-02	212	6.0558E-02	213	6.7108E-02	214	7.4142E-02	215	7.8010E-02
216	8.1996E-02	217	9.7980E-02	218	0.1296	219	0.1707	220	0.2269
221	0.3042	222	0.4119	223	0.6172	224	1.000	225	4.5372E-02
226	4.8945E-02	227	5.4916E-02	228	6.0558E-02	229	6.7108E-02	230	7.4142E-02
231	7.8010E-02	232	8.1996E-02	233	9.7980E-02	234	0.1296	235	0.1707
236	0.2269	237	0.3042	238	0.4119	239	0.6172	240	1.000
241	4.5372E-02	242	4.8945E-02	243	5.4916E-02	244	6.0558E-02	245	6.7108E-02
246	7.4142E-02	247	7.8010E-02	248	8.1996E-02	249	9.7980E-02	250	0.1296
251	0.1707	252	0.2269	253	0.3042	254	0.4119	255	0.6172
256	1.000								

10.5 PROBLEM 4: MULTI-COMPONENT TRANSPORT SIMULATION

10.5.1 Input Data

The input data file for this sample multi-component transport problem is presented in Table 10.7. Note that the modeling option parameters IMODL and ICHAIN are set to 0 and 1, respectively. This indicates that chain decay transport simulation is required. Solute transport parameters for multi-specie simulation are specified via record group 11c. The input data also includes the specification of two decaying source node boundary conditions and source characteristics via record groups 15 and 17.

Table 10.7. Input data for the multi-component 1-D transport problem.

```
   1                                                                            GROUP1
ONE DIMENSIONAL TRANSPORT OF A THREE-MEMBER STRAIGHT CHAIN                      GROUP2
   0    0    0    0    1    0    1   15   42   20    0    0    1    0           GROUP3
   0    0    1    0    0       0.0       1.0    0    0                         GROUP4
   0    0    0    0    0    0    0    1    1    1    0    0                     GROUP5
      0.0       18.2       1.0       18.2                                       GROUP6A
      0.0        0.0                                                            GROUP7
      8.5        8.5       0.0        0.0        0.1       2.34                 GROUP11A
   3    1                                                                       GROUP11C
   1
   1    3    1    2    3
   1    0
   2    1
   1       1.0
   3    1
   2       1.0
   1    0
  0.16E-2   4.62E-2   1.06E-4
   4.00E2    4.00E2    4.00E2
   2   21       32.8       2.0    0                                              GROUP12
     32.8        2.0     656.0       2.0        1.0        1.0        0.0        0.0 GROUP14
   0    0    0    0    2                                                         GROUP15A
   1                                                                             GROUP17A
   1    1.0E06
  0.16E-2   4.62E-2   1.06E-4
   1    1    2    239.4                                                          GROUP17B
    239.4        0.0       0.0
   2    1    2    239.4
    239.4        0.0       0.0
    239.4        0.0      0.10       0.0        1.0    1                         GROUP19
   4                                                                             GROUP23A
   1    2   41   42                                                              GROUP23B
    239.4      239.4    -239.4    -239.4                                         GROUP23C
   3                                                                             GROUP27
  19   19   19
   1    2    3
```

10.5.2 Sample Output

Output of the transport calculation is displayed in Table 10.8. This output consists of the following categories of information:

1. Brief summary of control input parameters and material properties
2. Mesh data
3. Boundary condition data
4. Decaying source data and related boundary conditions
5. Element numbers and centroidal coordinates
6. List of observation nodes and monitored specie component numbers
7. Mass balance summary for each specie component
8. Concentration values for each specie component.

Table 10.8. Sample output for the multi-component 1-D transport problem.

```
********************************************************************************

                         THIS OUTPUT GENERATED BY VAM2D-5.0
                         INPUT FILE NAME = CHNPR1.DAT

********************************************************************************


NUMBER OF PROBLEMS TO BE SOLVED =  1


PROBLEM NUMBER:  1


PROBLEM TITLE
--------------------------------------------------------------------------------

ONE DIMENSIONAL TRANSPORT OF A THREE-MEMBER STRAIGHT CHAIN

--------------------------------------------------------------------------------



PROBLEM SPECIFICATION PARAMETERS
--------------------------------
MODEL OPTION PARAMETER ....................(IMODL) =     0
  NOTE:  IMODL = 0 FOR SOLUTE TRANSPORT ONLY
               = 1 FOR WATER FLOW ONLY
               = 2 FOR COUPLED FLOW AND TRANSPORT
HYSTERETIC SOIL MOISTURE (1=YES, 0=NO)....(IHYST) =     0
ANISOTROPIC REL. COND.(1=YES, 0=NO)........(IANI) =     0
CONVERT INITIAL HEAD VALUES(1=YES, 0=NO).(INTSPC) =     0
CHAIN-DECAY REACTIONS(1=YES, 0=NO).......(ICHAIN) =     1
STEADY STATE SIMULATION(1=YES, 0=NO)......(ISSTA) =     0
TIME STEP GENERATION INDEX (1=YES, 0=NO) .(ITSGN) =     1
NUMBER OF TIME STEPS ........................(NTS) =    15
TOTAL NUMBER OF NODES ........................(NP) =    42
TOTAL NUMBER OF ELEMENTS .....................(NE) =    20
SEQUENTIAL NUMBERING INDEX (0=Y, 1=X-DIR) (ISWAP) =     0
AXISYMMETRIC SIMULATION(1=YES, 0=NO).....(IAXSYM) =     0
NUMBER OF POROUS MATRIX MATERIALS .........(NMAT) =     1
INITIAL CONDITION NON-UNIFORMITY INDEX.....(NONU) =     0
NUMBER OF INFIL./EVAP. ELEMENTS .........(NEIEVP) =     0
NUMBER PLANT SPECIES ....................(NPLANT) =     0


TIME STEPPING AND ITERATION CONTROL PARAMETERS
----------------------------------------------
TIME STEPPING INDEX (0=CNTRL, 1=BCKWD) ...(IKALL) =     0
TYPE OF ITERATION SCHEME (1=NEWT,0=PICARD)(INEWT) =     0
MAXIMUM NON-LINEAR ITERATIONS ...........(NITMAX) =     1
MAXIMUM NUMBER OF TIME STEP REFINEMENTS .(IRESOL) =     0
LUMPING OF ELEMENT MATRIX (1=YES, 0=NO) ..(ILUMP) =     0


INPUT / OUTPUT CONTROL PARAMETERS
--------------------------------
```

```
VELOCITY/SATURATION INPUT................(NVREAD) =    0
BOUNDARY NODE DATA READ (1=YES, 0=NO)....(IOUTLT) =    0
NUMBER OF NODES FOR WHICH I.C. ARE READ....(NPIN) =    0
OUTPUT REQUIREMENT INDICATOR:
 (0=ALL DATA, 1=NO ELEMENT DATA,
  2=NO DATA, 3=NO MESH AND I.C. DATA.......(IPRD) =    0
UNIT 9 OUTPUT OF VEL / SAT (1=YES, 0=NO).(NVWRIT) =    0
VELOCITY PRINTOUT CONTROL INDEX............(NVPR) =    0
UNIT 10 OUTPUT HEAD/CONC. (0=NONE, N=NTH).(NPLOT) =    0
NODAL VALUE PRINTOUT CONTROL INDEX........(NSTEP) =    1
OBSERVATION NODE INDEX...................(IOBSND) =    1
MASS BALANCE TO BE PERFORMED (1=YES,0=NO).(IMBAL) =    1
UNIT 8 OUTPUT OF HEAD/CONC (1=YES, 0=NO).(NOWRIT) =    0
PRINT CHECK OPTION INDEX.................(IPRCHK) =    0


TEMPORAL DISCRETIZATION DATA
----------------------------
INITIAL TIME VALUE ........................ (TIMA) =  0.0000E+00
VALUE OF FIRST TIME STEP .................. (TIN) =  0.1820E+02
TIME STEP MULTIPLIER ...................... (TFAC) =  0.1000E+01
MAXIMUM TIME STEP SIZE .................... (TMAX) =  0.1820E+02


*** LIST OF GENERATED TIME VALUES ***
-------------------------------------

0.182E+02 0.364E+02 0.546E+02 0.728E+02 0.910E+02 0.109E+03 0.127E+03 0.146E+03
0.164E+03 0.182E+03 0.200E+03 0.218E+03 0.237E+03 0.255E+03 0.273E+03

DEFAULT INITIAL CONCENTRATION VALUE
-----------------------------------

          0.0000E+00


TRANSPORT PROPERTIES OF POROUS MEDIA
------------------------------------


MATERIAL NUMBER:    1  (I)

LONGITUDINAL DISPERSIVITY ALPHA-L ....(PROPJ(I,1)) =  0.8500E+01
TRANSVERSE DISPERSIVITY ALPHA-T ......(PROPJ(I,2)) =  0.8500E+01
MOLECULAR DIFFUSION COMPONENT D-XX....(PROPJ(I,3)) =  0.0000E+00
MOLECULAR DIFFUSION COMPONENT D-YY....(PROPJ(I,4)) =  0.0000E+00
EFFECTIVE POROSITY(0 FOR STEADY STATE)(PROPJ(I,5)) =  0.1000E+00
BULK DENSITY (g/cm**2) ...............(PROPJ(I,6)) =  0.2340E+01


SOLUTE DATA FOR DECAY CHAIN MODELING
------------------------------------

NUMBER SPECIES COMPONENTS ........................ =    3

DECAYING SOURCE BOUNDARY CONDITION INDEX ......... =    1

REACTION PATH DATA
------------------
     NUMBER OF DECAY CHAINS OR REACTION PATHS ......... =    1

     REACTION PATH NUMBER ............................. =    1
     NUMBER OF COMPONENTS IN THE PATH ................. =    3

     LIST OF COMPONENT NUMBERS
```

----

1 2 3

SPECIES TRANSFORMATION DATA

SPECIES COMPONENT NUMBER .... = 1
NUMBER OF IMMEDIATE PARENTS .... = 0

SPECIES TRANSFORMATION DATA

SPECIES COMPONENT NUMBER .... = 2
NUMBER OF IMMEDIATE PARENTS .... = 1

LIST OF PARENT-SPECIES COMPONENT NUMBER AND TRANS. MASS FRACTION

1 0.100E+01

SPECIES TRANSFORMATION DATA

SPECIES COMPONENT NUMBER .... = 3
NUMBER OF IMMEDIATE PARENTS .... = 1

LIST OF PARENT-SPECIES COMPONENT NUMBER AND TRANS. MASS FRACTION

2 0.100E+01

DECAY AND DISTRIBUTION COEFF. DATA

SOIL MATERIAL NUMBER .... = 1

SOLUTE SPECIES COMPONENT NUMBER .... = 1
DECAY COEFFICIENT VALUE .... = 0.160E-02
DISTRIBUTION COEFFICIENT VALUE .... = 0.400E+03

SOLUTE SPECIES COMPONENT NUMBER .... = 2
DECAY COEFFICIENT VALUE .... = 0.462E-01
DISTRIBUTION COEFFICIENT VALUE .... = 0.400E+03

SOLUTE SPECIES COMPONENT NUMBER .... = 3
DECAY COEFFICIENT VALUE .... = 0.106E-03
DISTRIBUTION COEFFICIENT VALUE .... = 0.400E+03

*** FINITE-ELEMENT MESH CONNECTIONS ***

(NUMBERING IS COUNTER-CLOCKWISE)

ELEMENT	NODE NUMBERING				ELEMENT	NODE NUMBERING				ELEMENT	NODE NUMBERING			
1	1	3	4	2	2	3	5	6	4	3	5	7	8	6
4	7	9	10	8	5	9	11	12	10	6	11	13	14	12
7	13	15	16	14	8	15	17	18	16	9	17	19	20	18
10	19	21	22	20	11	21	23	24	22	12	23	25	26	24
13	25	27	28	26	14	27	29	30	28	15	29	31	32	30
16	31	33	34	32	17	33	35	36	34	18	35	37	38	36

19	37	39	40	38		20	39	41	42	40

*** NODAL COORDINATES ***

NODE	X-COOR.	Y-COOR.	NODE	X-COOR.	Y-COOR.	NODE	X-COOR.	Y-COOR.
1	0.00	0.00	2	0.00	2.00	3	32.80	0.00
4	32.80	2.00	5	65.60	0.00	6	65.60	2.00
7	98.40	0.00	8	98.40	2.00	9	131.20	0.00
10	131.20	2.00	11	164.00	0.00	12	164.00	2.00
13	196.80	0.00	14	196.80	2.00	15	229.60	0.00
16	229.60	2.00	17	262.40	0.00	18	262.40	2.00
19	295.20	0.00	20	295.20	2.00	21	328.00	0.00
22	328.00	2.00	23	360.80	0.00	24	360.80	2.00
25	393.60	0.00	26	393.60	2.00	27	426.40	0.00
28	426.40	2.00	29	459.20	0.00	30	459.20	2.00
31	492.00	0.00	32	492.00	2.00	33	524.80	0.00
34	524.80	2.00	35	557.60	0.00	36	557.60	2.00
37	590.40	0.00	38	590.40	2.00	39	623.20	0.00
40	623.20	2.00	41	656.00	0.00	42	656.00	2.00

BOUNDARY CONDITION DATA

NUMBER OF STEADY DIRICHLET BOUNDARIES .... (NBTO) = 0
NUMBER OF STEADY FLUX BOUNDARIES .... (NDFLUX) = 0
NUMBER OF TRANSIENT DIRICHLET BOUNDARIES.... (NBHVAR) = 0
NUMBER OF TRANSIENT FLUX BOUNDARIES.... .... (NBFVAR) = 0

NUMBER OF DECAYING SOURCE BOUNDARY NODES .... = 2

DECAYING SOURCE DATA

SOURCE IDENTIFICATION NUMBER 1

LEACH TIME DURATION .... = 0.100E+07

DECAY COEFFICIENT FOR SPECIES COMPONENT 1 = 0.160E-02

DECAY COEFFICIENT FOR SPECIES COMPONENT 2 = 0.462E-01

DECAY COEFFICIENT FOR SPECIES COMPONENT 3 = 0.106E-03

SOURCE NODE BOUNDARY CONDITIONS

NODE NUMBER = 1 SOURCE I.D. NUMBER = 1
BOUNDARY CONDITION INDEX = 2 NET FLUID FLUX = 0.239E+03
LIST OF PRESCRIBED SOLUTE MASS FLUX FOR COMPONENTS 1 TO NSPECI

0.239E+03 0.000E+00 0.000E+00

NODE NUMBER = 2 SOURCE I.D. NUMBER = 1
BOUNDARY CONDITION INDEX = 2 NET FLUID FLUX = 0.239E+03
LIST OF PRESCRIBED SOLUTE MASS FLUX FOR COMPONENTS 1 TO NSPECI

0.239E+03 0.000E+00 0.000E+00

DEFAULT VALUES AND WEIGHTING FACTORS

DEFAULT VALUE OF X-VELOCITY ....(VCX) = 0.2394E+03
DEFAULT VALUE OF Y-VELOCITY ....(VCY) = 0.0000E+00
X-DIRECTION UPSTREAM WEIGHTING FACTOR ......(WFAC) = 0.1000E+00
Y-DIRECTION UPSTREAM WEIGHTING FACTOR ......(YFAC) = 0.0000E+00
DEFAULT WATER SATURATION ....(SWD) = 0.1000E+01
STEADY-STATE VELOCITY FIELD (0=NO, 1=YES).(IVSTED) = 1

LIST OF BOUNDARY NODE NUMBERS
----

1 2 41 42

BOUNDARY NODAL DATA

NODE	FLUID FLOW RATE
1	239.4
2	239.4
41	-239.4
42	-239.4

------- ACTUAL HALF BAND WIDTH = 3 FULL BANDWIDTH = 7 -------

*** ELEMENT CENTROIDAL COORDINATES ***

ELEMENT	X-COOR.	Y-COOR.	ELEMENT	X-COOR.	Y-COOR.	ELEMENT	X-COOR.	Y-COOR.
1	16.40	1.00	2	49.20	1.00	3	82.00	1.00
4	114.80	1.00	5	147.60	1.00	6	180.40	1.00
7	213.20	1.00	8	246.00	1.00	9	278.80	1.00
10	311.60	1.00	11	344.40	1.00	12	377.20	1.00
13	410.00	1.00	14	442.80	1.00	15	475.60	1.00
16	508.40	1.00	17	541.20	1.00	18	574.00	1.00
19	606.80	1.00	20	639.60	1.00			

LIST OF OBSERVATION NODES
----

19 19 19

LIST OF SELECTED DEPENDENT VARIABLES
----

1 2 3

+++++++++ BEGIN TRANSIENT CALCULATIONS ++++++++

****	ELAPSED SIMULATION TIME :	18.20	TIME STEP NUMBER :	1	TIME STEP SIZE: 0.182E+02	****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	162.7	2	162.7	41	0.0000E+00	42	-1.8489E-32		

SUM OF ABOVE FLUX VALUES = 325.44

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	325.44
TOTAL ADVECTIVE FLUX RATE	153.36
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	478.80
RATE OF MASS DECAY AND TRANSFORMATION	13.548
NET RATE OF MATERIAL ACCUMULATION	478.80
MASS BALANCE ERROR	9.14089E-06
NORMALIZED MASS BALANCE ERROR	9.54563E-09
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	8467.6
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	246.58

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	-0.9527	2	-0.9527	41	-1.3333E-28	42	-5.4371E-28		

SUM OF ABOVE FLUX VALUES = -1.9054

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	-1.9054
TOTAL ADVECTIVE FLUX RATE	1.9054
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	-7.21911E-12
RATE OF MASS DECAY AND TRANSFORMATION	-7.3598
NET RATE OF MATERIAL ACCUMULATION	-1.13570E-07
MASS BALANCE ERROR	1.13563E-07
NORMALIZED MASS BALANCE ERROR	2.98011E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	8601.5
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	112.63

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	-0.5339	2	-0.5339	41	-1.8933E-28	42	-9.4663E-29		

SUM OF ABOVE FLUX VALUES = -1.0678

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	-1.0678
TOTAL ADVECTIVE FLUX RATE	1.0678
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	-2.84217E-13
RATE OF MASS DECAY AND TRANSFORMATION	-6.1765
NET RATE OF MATERIAL ACCUMULATION	-6.36425E-08
MASS BALANCE ERROR	6.36422E-08
NORMALIZED MASS BALANCE ERROR	2.98002E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE 8713.9
CUMULATIVE MASS DECAY AND TRANSFORMATION..................... 0.21686

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.3203	2	0.3203	3	-2.3928E-02	4	-2.3928E-02	5	1.7875E-03
6	1.7875E-03	7	-1.3353E-04	8	-1.3353E-04	9	9.9747E-06	10	9.9747E-06
11	-7.4513E-07	12	-7.4513E-07	13	5.5663E-08	14	5.5663E-08	15	-4.1581E-09
16	-4.1581E-09	17	3.1062E-10	18	3.1062E-10	19	-2.3204E-11	20	-2.3204E-11
21	1.7334E-12	22	1.7334E-12	23	-1.2949E-13	24	-1.2949E-13	25	9.6731E-15
26	9.6731E-15	27	-7.2260E-16	28	-7.2260E-16	29	5.3980E-17	30	5.3980E-17
31	-4.0324E-18	32	-4.0324E-18	33	3.0123E-19	34	3.0123E-19	35	-2.2502E-20
36	-2.2503E-20	37	1.6814E-21	38	1.6815E-21	39	-1.2723E-22	40	-1.2725E-22
41	1.5749E-23	42	1.5763E-23						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	3.9794E-03	2	3.9794E-03	3	2.8226E-04	4	2.8226E-04	5	-1.0909E-04
6	-1.0909E-04	7	2.1513E-05	8	2.1513E-05	9	-3.6364E-06	10	-3.6364E-06
11	5.7982E-07	12	5.7982E-07	13	-9.0111E-08	14	-9.0111E-08	15	1.3838E-08
16	1.3838E-08	17	-2.1128E-09	18	-2.1128E-09	19	3.2171E-10	20	3.2171E-10
21	-4.8917E-11	22	-4.8917E-11	23	7.4330E-12	24	7.4330E-12	25	-1.1291E-12
26	-1.1291E-12	27	1.7149E-13	28	1.7149E-13	29	-2.6043E-14	30	-2.6043E-14
31	3.9549E-15	32	3.9549E-15	33	-6.0058E-16	34	-6.0058E-16	35	9.1206E-17
36	9.1206E-17	37	-1.3867E-17	38	-1.3867E-17	39	2.1698E-18	40	2.1698E-18
41	-5.7186E-19	42	-5.7186E-19						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	2.2302E-03	2	2.2302E-03	3	7.9356E-04	4	7.9356E-04	5	-7.9407E-05
6	-7.9407E-05	7	1.5303E-07	8	1.5303E-07	9	1.4872E-06	10	1.4872E-06
11	-3.8234E-07	12	-3.8234E-07	13	7.2820E-08	14	7.2820E-08	15	-1.2376E-08
16	-1.2376E-08	17	1.9931E-09	18	1.9931E-09	19	-3.1222E-10	20	-3.1222E-10
21	4.8200E-11	22	4.8200E-11	23	-7.3837E-12	24	-7.3837E-12	25	1.1264E-12
26	1.1264E-12	27	-1.7146E-13	28	-1.7146E-13	29	2.6070E-14	30	2.6070E-14
31	-3.9614E-15	32	-3.9614E-15	33	6.0176E-16	34	6.0176E-16	35	-9.1401E-17
36	-9.1401E-17	37	1.3898E-17	38	1.3898E-17	39	-2.1747E-18	40	-2.1747E-18
41	5.7317E-19	42	5.7317E-19						

**** ELAPSED SIMULATION TIME : 36.40 TIME STEP NUMBER : 2 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	107.3	2	107.3	41	-4.5593E-26	42	-5.7355E-26		

```
.......................................
SUM OF ABOVE FLUX VALUES =  214.70
.......................................


SPECIES COMPONENT NUMBER     1
-----------------------


*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***
--------------------------------------------------------

TOTAL DISPERSIVE FLUX RATE ..................................        214.70
TOTAL ADVECTIVE FLUX RATE ...................................        201.86
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE ......................        416.56
RATE OF MASS DECAY AND TRANSFORMATION .......................        19.332
NET RATE OF MATERIAL ACCUMULATION ...........................        416.56
MASS BALANCE ERROR ..........................................        1.20316E-05
NORMALIZED MASS BALANCE ERROR ...............................        1.44416E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE .......        0.00000E+00


*** CUMULATIVE MASS BALANCE RESULTS ***
---------------------------------------

CUMULATIVE MATERIAL STORAGE .................................        15944.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................        352.06



     *** NODAL DISPERSIVE FLUX VALUES ***
     ------------------------------------

NODE    DISP. FLUX     NODE    DISP. FLUX     NODE    DISP. FLUX     NODE    DISP. FLUX     NODE    DISP. FLUX
----   -----------     ----   -----------     ----   -----------     ----   -----------     ----   -----------

  1      1.632           2      1.632          41    -1.8188E-26      42    -5.3138E-27

.......................................
SUM OF ABOVE FLUX VALUES =  3.2632
.......................................


SPECIES COMPONENT NUMBER     2
-----------------------


*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***
--------------------------------------------------------

TOTAL DISPERSIVE FLUX RATE ..................................        3.2632
TOTAL ADVECTIVE FLUX RATE ...................................        3.9583
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE ......................        7.2216
RATE OF MASS DECAY AND TRANSFORMATION .......................        -7.1157
NET RATE OF MATERIAL ACCUMULATION ...........................        7.2216
MASS BALANCE ERROR ..........................................        2.35930E-07
NORMALIZED MASS BALANCE ERROR ...............................        1.63350E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE .......        0.00000E+00
```

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	16204.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	222.55

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	3.2711E-02	2	3.2711E-02	41	-6.2604E-27	42	-3.2716E-26		

SUM OF ABOVE FLUX VALUES = 6.54220E-02

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	6.54220E-02
TOTAL ADVECTIVE FLUX RATE	2.7332
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	2.7986
RATE OF MASS DECAY AND TRANSFORMATION	-12.190
NET RATE OF MATERIAL ACCUMULATION	2.7986
MASS BALANCE ERROR	1.62903E-07
NORMALIZED MASS BALANCE ERROR	2.91045E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	16477.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	0.69686

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.5229	2	0.5229	3	-9.5629E-04	4	-9.5629E-04	5	-6.0898E-03
6	-6.0898E-03	7	1.4511E-03	8	1.4511E-03	9	-2.6948E-04	10	-2.6948E-04
11	4.6176E-05	12	4.6176E-05	13	-7.6607E-06	14	-7.6607E-06	15	1.2532E-06
16	1.2532E-06	17	-2.0371E-07	18	-2.0371E-07	19	3.3020E-08	20	3.3020E-08
21	-5.3451E-09	22	-5.3451E-09	23	8.6471E-10	24	8.6471E-10	25	-1.3985E-10
26	-1.3985E-10	27	2.2615E-11	28	2.2615E-11	29	-3.6568E-12	30	-3.6568E-12
31	5.9129E-13	32	5.9129E-13	33	-9.5608E-14	34	-9.5608E-14	35	1.5460E-14
36	1.5460E-14	37	-2.5033E-15	38	-2.5033E-15	39	4.1809E-16	40	4.1809E-16
41	-1.1803E-16	42	-1.1803E-16						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	1.2555E-02	2	1.2555E-02	3	2.8283E-04	4	2.8283E-04	5	-1.4782E-04
6	-1.4782E-04	7	1.8745E-05	8	1.8745E-05	9	-3.1469E-07	10	-3.1469E-07
11	-5.8010E-07	12	-5.8010E-07	13	2.2003E-07	14	2.2003E-07	15	-5.9695E-08
16	-5.9695E-08	17	1.4194E-08	18	1.4194E-08	19	-3.1471E-09	20	-3.1471E-09
21	6.6880E-10	22	6.6880E-10	23	-1.3821E-10	24	-1.3821E-10	25	2.8010E-11
26	2.8010E-11	27	-5.5974E-12	28	-5.5974E-12	29	1.1069E-12	30	1.1069E-12
31	-2.1716E-13	32	-2.1716E-13	33	4.2343E-14	34	4.2343E-14	35	-8.2176E-15
36	-8.2176E-15	37	1.5919E-15	38	1.5919E-15	39	-3.1948E-16	40	-3.1948E-16
41	1.0923E-16	42	1.0923E-16						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	9.1866E-03	2	9.1866E-03	3	1.8276E-03	4	1.8276E-03	5	-1.3865E-04
6	-1.3865E-04	7	-1.4634E-05	8	-1.4634E-05	9	6.2407E-06	10	6.2407E-06
11	-1.2335E-06	12	-1.2335E-06	13	1.8210E-07	14	1.8210E-07	15	-1.9738E-08
16	-1.9738E-08	17	6.6756E-10	18	6.6756E-10	19	4.4733E-10	20	4.4733E-10
21	-1.8702E-10	22	-1.8702E-10	23	5.3254E-11	24	5.3254E-11	25	-1.3161E-11
26	-1.3161E-11	27	3.0195E-12	28	3.0195E-12	29	-6.6191E-13	30	-6.6191E-13
31	1.4071E-13	32	1.4071E-13	33	-2.9264E-14	34	-2.9264E-14	35	5.9879E-15
36	5.9879E-15	37	-1.2125E-15	38	-1.2125E-15	39	2.5298E-16	40	2.5298E-16
41	-8.9539E-17	42	-8.9539E-17						

**** ELAPSED SIMULATION TIME : 54.60 TIME STEP NUMBER : 3 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	71.34	2	71.34	41	-2.5849E-25	42	-4.5236E-25		

SUM OF ABOVE FLUX VALUES = 142.67

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE 142.67
TOTAL ADVECTIVE FLUX RATE 279.70

TOTAL DISPERSIVE + ADVECTIVE FLUX RATE 422.37
RATE OF MASS DECAY AND TRANSFORMATION 30.816
NET RATE OF MATERIAL ACCUMULATION 422.37
MASS BALANCE ERROR 1.66710E-05
NORMALIZED MASS BALANCE ERROR 1.97351E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE .... 0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE .... 23604.
CUMULATIVE MASS DECAY AND TRANSFORMATION..................... 561.56

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	1.814	2	1.814	41	-1.7125E-25	42	-2.6173E-25		

SUM OF ABOVE FLUX VALUES = 3.6287

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE 3.6287
TOTAL ADVECTIVE FLUX RATE 7.6958
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE 11.324
RATE OF MASS DECAY AND TRANSFORMATION .... -5.4995
NET RATE OF MATERIAL ACCUMULATION 11.324
MASS BALANCE ERROR 4.58699E-07
NORMALIZED MASS BALANCE ERROR 2.02525E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE .... 0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE .... 23910.
CUMULATIVE MASS DECAY AND TRANSFORMATION..................... 461.46

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX

1	1.101	2	1.101	41	-1.0582E-25	42	4.3621E-26

....
SUM OF ABOVE FLUX VALUES = 2.2014
....

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	2.2014
TOTAL ADVECTIVE FLUX RATE	8.1283
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	10.330
RATE OF MASS DECAY AND TRANSFORMATION	-25.242
NET RATE OF MATERIAL ACCUMULATION	10.330
MASS BALANCE ERROR	4.84466E-07
NORMALIZED MASS BALANCE ERROR	2.34502E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	24557.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	2.0645

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.6454	2	0.6454	3	6.2627E-02	4	6.2627E-02	5	-1.5313E-02
6	-1.5313E-02	7	1.6850E-03	8	1.6850E-03	9	-2.2820E-05	10	-2.2820E-05
11	-4.5766E-05	12	-4.5766E-05	13	1.6076E-05	14	1.6076E-05	15	-4.0529E-06
16	-4.0529E-06	17	8.9414E-07	18	8.9414E-07	19	-1.8347E-07	20	-1.8347E-07
21	3.5976E-08	22	3.5976E-08	23	-6.8390E-09	24	-6.8390E-09	25	1.2712E-09
26	1.2712E-09	27	-2.3228E-10	28	-2.3228E-10	29	4.1883E-11	30	4.1883E-11
31	-7.4716E-12	32	-7.4716E-12	33	1.3212E-12	34	1.3212E-12	35	-2.3193E-13
36	-2.3193E-13	37	4.0524E-14	38	4.0524E-14	39	-7.2832E-15	40	-7.2832E-15
41	2.2095E-15	42	2.2095E-15						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	1.9591E-02	2	1.9591E-02	3	2.0131E-03	4	2.0131E-03	5	-4.3066E-04
6	-4.3066E-04	7	3.8797E-05	8	3.8797E-05	9	8.4167E-07	10	8.4167E-07
11	-1.1440E-06	12	-1.1440E-06	13	2.7478E-07	14	2.7478E-07	15	-4.0592E-08
16	-4.0592E-08	17	1.9262E-09	18	1.9262E-09	19	1.2785E-09	20	1.2785E-09
21	-6.3640E-10	22	-6.3640E-10	23	2.0752E-10	24	2.0752E-10	25	-5.7585E-11
26	-5.7585E-11	27	1.4632E-11	28	1.4632E-11	29	-3.5147E-12	30	-3.5147E-12
31	8.1191E-13	32	8.1191E-13	33	-1.8223E-13	34	-1.8223E-13	35	4.0018E-14
36	4.0018E-14	37	-8.6580E-15	38	-8.6580E-15	39	1.9281E-15	40	1.9281E-15
41	-7.2829E-16	42	-7.2829E-16						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	2.4766E-02	2	2.4766E-02	3	4.7320E-03	4	4.7320E-03	5	-2.5966E-04
6	-2.5966E-04	7	-5.3233E-05	8	-5.3233E-05	9	1.4986E-05	10	1.4986E-05
11	-1.9785E-06	12	-1.9785E-06	13	7.5232E-08	14	7.5232E-08	15	4.3779E-08
16	4.3779E-08	17	-1.7063E-08	18	-1.7063E-08	19	4.2621E-09	20	4.2621E-09
21	-8.7007E-10	22	-8.7007E-10	23	1.5189E-10	24	1.5189E-10	25	-2.1938E-11
26	-2.1938E-11	27	2.1118E-12	28	2.1118E-12	29	1.1197E-13	30	1.1197E-13
31	-1.3858E-13	32	-1.3858E-13	33	5.1754E-14	34	5.1754E-14	35	-1.5154E-14
36	-1.5154E-14	37	3.9773E-15	38	3.9773E-15	39	-1.0252E-15	40	-1.0252E-15
41	4.3497E-16	42	4.3497E-16						

**** ELAPSED SIMULATION TIME : 72.80 TIME STEP NUMBER : 4 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	47.78	2	47.78	41	-5.1699E-24	42	-5.7903E-24		

SUM OF ABOVE FLUX VALUES = 95.564

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	95.564
TOTAL ADVECTIVE FLUX RATE	326.11
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	421.68
RATE OF MASS DECAY AND TRANSFORMATION	42.045
NET RATE OF MATERIAL ACCUMULATION	421.68
MASS BALANCE ERROR	1.94371E-05
NORMALIZED MASS BALANCE ERROR	2.30474E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	31466.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	767.28

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	1.457	2	1.457	41	9.5966E-25	42	-1.5736E-24		

SUM OF ABOVE FLUX VALUES = 2.9141

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	2.9141
TOTAL ADVECTIVE FLUX RATE	10.414
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	13.328
RATE OF MASS DECAY AND TRANSFORMATION	-2.8524
NET RATE OF MATERIAL ACCUMULATION	13.328
MASS BALANCE ERROR	6.20696E-07
NORMALIZED MASS BALANCE ERROR	2.32857E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	31761.
CUMULATIVE MASS DECAY AND TRANSFORMATION	715.37

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	1.745	2	1.745	41	-1.0178E-25	42	-4.3621E-26		

SUM OF ABOVE FLUX VALUES = 3.4893

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE 3.4893
TOTAL ADVECTIVE FLUX RATE 17.001
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE 20.490
RATE OF MASS DECAY AND TRANSFORMATION .... -39.026
NET RATE OF MATERIAL ACCUMULATION 20.490
MASS BALANCE ERROR 1.01330E-06
NORMALIZED MASS BALANCE ERROR 2.47264E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE .... 0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE .... 32844.
CUMULATIVE MASS DECAY AND TRANSFORMATION..................... 5.1014

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.7168	2	0.7168	3	0.1414	4	0.1414	5	-1.5051E-02
6	-1.5051E-02	7	-1.1277E-03	8	-1.1277E-03	9	7.0443E-04	10	7.0443E-04
11	-1.5786E-04	12	-1.5786E-04	13	2.3718E-05	14	2.3718E-05	15	-1.9242E-06
16	-1.9242E-06	17	-2.7282E-07	18	-2.7282E-07	19	1.8398E-07	20	1.8398E-07
21	-5.9786E-08	22	-5.9786E-08	23	1.5730E-08	24	1.5730E-08	25	-3.7190E-09
26	-3.7190E-09	27	8.2304E-10	28	8.2304E-10	29	-1.7404E-10	30	-1.7404E-10
31	3.5592E-11	32	3.5592E-11	33	-7.0934E-12	34	-7.0934E-12	35	1.3851E-12
36	1.3851E-12	37	-2.6649E-13	38	-2.6649E-13	39	5.2462E-14	40	5.2462E-14
41	-1.7378E-14	42	-1.7378E-14						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	2.3908E-02	2	2.3908E-02	3	4.7602E-03	4	4.7602E-03	5	-4.8070E-04
6	-4.8070E-04	7	-3.9261E-05	8	-3.9261E-05	9	2.2042E-05	10	2.2042E-05
11	-4.6200E-06	12	-4.6200E-06	13	6.3763E-07	14	6.3763E-07	15	-4.4373E-08
16	-4.4373E-08	17	-6.9783E-09	18	-6.9783E-09	19	3.6506E-09	20	3.6506E-09
21	-9.1534E-10	22	-9.1534E-10	23	1.6039E-10	24	1.6039E-10	25	-1.5608E-11
26	-1.5608E-11	27	-2.3923E-12	28	-2.3923E-12	29	1.9733E-12	30	1.9733E-12
31	-7.5997E-13	32	-7.5997E-13	33	2.3582E-13	34	2.3582E-13	35	-6.5615E-14
36	-6.5615E-14	37	1.7117E-14	38	1.7117E-14	39	-4.4799E-15	40	-4.4799E-15
41	1.9542E-15	42	1.9542E-15						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	4.6249E-02	2	4.6249E-02	3	1.1679E-02	4	1.1679E-02	5	-1.8865E-04
6	-1.8865E-04	7	-1.9255E-04	8	-1.9255E-04	9	3.4486E-05	10	3.4486E-05
11	-2.1045E-06	12	-2.1045E-06	13	-4.9148E-07	14	-4.9148E-07	15	2.0063E-07
16	2.0063E-07	17	-4.2517E-08	18	-4.2517E-08	19	6.1001E-09	20	6.1001E-09
21	-3.8505E-10	22	-3.8505E-10	23	-1.1693E-10	24	-1.1693E-10	25	6.0234E-11
26	6.0234E-11	27	-1.7940E-11	28	-1.7940E-11	29	4.3274E-12	30	4.3274E-12
31	-9.0957E-13	32	-9.0957E-13	33	1.6885E-13	34	1.6885E-13	35	-2.6868E-14
36	-2.6868E-14	37	3.1864E-15	38	3.1864E-15	39	-1.8290E-17	40	-1.8290E-17
41	-2.9326E-16	42	-2.9326E-16						

**** ELAPSED SIMULATION TIME : 91.00 TIME STEP NUMBER : 5 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	32.28	2	32.28	41	0.0000E+00	42	-1.4889E-23		

SUM OF ABOVE FLUX VALUES = 64.569

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	64.569
TOTAL ADVECTIVE FLUX RATE	352.38
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	416.95
RATE OF MASS DECAY AND TRANSFORMATION	52.873
NET RATE OF MATERIAL ACCUMULATION	416.95
MASS BALANCE ERROR	2.10031E-05
NORMALIZED MASS BALANCE ERROR	2.51864E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	39470.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	967.40

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	1.067	2	1.067	41	-4.5753E-24	42	2.1455E-24		

SUM OF ABOVE FLUX VALUES = 2.1335

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	2.1335
TOTAL ADVECTIVE FLUX RATE	12.004
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	14.137
RATE OF MASS DECAY AND TRANSFORMATION	-0.65814
NET RATE OF MATERIAL ACCUMULATION	14.137
MASS BALANCE ERROR	7.15440E-07
NORMALIZED MASS BALANCE ERROR	2.53037E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	39740.
CUMULATIVE MASS DECAY AND TRANSFORMATION....................	955.42

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	1.968	2	1.968	41	-1.7125E-25	42	-6.4300E-25		

SUM OF ABOVE FLUX VALUES = 3.9366

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	3.9366
TOTAL ADVECTIVE FLUX RATE	28.020
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	31.956
RATE OF MASS DECAY AND TRANSFORMATION	-51.910
NET RATE OF MATERIAL ACCUMULATION	31.956
MASS BALANCE ERROR	1.67005E-06
NORMALIZED MASS BALANCE ERROR	2.61303E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	41266.
CUMULATIVE MASS DECAY AND TRANSFORMATION....................	10.656

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.7552	2	0.7552	3	0.2213	4	0.2213	5	-2.4982E-03
6	-2.4982E-03	7	-5.3268E-03	8	-5.3268E-03	9	1.0639E-03	10	1.0639E-03
11	-7.2560E-05	12	-7.2560E-05	13	-1.9896E-05	14	-1.9896E-05	15	9.2817E-06
16	9.2817E-06	17	-2.3361E-06	18	-2.3361E-06	19	4.3749E-07	20	4.3749E-07
21	-5.9593E-08	22	-5.9593E-08	23	3.0540E-09	24	3.0540E-09	25	1.5735E-09
26	1.5735E-09	27	-7.8824E-10	28	-7.8824E-10	29	2.5207E-10	30	2.5207E-10
31	-6.8081E-11	32	-6.8081E-11	33	1.6744E-11	34	1.6744E-11	35	-3.8741E-12
36	-3.8741E-12	37	8.5995E-13	38	8.5995E-13	39	-1.9255E-13	40	-1.9255E-13
41	7.1847E-14	42	7.1847E-14						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	2.6232E-02	2	2.6232E-02	3	7.7092E-03	4	7.7092E-03	5	-7.7831E-05
6	-7.7831E-05	7	-1.8329E-04	8	-1.8329E-04	9	3.5851E-05	10	3.5851E-05
11	-2.3568E-06	12	-2.3568E-06	13	-6.5839E-07	14	-6.5839E-07	15	2.9553E-07
16	2.9553E-07	17	-7.1772E-08	18	-7.1772E-08	19	1.2926E-08	20	1.2926E-08
21	-1.7014E-09	22	-1.7014E-09	23	9.8559E-11	24	9.8559E-11	25	3.0160E-11
26	3.0160E-11	27	-1.4223E-11	28	-1.4223E-11	29	3.7804E-12	30	3.7804E-12
31	-7.4993E-13	32	-7.4993E-13	33	1.0275E-13	34	1.0275E-13	35	-1.0005E-15
36	-1.0005E-15	37	-5.8718E-15	38	-5.8718E-15	39	3.0513E-15	40	3.0513E-15
41	-1.9729E-15	42	-1.9729E-15						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	7.0792E-02	2	7.0792E-02	3	2.3395E-02	4	2.3395E-02	5	9.9041E-04
6	9.9041E-04	7	-5.2209E-04	8	-5.2209E-04	9	4.8325E-05	10	4.8325E-05
11	5.0973E-06	12	5.0973E-06	13	-2.6366E-06	14	-2.6366E-06	15	5.2094E-07
16	5.2094E-07	17	-5.7141E-08	18	-5.7141E-08	19	-1.4903E-09	20	-1.4903E-09
21	2.6214E-09	22	2.6214E-09	23	-8.1225E-10	24	-8.1225E-10	25	1.7363E-10
26	1.7363E-10	27	-2.7725E-11	28	-2.7725E-11	29	2.6222E-12	30	2.6222E-12
31	2.6236E-13	32	2.6236E-13	33	-2.2670E-13	34	-2.2670E-13	35	7.8868E-14
36	7.8868E-14	37	-2.1415E-14	38	-2.1415E-14	39	5.2568E-15	40	5.2568E-15
41	-1.9506E-15	42	-1.9506E-15						

**** ELAPSED SIMULATION TIME : 109.2 TIME STEP NUMBER : 6 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	22.02	2	22.02	41	-1.9852E-23	42	-5.9557E-23		

....

SUM OF ABOVE FLUX VALUES = 44.033

....

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	44.033
TOTAL ADVECTIVE FLUX RATE	365.74
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	409.77
RATE OF MASS DECAY AND TRANSFORMATION	63.220
NET RATE OF MATERIAL ACCUMULATION	409.77
MASS BALANCE ERROR	2.17988E-05
NORMALIZED MASS BALANCE ERROR	2.65987E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	47573.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	1161.3

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	0.7563	2	0.7563	41	3.6221E-24	42	-6.0391E-24		

....

SUM OF ABOVE FLUX VALUES = 1.5127

....

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	1.5127
TOTAL ADVECTIVE FLUX RATE	12.820
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	14.333
RATE OF MASS DECAY AND TRANSFORMATION	0.87370
NET RATE OF MATERIAL ACCUMULATION	14.333
MASS BALANCE ERROR	7.64102E-07
NORMALIZED MASS BALANCE ERROR	2.66559E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	47818.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	1177.2

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	1.929	2	1.929	41	1.8095E-25	42	2.5849E-26		

SUM OF ABOVE FLUX VALUES = 3.8577

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	3.8577
TOTAL ADVECTIVE FLUX RATE	40.058
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	43.916
RATE OF MASS DECAY AND TRANSFORMATION	-63.604
NET RATE OF MATERIAL ACCUMULATION	43.916
MASS BALANCE ERROR	2.38754E-06
NORMALIZED MASS BALANCE ERROR	2.71832E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	49775.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	19.570

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.7725	2	0.7725	3	0.2951	4	0.2951	5	2.1273E-02
6	2.1273E-02	7	-8.5111E-03	8	-8.5111E-03	9	5.2049E-04	10	5.2049E-04
11	1.9888E-04	12	1.9888E-04	13	-7.1356E-05	14	-7.1356E-05	15	1.2589E-05
16	1.2589E-05	17	-9.2969E-07	18	-9.2969E-07	19	-2.4848E-07	20	-2.4848E-07
21	1.3274E-07	22	1.3274E-07	23	-3.8125E-08	24	-3.8125E-08	25	8.4026E-09
26	8.4026E-09	27	-1.4848E-09	28	-1.4848E-09	29	1.8906E-10	30	1.8906E-10
31	-4.2269E-12	32	-4.2269E-12	33	-7.7470E-12	34	-7.7470E-12	35	3.5230E-12
36	3.5230E-12	37	-1.1303E-12	38	-1.1303E-12	39	3.2951E-13	40	3.2951E-13

41	-1.5168E-13	42	-1.5168E-13

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	2.7319E-02	2	2.7319E-02	3	1.0448E-02	4	1.0448E-02	5	7.5564E-04
6	7.5564E-04	7	-2.9949E-04	8	-2.9949E-04	9	1.8095E-05	10	1.8095E-05
11	6.9450E-06	12	6.9450E-06	13	-2.4660E-06	14	-2.4660E-06	15	4.3089E-07
16	4.3089E-07	17	-3.1685E-08	18	-3.1685E-08	19	-8.1501E-09	20	-8.1501E-09
21	4.3044E-09	22	4.3044E-09	23	-1.2131E-09	24	-1.2131E-09	25	2.6188E-10
26	2.6188E-10	27	-4.5564E-11	28	-4.5564E-11	29	5.9355E-12	30	5.9355E-12
31	-3.1030E-13	32	-3.1030E-13	33	-1.3017E-13	34	-1.3017E-13	35	6.0945E-14
36	6.0945E-14	37	-1.7096E-14	38	-1.7096E-14	39	3.8100E-15	40	3.8100E-15
41	-1.0102E-15	42	-1.0102E-15						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	9.6534E-02	2	9.6534E-02	3	3.9531E-02	4	3.9531E-02	5	4.2768E-03
6	4.2768E-03	7	-9.0689E-04	8	-9.0689E-04	9	-1.4877E-05	10	-1.4877E-05
11	2.9732E-05	12	2.9732E-05	13	-5.9942E-06	14	-5.9942E-06	15	4.8317E-07
16	4.8317E-07	17	8.1241E-08	18	8.1241E-08	19	-4.1784E-08	20	-4.1784E-08
21	9.8576E-09	22	9.8576E-09	23	-1.5495E-09	24	-1.5495E-09	25	1.2253E-10
26	1.2253E-10	27	2.1543E-11	28	2.1543E-11	29	-1.2803E-11	30	-1.2803E-11
31	3.7198E-12	32	3.7198E-12	33	-8.1632E-13	34	-8.1632E-13	35	1.4156E-13
36	1.4156E-13	37	-1.6949E-14	38	-1.6949E-14	39	-2.8414E-16	40	-2.8414E-16
41	1.8751E-15	42	1.8751E-15						

**** ELAPSED SIMULATION TIME : 127.4 TIME STEP NUMBER : 7 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	15.16	2	15.16	41	9.9262E-24	42	-6.6174E-24		

SUM OF ABOVE FLUX VALUES = 30.323

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE 30.323

TOTAL ADVECTIVE FLUX RATE 370.81
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE 401.13
RATE OF MASS DECAY AND TRANSFORMATION 73.043
NET RATE OF MATERIAL ACCUMULATION 401.13
MASS BALANCE ERROR 2.21007E-05
NORMALIZED MASS BALANCE ERROR 2.75481E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE .... 0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE .... 55746.
CUMULATIVE MASS DECAY AND TRANSFORMATION..................... 1348.9

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	0.5313	2	0.5313	41	7.7548E-25	42	-1.6802E-24		

SUM OF ABOVE FLUX VALUES = 1.0626

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE 1.0626
TOTAL ADVECTIVE FLUX RATE 13.165
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE 14.228
RATE OF MASS DECAY AND TRANSFORMATION 1.8945
NET RATE OF MATERIAL ACCUMULATION 14.228
MASS BALANCE ERROR 7.84658E-07
NORMALIZED MASS BALANCE ERROR 2.75752E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE .... 0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE .... 55971.
CUMULATIVE MASS DECAY AND TRANSFORMATION..................... 1383.4

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX

1	1.757	2	1.757	41	1.4217E-25	42	-9.6935E-25

SUM OF ABOVE FLUX VALUES = 3.5149

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	3.5149
TOTAL ADVECTIVE FLUX RATE	52.418
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	55.933
RATE OF MASS DECAY AND TRANSFORMATION	-74.218
NET RATE OF MATERIAL ACCUMULATION	55.933
MASS BALANCE ERROR	3.12423E-06
NORMALIZED MASS BALANCE ERROR	2.79284E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	58339.
CUMULATIVE MASS DECAY AND TRANSFORMATION	32.656

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.7764	2	0.7764	3	0.3594	4	0.3594	5	5.3611E-02
6	5.3611E-02	7	-8.6717E-03	8	-8.6717E-03	9	-9.0996E-04	10	-9.0996E-04
11	4.7337E-04	12	4.7337E-04	13	-6.9925E-05	14	-6.9925E-05	15	-1.4907E-06
16	-1.4907E-06	17	3.5329E-06	18	3.5329E-06	19	-1.0682E-06	20	-1.0682E-06
21	1.9931E-07	22	1.9931E-07	23	-2.0182E-08	24	-2.0182E-08	25	-2.2349E-09
26	-2.2349E-09	27	1.8669E-09	28	1.8669E-09	29	-6.2659E-10	30	-6.2659E-10
31	1.5854E-10	32	1.5854E-10	33	-3.3187E-11	34	-3.3187E-11	35	5.6990E-12
36	5.6990E-12	37	-6.8928E-13	38	-6.8928E-13	39	-1.3665E-14	40	-1.3665E-14
41	8.4545E-14	42	8.4545E-14						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	2.7673E-02	2	2.7673E-02	3	1.2819E-02	4	1.2819E-02	5	1.9125E-03
6	1.9125E-03	7	-3.0840E-04	8	-3.0840E-04	9	-3.2387E-05	10	-3.2387E-05
11	1.6779E-05	12	1.6779E-05	13	-2.4709E-06	14	-2.4709E-06	15	-5.1933E-08
16	-5.1933E-08	17	1.2360E-07	18	1.2360E-07	19	-3.7209E-08	20	-3.7209E-08
21	6.9173E-09	22	6.9173E-09	23	-7.0517E-10	24	-7.0517E-10	25	-7.1129E-11
26	-7.1129E-11	27	6.1257E-11	28	6.1257E-11	29	-2.0405E-11	30	-2.0405E-11
31	5.1048E-12	32	5.1048E-12	33	-1.0587E-12	34	-1.0587E-12	35	1.8268E-13
36	1.8268E-13	37	-2.3910E-14	38	-2.3910E-14	39	1.0410E-15	40	1.0410E-15
41	1.3252E-15	42	1.3252E-15						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	0.1224	2	0.1224	3	5.9273E-02	4	5.9273E-02	5	1.0404E-02
6	1.0404E-02	7	-9.7258E-04	8	-9.7258E-04	9	-2.2164E-04	10	-2.2164E-04
11	6.2786E-05	12	6.2786E-05	13	-4.7116E-06	14	-4.7116E-06	15	-1.1740E-06
16	-1.1740E-06	17	4.8774E-07	18	4.8774E-07	19	-9.3921E-08	20	-9.3921E-08
21	9.1176E-09	22	9.1176E-09	23	9.1198E-10	24	9.1198E-10	25	-6.7737E-10
26	-6.7737E-10	27	1.9213E-10	28	1.9213E-10	29	-3.8216E-11	30	-3.8216E-11
31	5.3430E-12	32	5.3430E-12	33	-2.7209E-13	34	-2.7209E-13	35	-1.3630E-13
36	-1.3630E-13	37	6.3788E-14	38	6.3788E-14	39	-1.8983E-14	40	-1.8983E-14
41	7.4521E-15	42	7.4521E-15						

**** ELAPSED SIMULATION TIME : 145.6 TIME STEP NUMBER : 8 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	10.55	2	10.55	41	-8.6854E-24	42	-1.7371E-23		

SUM OF ABOVE FLUX VALUES = 21.095

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	21.095
TOTAL ADVECTIVE FLUX RATE	370.57
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	391.66
RATE OF MASS DECAY AND TRANSFORMATION	82.324
NET RATE OF MATERIAL ACCUMULATION	391.66
MASS BALANCE ERROR	2.20863E-05
NORMALIZED MASS BALANCE ERROR	2.81957E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	63969.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	1530.9

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	0.3735	2	0.3735	41	9.2250E-24	42	-1.1978E-23		

SUM OF ABOVE FLUX VALUES = 0.74702

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	0.74702
TOTAL ADVECTIVE FLUX RATE	13.232
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	13.979
RATE OF MASS DECAY AND TRANSFORMATION	2.5878
NET RATE OF MATERIAL ACCUMULATION	13.979
MASS BALANCE ERROR	7.88672E-07
NORMALIZED MASS BALANCE ERROR	2.82088E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	64177.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	1578.0

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	1.536	2	1.536	41	-2.0680E-25	42	-1.6027E-24		

SUM OF ABOVE FLUX VALUES = 3.0728

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	3.0728
TOTAL ADVECTIVE FLUX RATE	64.715
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	67.788
RATE OF MASS DECAY AND TRANSFORMATION	-83.921
NET RATE OF MATERIAL ACCUMULATION	67.788
MASS BALANCE ERROR	3.85721E-06
NORMALIZED MASS BALANCE ERROR	2.84504E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	66938.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	50.691

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.7715	2	0.7715	3	0.4132	4	0.4132	5	9.1508E-02
6	9.1508E-02	7	-4.5597E-03	8	-4.5597E-03	9	-2.7731E-03	10	-2.7731E-03
11	5.3598E-04	12	5.3598E-04	13	9.0952E-06	14	9.0952E-06	15	-2.5084E-05
16	-2.5084E-05	17	6.4069E-06	18	6.4069E-06	19	-7.5854E-07	20	-7.5854E-07
21	-6.0261E-08	22	-6.0261E-08	23	5.7484E-08	24	5.7484E-08	25	-1.7553E-08
26	-1.7553E-08	27	3.6157E-09	28	3.6157E-09	29	-4.8755E-10	30	-4.8755E-10
31	4.8239E-12	32	4.8239E-12	33	2.3490E-11	34	2.3490E-11	35	-9.8781E-12
36	-9.8781E-12	37	2.8776E-12	38	2.8776E-12	39	-7.1630E-13	40	-7.1630E-13
41	2.5250E-13	42	2.5250E-13						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	2.7599E-02	2	2.7599E-02	3	1.4787E-02	4	1.4787E-02	5	3.2743E-03
6	3.2743E-03	7	-1.6286E-04	8	-1.6286E-04	9	-9.9098E-05	10	-9.9098E-05
11	1.9132E-05	12	1.9132E-05	13	3.2344E-07	14	3.2344E-07	15	-8.9269E-07
16	-8.9269E-07	17	2.2773E-07	18	2.2773E-07	19	-2.6969E-08	20	-2.6969E-08
21	-2.1008E-09	22	-2.1008E-09	23	2.0187E-09	24	2.0187E-09	25	-6.1548E-10
26	-6.1548E-10	27	1.2666E-10	28	1.2666E-10	29	-1.7183E-11	30	-1.7183E-11
31	2.6727E-13	32	2.6727E-13	33	7.7173E-13	34	7.7173E-13	35	-3.2631E-13
36	-3.2631E-13	37	9.4609E-14	38	9.4609E-14	39	-2.3431E-14	40	-2.3431E-14
41	8.3003E-15	42	8.3003E-15						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	0.1479	2	0.1479	3	8.1707E-02	4	8.1707E-02	5	1.9754E-02
6	1.9754E-02	7	-2.0564E-04	8	-2.0564E-04	9	-5.6752E-04	10	-5.6752E-04
11	7.0326E-05	12	7.0326E-05	13	8.2952E-06	14	8.2952E-06	15	-4.4248E-06
16	-4.4248E-06	17	7.6389E-07	18	7.6389E-07	19	-2.8411E-08	20	-2.8411E-08
21	-2.3480E-08	22	-2.3480E-08	23	8.5038E-09	24	8.5038E-09	25	-1.7505E-09
26	-1.7505E-09	27	2.1824E-10	28	2.1824E-10	29	1.4422E-12	30	1.4422E-12
31	-1.0166E-11	32	-1.0166E-11	33	3.5999E-12	34	3.5999E-12	35	-8.6307E-13
36	-8.6307E-13	37	1.5817E-13	38	1.5817E-13	39	-2.0018E-14	40	-2.0018E-14
41	-5.7903E-16	42	-5.7903E-16						

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****     ELAPSED SIMULATION TIME :     163.8              TIME STEP NUMBER :      9          TIME STEP SIZE: 0.182E+02  ****
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*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	7.414	2	7.414	41	-6.6174E-23	42	-6.6174E-23		

SUM OF ABOVE FLUX VALUES = 14.828

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	14.828
TOTAL ADVECTIVE FLUX RATE	366.94
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	381.77
RATE OF MASS DECAY AND TRANSFORMATION	91.060
NET RATE OF MATERIAL ACCUMULATION	381.77
MASS BALANCE ERROR	2.18700E-05
NORMALIZED MASS BALANCE ERROR	2.86430E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	72229.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	1708.0

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	0.2640	2	0.2640	41	-1.3855E-23	42	5.5318E-24		

SUM OF ABOVE FLUX VALUES = 0.52808

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	0.52808
TOTAL ADVECTIVE FLUX RATE	13.136
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	13.665
RATE OF MASS DECAY AND TRANSFORMATION	3.0872
NET RATE OF MATERIAL ACCUMULATION	13.665
MASS BALANCE ERROR	7.82963E-07
NORMALIZED MASS BALANCE ERROR	2.86495E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	72421.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	1764.2

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	1.311	2	1.311	41	-2.4815E-24	42	-1.1270E-23		

SUM OF ABOVE FLUX VALUES = 2.6214

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	2.6214
TOTAL ADVECTIVE FLUX RATE	76.756
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	79.377
RATE OF MASS DECAY AND TRANSFORMATION	-92.844
NET RATE OF MATERIAL ACCUMULATION	79.377
MASS BALANCE ERROR	4.57478E-06
NORMALIZED MASS BALANCE ERROR	2.88166E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	75556.

CUMULATIVE MASS DECAY AND TRANSFORMATION.................... 74.412

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.7612	2	0.7612	3	0.4568	4	0.4568	5	0.1322
6	0.1322	7	4.3136E-03	8	4.3136E-03	9	-4.3837E-03	10	-4.3837E-03
11	2.4927E-04	12	2.4927E-04	13	1.3883E-04	14	1.3883E-04	15	-3.9627E-05
16	-3.9627E-05	17	3.4968E-06	18	3.4968E-06	19	8.8121E-07	20	8.8121E-07
21	-4.3391E-07	22	-4.3391E-07	23	9.6857E-08	24	9.6857E-08	25	-1.1283E-08
26	-1.1283E-08	27	-9.0869E-10	28	-9.0869E-10	29	9.1581E-10	30	9.1581E-10
31	-3.0051E-10	32	-3.0051E-10	33	6.8929E-11	34	6.8929E-11	35	-1.1515E-11
36	-1.1515E-11	37	9.8115E-13	38	9.8115E-13	39	2.5250E-13	40	2.5250E-13
41	-2.9961E-13	42	-2.9961E-13						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	2.7273E-02	2	2.7273E-02	3	1.6369E-02	4	1.6369E-02	5	4.7368E-03
6	4.7368E-03	7	1.5462E-04	8	1.5462E-04	9	-1.5700E-04	10	-1.5700E-04
11	8.9247E-06	12	8.9247E-06	13	4.9674E-06	14	4.9674E-06	15	-1.4173E-06
16	-1.4173E-06	17	1.2512E-07	18	1.2512E-07	19	3.1409E-08	20	3.1409E-08
21	-1.5468E-08	22	-1.5468E-08	23	3.4522E-09	24	3.4522E-09	25	-4.0306E-10
26	-4.0306E-10	27	-3.1576E-11	28	-3.1576E-11	29	3.2261E-11	30	3.2261E-11
31	-1.0588E-11	32	-1.0588E-11	33	2.4289E-12	34	2.4289E-12	35	-4.0739E-13
36	-4.0739E-13	37	3.5981E-14	38	3.5981E-14	39	8.0967E-15	40	8.0967E-15
41	-9.9601E-15	42	-9.9601E-15						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	0.1727	2	0.1727	3	0.1060	4	0.1060	5	3.2393E-02
6	3.2393E-02	7	1.9343E-03	8	1.9343E-03	9	-9.4465E-04	10	-9.4465E-04
11	7.7936E-06	12	7.7936E-06	13	3.3556E-05	14	3.3556E-05	15	-6.6479E-06
16	-6.6479E-06	17	1.4228E-07	18	1.4228E-07	19	2.4221E-07	20	2.4221E-07
21	-7.3767E-08	22	-7.3767E-08	23	1.1423E-08	24	1.1423E-08	25	-3.1287E-10
26	-3.1287E-10	27	-4.1232E-10	28	-4.1232E-10	29	1.5441E-10	30	1.5441E-10
31	-3.5062E-11	32	-3.5062E-11	33	5.4186E-12	34	5.4186E-12	35	-3.5100E-13
36	-3.5100E-13	37	-1.2281E-13	38	-1.2281E-13	39	6.6281E-14	40	6.6281E-14
41	-3.3757E-14	42	-3.3757E-14						

**** ELAPSED SIMULATION TIME : 182.0 TIME STEP NUMBER : 10 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX

1	5.265	2	5.265	41	-7.2792E-23	42	-9.2644E-23

SUM OF ABOVE FLUX VALUES = 10.531

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	10.531
TOTAL ADVECTIVE FLUX RATE	361.18
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	371.71
RATE OF MASS DECAY AND TRANSFORMATION	99.260
NET RATE OF MATERIAL ACCUMULATION	371.71
MASS BALANCE ERROR	2.15264E-05
NORMALIZED MASS BALANCE ERROR	2.89561E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	80514.
CUMULATIVE MASS DECAY AND TRANSFORMATION	1880.9

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	0.1881	2	0.1881	41	2.0770E-23	42	-3.6286E-23		

SUM OF ABOVE FLUX VALUES = 0.37623

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	0.37623
TOTAL ADVECTIVE FLUX RATE	12.945
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	13.321
RATE OF MASS DECAY AND TRANSFORMATION	3.4744
NET RATE OF MATERIAL ACCUMULATION	13.321
MASS BALANCE ERROR	7.71534E-07
NORMALIZED MASS BALANCE ERROR	2.89589E-08

RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE .... 0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	80693.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	1944.2

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	1.102	2	1.102	41	0.0000E+00	42	-1.6233E-23		

SUM OF ABOVE FLUX VALUES = 2.2039

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	2.2039
TOTAL ADVECTIVE FLUX RATE	88.449
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	90.653
RATE OF MASS DECAY AND TRANSFORMATION	-101.08
NET RATE OF MATERIAL ACCUMULATION	90.653
MASS BALANCE ERROR	5.27171E-06
NORMALIZED MASS BALANCE ERROR	2.90762E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	84183.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	104.52

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.7475	2	0.7475	3	0.4909	4	0.4909	5	0.1734
6	0.1734	7	1.7825E-02	8	1.7825E-02	9	-5.0158E-03	10	-5.0158E-03
11	-3.9474E-04	12	-3.9474E-04	13	2.5503E-04	14	2.5503E-04	15	-2.8476E-05
16	-2.8476E-05	17	-5.2989E-06	18	-5.2989E-06	19	2.6836E-06	20	2.6836E-06
21	-4.9887E-07	22	-4.9887E-07	23	1.9111E-08	24	1.9111E-08	25	1.8927E-08
26	1.8927E-08	27	-7.4047E-09	28	-7.4047E-09	29	1.6390E-09	30	1.6390E-09
31	-2.1193E-10	32	-2.1193E-10	33	-6.9010E-12	34	-6.9010E-12	35	1.3998E-11

36	1.3998E-11	37	-5.1738E-12	38	-5.1738E-12	39	1.3708E-12	40	1.3708E-12
41	-4.5080E-13	42	-4.5080E-13						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	2.6799E-02	2	2.6799E-02	3	1.7602E-02	4	1.7602E-02	5	6.2162E-03
6	6.2162E-03	7	6.3914E-04	8	6.3914E-04	9	-1.7981E-04	10	-1.7981E-04
11	-1.4148E-05	12	-1.4148E-05	13	9.1394E-06	14	9.1394E-06	15	-1.0205E-06
16	-1.0205E-06	17	-1.8969E-07	18	-1.8969E-07	19	9.6078E-08	20	9.6078E-08
21	-1.7862E-08	22	-1.7862E-08	23	6.8773E-10	24	6.8773E-10	25	6.7546E-10
26	6.7546E-10	27	-2.6436E-10	28	-2.6436E-10	29	5.8532E-11	30	5.8532E-11
31	-7.5879E-12	32	-7.5879E-12	33	-2.3295E-13	34	-2.3295E-13	35	4.9406E-13
36	4.9406E-13	37	-1.8289E-13	38	-1.8289E-13	39	4.8501E-14	40	4.8501E-14
41	-1.6022E-14	42	-1.6022E-14						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	0.1967	2	0.1967	3	0.1314	4	0.1314	5	4.8148E-02
6	4.8148E-02	7	5.9290E-03	8	5.9290E-03	9	-1.1432E-03	10	-1.1432E-03
11	-1.5663E-04	12	-1.5663E-04	13	6.0199E-05	14	6.0199E-05	15	-3.6127E-06
16	-3.6127E-06	17	-1.7585E-06	18	-1.7585E-06	19	5.7034E-07	20	5.7034E-07
21	-7.2461E-08	22	-7.2461E-08	23	-4.9992E-09	24	-4.9992E-09	25	4.8192E-09
26	4.8192E-09	27	-1.3002E-09	28	-1.3002E-09	29	2.0481E-10	30	2.0481E-10
31	-8.7115E-12	32	-8.7115E-12	33	-6.6652E-12	34	-6.6652E-12	35	2.8152E-12
36	2.8152E-12	37	-7.1430E-13	38	-7.1430E-13	39	1.3285E-13	40	1.3285E-13
41	-2.2178E-14	42	-2.2178E-14						

**** ELAPSED SIMULATION TIME : 200.2 TIME STEP NUMBER : 11 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	3.778	2	3.778	41	9.9262E-24	42	-5.2940E-23		

SUM OF ABOVE FLUX VALUES = 7.5556

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	7.5556
TOTAL ADVECTIVE FLUX RATE	354.08
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	361.64
RATE OF MASS DECAY AND TRANSFORMATION	106.94
NET RATE OF MATERIAL ACCUMULATION	361.64
MASS BALANCE ERROR	2.11032E-05
NORMALIZED MASS BALANCE ERROR	2.91773E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	88818.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	2050.7

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	0.1352	2	0.1352	41	-4.9631E-24	42	3.5155E-24		

SUM OF ABOVE FLUX VALUES = 0.27042

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	0.27042
TOTAL ADVECTIVE FLUX RATE	12.697
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	12.968
RATE OF MASS DECAY AND TRANSFORMATION	3.7952
NET RATE OF MATERIAL ACCUMULATION	12.968
MASS BALANCE ERROR	7.56760E-07
NORMALIZED MASS BALANCE ERROR	2.91787E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	88985.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	2119.8

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	0.9186	2	0.9186	41	-2.8951E-24	42	-2.8951E-24		

SUM OF ABOVE FLUX VALUES = 1.8371

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	1.8371
TOTAL ADVECTIVE FLUX RATE	99.762
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	101.60
RATE OF MASS DECAY AND TRANSFORMATION	-108.69
NET RATE OF MATERIAL ACCUMULATION	101.60
MASS BALANCE ERROR	5.94593E-06
NORMALIZED MASS BALANCE ERROR	2.92617E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	92813.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	141.69

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.7316	2	0.7316	3	0.5166	4	0.5166	5	0.2133
6	0.2133	7	3.5428E-02	8	3.5428E-02	9	-4.0376E-03	10	-4.0376E-03
11	-1.2721E-03	12	-1.2721E-03	13	2.8358E-04	14	2.8358E-04	15	1.3091E-05
16	1.3091E-05	17	-1.5492E-05	18	-1.5492E-05	19	2.9558E-06	20	2.9558E-06
21	-1.7152E-08	22	-1.7152E-08	23	-1.4185E-07	24	-1.4185E-07	25	4.4216E-08
26	4.4216E-08	27	-7.0099E-09	28	-7.0099E-09	29	7.1732E-11	30	7.1732E-11
31	3.4415E-10	32	3.4415E-10	33	-1.2910E-10	34	-1.2910E-10	35	2.9858E-11
36	2.9858E-11	37	-4.4540E-12	38	-4.4540E-12	39	5.8728E-14	40	5.8728E-14
41	4.4255E-13	42	4.4255E-13						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	2.6239E-02	2	2.6239E-02	3	1.8530E-02	4	1.8530E-02	5	7.6495E-03
6	7.6495E-03	7	1.2707E-03	8	1.2707E-03	9	-1.4480E-04	10	-1.4480E-04
11	-4.5618E-05	12	-4.5618E-05	13	1.0169E-05	14	1.0169E-05	15	4.6920E-07
16	4.6920E-07	17	-5.5538E-07	18	-5.5538E-07	19	1.0597E-07	20	1.0597E-07
21	-6.2272E-10	22	-6.2272E-10	23	-5.0810E-09	24	-5.0810E-09	25	1.5840E-09
26	1.5840E-09	27	-2.5122E-10	28	-2.5122E-10	29	2.6478E-12	30	2.6478E-12
31	1.2294E-11	32	1.2294E-11	33	-4.6144E-12	34	-4.6144E-12	35	1.0677E-12
36	1.0677E-12	37	-1.5960E-13	38	-1.5960E-13	39	2.3336E-15	40	2.3336E-15

41	1.5643E-14	42	1.5643E-14

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	0.2200	2	0.2200	3	0.1573	4	0.1573	5	6.6690E-02
6	6.6690E-02	7	1.2149E-02	8	1.2149E-02	9	-8.7533E-04	10	-8.7533E-04
11	-4.1994E-04	12	-4.1994E-04	13	6.6864E-05	14	6.6864E-05	15	7.8119E-06
16	7.8119E-06	17	-4.2282E-06	18	-4.2282E-06	19	5.7212E-07	20	5.7212E-07
21	4.9257E-08	22	4.9257E-08	23	-3.9356E-08	24	-3.9356E-08	25	9.0543E-09
26	9.0543E-09	27	-9.0772E-10	28	-9.0772E-10	29	-1.4169E-10	30	-1.4169E-10
31	9.0790E-11	32	9.0790E-11	33	-2.4275E-11	34	-2.4275E-11	35	4.1239E-12
36	4.1239E-12	37	-2.9329E-13	38	-2.9329E-13	39	-1.0729E-13	40	-1.0729E-13
41	9.9429E-14	42	9.9429E-14						

**** ELAPSED SIMULATION TIME : 218.4 TIME STEP NUMBER : 12 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	2.737	2	2.737	41	1.2904E-22	42	-1.7867E-22		

SUM OF ABOVE FLUX VALUES = 5.4745

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	5.4745
TOTAL ADVECTIVE FLUX RATE	346.19
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	351.66
RATE OF MASS DECAY AND TRANSFORMATION	114.10
NET RATE OF MATERIAL ACCUMULATION	351.66
MASS BALANCE ERROR	2.06326E-05
NORMALIZED MASS BALANCE ERROR	2.93357E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	97136.
CUMULATIVE MASS DECAY AND TRANSFORMATION....................	2218.4

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	9.8065E-02	2	9.8065E-02	41	8.5820E-24	42	-2.8538E-23		

SUM OF ABOVE FLUX VALUES = 0.19613

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	0.19613
TOTAL ADVECTIVE FLUX RATE	12.417
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	12.613
RATE OF MASS DECAY AND TRANSFORMATION	4.0741
NET RATE OF MATERIAL ACCUMULATION	12.613
MASS BALANCE ERROR	7.40073E-07
NORMALIZED MASS BALANCE ERROR	2.93373E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	97292.
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	2292.5

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	0.7620	2	0.7620	41	-3.4121E-24	42	-2.2954E-23		

SUM OF ABOVE FLUX VALUES = 1.5241

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	1.5241
TOTAL ADVECTIVE FLUX RATE	110.69
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	112.21
RATE OF MASS DECAY AND TRANSFORMATION	-115.71
NET RATE OF MATERIAL ACCUMULATION	112.21
MASS BALANCE ERROR	6.59709E-06
NORMALIZED MASS BALANCE ERROR	2.93958E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	1.01440E+05
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	186.55

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.7145	2	0.7145	3	0.5352	4	0.5352	5	0.2507
6	0.2507	7	5.6327E-02	8	5.6327E-02	9	-9.8770E-04	10	-9.8770E-04
11	-2.1555E-03	12	-2.1555E-03	13	1.6807E-04	14	1.6807E-04	15	7.4240E-05
16	7.4240E-05	17	-2.0222E-05	18	-2.0222E-05	19	6.7129E-07	20	6.7129E-07
21	8.2531E-07	22	8.2531E-07	23	-2.5255E-07	24	-2.5255E-07	25	3.0769E-08
26	3.0769E-08	27	3.5865E-09	28	3.5865E-09	29	-2.7696E-09	30	-2.7696E-09
31	7.4629E-10	32	7.4629E-10	33	-1.1368E-10	34	-1.1368E-10	35	8.9048E-13
36	8.9048E-13	37	5.8791E-12	38	5.8791E-12	39	-2.3965E-12	40	-2.3965E-12
41	1.0127E-12	42	1.0127E-12						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	2.5629E-02	2	2.5629E-02	3	1.9198E-02	4	1.9198E-02	5	8.9922E-03
6	8.9922E-03	7	2.0205E-03	8	2.0205E-03	9	-3.5429E-05	10	-3.5429E-05
11	-7.7315E-05	12	-7.7315E-05	13	6.0285E-06	14	6.0285E-06	15	2.6627E-06
16	2.6627E-06	17	-7.2528E-07	18	-7.2528E-07	19	2.4089E-08	20	2.4089E-08
21	2.9593E-08	22	2.9593E-08	23	-9.0560E-09	24	-9.0560E-09	25	1.1036E-09
26	1.1036E-09	27	1.2842E-10	28	1.2842E-10	29	-9.9244E-11	30	-9.9244E-11
31	2.6747E-11	32	2.6747E-11	33	-4.0766E-12	34	-4.0766E-12	35	3.3296E-14
36	3.3296E-14	37	2.1015E-13	38	2.1015E-13	39	-8.5730E-14	40	-8.5730E-14
41	3.6254E-14	42	3.6254E-14						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	0.2424	2	0.2424	3	0.1833	4	0.1833	5	8.7595E-02
6	8.7595E-02	7	2.0832E-02	8	2.0832E-02	9	1.9028E-04	10	1.9028E-04
11	-7.2957E-04	12	-7.2957E-04	13	2.8001E-05	14	2.8001E-05	15	2.6737E-05
16	2.6737E-05	17	-5.3791E-06	18	-5.3791E-06	19	-1.3417E-07	20	-1.3417E-07
21	2.7413E-07	22	2.7413E-07	23	-6.2661E-08	24	-6.2661E-08	25	4.1774E-09
26	4.1774E-09	27	1.7805E-09	28	1.7805E-09	29	-7.4940E-10	30	-7.4940E-10
31	1.5349E-10	32	1.5349E-10	33	-1.4147E-11	34	-1.4147E-11	35	-2.7674E-12
36	-2.7674E-12	37	1.6877E-12	38	1.6877E-12	39	-4.8476E-13	40	-4.8476E-13
41	1.4792E-13	42	1.4792E-13						

**** ELAPSED SIMULATION TIME : 236.6 TIME STEP NUMBER : 13 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	2.002	2	2.002	41	-1.0588E-22	42	-1.8860E-22		

SUM OF ABOVE FLUX VALUES = 4.0040

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	4.0040
TOTAL ADVECTIVE FLUX RATE	337.84
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	341.85
RATE OF MASS DECAY AND TRANSFORMATION	120.78
NET RATE OF MATERIAL ACCUMULATION	341.85
MASS BALANCE ERROR	2.01348E-05
NORMALIZED MASS BALANCE ERROR	2.94501E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	1.05463E+05
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	2384.8

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	7.1764E-02	2	7.1764E-02	41	3.1019E-23	42	-4.5495E-23		

SUM OF ABOVE FLUX VALUES = 0.14353

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	0.14353
TOTAL ADVECTIVE FLUX RATE	12.119
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	12.262
RATE OF MASS DECAY AND TRANSFORMATION	4.3240
NET RATE OF MATERIAL ACCUMULATION	12.262
MASS BALANCE ERROR	7.22311E-07
NORMALIZED MASS BALANCE ERROR	2.94522E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	1.05608E+05
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	2463.5

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	0.6307	2	0.6307	41	-2.3161E-23	42	-3.4742E-23		

....

SUM OF ABOVE FLUX VALUES = 1.2613

....

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	1.2613
TOTAL ADVECTIVE FLUX RATE	121.23
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	122.49
RATE OF MASS DECAY AND TRANSFORMATION	-122.18
NET RATE OF MATERIAL ACCUMULATION	122.49
MASS BALANCE ERROR	7.22562E-06
NORMALIZED MASS BALANCE ERROR	2.94938E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE .... 1.10061E+05
CUMULATIVE MASS DECAY AND TRANSFORMATION..................... 239.71

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.6967	2	0.6967	3	0.5477	4	0.5477	5	0.2848
6	0.2848	7	7.9615E-02	8	7.9615E-02	9	4.3964E-03	10	4.3964E-03
11	-2.7573E-03	12	-2.7573E-03	13	-1.1048E-04	14	-1.1048E-04	15	1.3127E-04
16	1.3127E-04	17	-1.3633E-05	18	-1.3633E-05	19	-3.7408E-06	20	-3.7408E-06
21	1.4813E-06	22	1.4813E-06	23	-1.7723E-07	24	-1.7723E-07	25	-2.7662E-08
26	-2.7662E-08	27	1.7208E-08	28	1.7208E-08	29	-3.8502E-09	30	-3.8502E-09
31	3.3222E-10	32	3.3222E-10	33	9.4502E-11	34	9.4502E-11	35	-5.0999E-11
36	-5.0999E-11	37	1.3205E-11	38	1.3205E-11	39	-2.0485E-12	40	-2.0485E-12
41	-7.0524E-14	42	-7.0524E-14						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	2.4993E-02	2	2.4993E-02	3	1.9646E-02	4	1.9646E-02	5	1.0215E-02
6	1.0215E-02	7	2.8560E-03	8	2.8560E-03	9	1.5771E-04	10	1.5771E-04
11	-9.8911E-05	12	-9.8911E-05	13	-3.9629E-06	14	-3.9629E-06	15	4.7089E-06
16	4.7089E-06	17	-4.8905E-07	18	-4.8905E-07	19	-1.3417E-07	20	-1.3417E-07
21	5.3131E-08	22	5.3131E-08	23	-6.3574E-09	24	-6.3574E-09	25	-9.9184E-10
26	-9.9184E-10	27	6.1712E-10	28	6.1712E-10	29	-1.3809E-10	30	-1.3809E-10
31	1.1921E-11	32	1.1921E-11	33	3.3860E-12	34	3.3860E-12	35	-1.8281E-12
36	-1.8281E-12	37	4.7340E-13	38	4.7340E-13	39	-7.3485E-14	40	-7.3485E-14
41	-2.4798E-15	42	-2.4798E-15						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	0.2640	2	0.2640	3	0.2091	4	0.2091	5	0.1104
6	0.1104	7	3.2078E-02	8	3.2078E-02	9	2.3925E-03	10	2.3925E-03
11	-9.7818E-04	12	-9.7818E-04	13	-7.6594E-05	14	-7.6594E-05	15	4.6542E-05
16	4.6542E-05	17	-2.8378E-06	18	-2.8378E-06	19	-1.5861E-06	20	-1.5861E-06
21	4.5656E-07	22	4.5656E-07	23	-3.2350E-08	24	-3.2350E-08	25	-1.3457E-08
26	-1.3457E-08	27	5.2908E-09	28	5.2908E-09	29	-8.9600E-10	30	-8.9600E-10
31	1.4774E-11	32	1.4774E-11	33	4.0017E-11	34	4.0017E-11	35	-1.4090E-11
36	-1.4090E-11	37	2.8102E-12	38	2.8102E-12	39	-2.5531E-13	40	-2.5531E-13
41	-1.1831E-13	42	-1.1831E-13						

**** ELAPSED SIMULATION TIME : 254.8 TIME STEP NUMBER : 14 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX

1	1.477	2	1.477	41	-4.2352E-22	42	-2.1176E-22

....
SUM OF ABOVE FLUX VALUES = 2.9542
....

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	2.9542
TOTAL ADVECTIVE FLUX RATE	329.27
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	332.22
RATE OF MASS DECAY AND TRANSFORMATION	126.99
NET RATE OF MATERIAL ACCUMULATION	332.22
MASS BALANCE ERROR	1.96239E-05
NORMALIZED MASS BALANCE ERROR	2.95341E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	1.13796E+05
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	2550.9

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	5.2968E-02	2	5.2968E-02	41	2.2334E-23	42	-6.5761E-23		

....
SUM OF ABOVE FLUX VALUES = 0.10594
....

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	0.10594
TOTAL ADVECTIVE FLUX RATE	11.812
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	11.918
RATE OF MASS DECAY AND TRANSFORMATION	4.5515
NET RATE OF MATERIAL ACCUMULATION	11.918
MASS BALANCE ERROR	7.03994E-07

NORMALIZED MASS BALANCE ERROR 2.95352E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE .... 0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE .... 1.13930E+05
CUMULATIVE MASS DECAY AND TRANSFORMATION..................... 2633.7

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	0.5215	2	0.5215	41	-6.1211E-23	42	-2.1341E-22		

SUM OF ABOVE FLUX VALUES = 1.0429

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE 1.0429
TOTAL ADVECTIVE FLUX RATE 131.41
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE 132.45
RATE OF MASS DECAY AND TRANSFORMATION .... -128.13
NET RATE OF MATERIAL ACCUMULATION 132.45
MASS BALANCE ERROR 7.83222E-06
NORMALIZED MASS BALANCE ERROR 2.95658E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE .... 0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE .... 1.18673E+05
CUMULATIVE MASS DECAY AND TRANSFORMATION..................... 301.74

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.6787	2	0.6787	3	0.5550	4	0.5550	5	0.3151
6	0.3151	7	0.1044	8	0.1044	9	1.2184E-02	10	1.2184E-02
11	-2.7736E-03	12	-2.7736E-03	13	-5.2425E-04	14	-5.2425E-04	15	1.5462E-04
16	1.5462E-04	17	6.1564E-06	18	6.1564E-06	19	-8.3642E-06	20	-8.3642E-06
21	1.3401E-06	22	1.3401E-06	23	1.1619E-07	24	1.1619E-07	25	-9.7757E-08
26	-9.7757E-08	27	2.0721E-08	28	2.0721E-08	29	-9.1728E-10	30	-9.1728E-10

31	-8.1988E-10	32	-8.1988E-10	33	3.1471E-10	34	3.1471E-10	35	-6.1407E-11
36	-6.1407E-11	37	4.0996E-12	38	4.0996E-12	39	2.1249E-12	40	2.1249E-12
41	-1.7960E-12	42	-1.7960E-12						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	2.4347E-02	2	2.4347E-02	3	1.9911E-02	4	1.9911E-02	5	1.1302E-02
6	1.1302E-02	7	3.7446E-03	8	3.7446E-03	9	4.3709E-04	10	4.3709E-04
11	-9.9499E-05	12	-9.9499E-05	13	-1.8807E-05	14	-1.8807E-05	15	5.5468E-06
16	5.5468E-06	17	2.2083E-07	18	2.2083E-07	19	-3.0004E-07	20	-3.0004E-07
21	4.8074E-08	22	4.8074E-08	23	4.1674E-09	24	4.1674E-09	25	-3.5066E-09
26	-3.5066E-09	27	7.4328E-10	28	7.4328E-10	29	-3.2918E-11	30	-3.2918E-11
31	-2.9404E-11	32	-2.9404E-11	33	1.1288E-11	34	1.1288E-11	35	-2.2026E-12
36	-2.2026E-12	37	1.4717E-13	38	1.4717E-13	39	7.6159E-14	40	7.6159E-14
41	-6.4392E-14	42	-6.4392E-14						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	0.2849	2	0.2849	3	0.2344	4	0.2344	5	0.1347
6	0.1347	7	4.5868E-02	8	4.5868E-02	9	6.0463E-03	10	6.0463E-03
11	-1.0072E-03	12	-1.0072E-03	13	-2.5153E-04	14	-2.5153E-04	15	5.5186E-05
16	5.5186E-05	17	5.0228E-06	18	5.0228E-06	19	-3.2369E-06	20	-3.2369E-06
21	3.6934E-07	22	3.6934E-07	23	7.3377E-08	24	7.3377E-08	25	-3.5405E-08
26	-3.5405E-08	27	5.6813E-09	28	5.6813E-09	29	1.6009E-10	30	1.6009E-10
31	-3.3154E-10	32	-3.3154E-10	33	9.4777E-11	34	9.4777E-11	35	-1.3711E-11
36	-1.3711E-11	37	-2.9425E-13	38	-2.9425E-13	39	8.6223E-13	40	8.6223E-13
41	-4.9429E-13	42	-4.9429E-13						

**** ELAPSED SIMULATION TIME : 273.0 TIME STEP NUMBER : 15 TIME STEP SIZE: 0.182E+02 ****

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	1.099	2	1.099	41	-7.4115E-22	42	-4.2352E-22		

SUM OF ABOVE FLUX VALUES = 2.1975

SPECIES COMPONENT NUMBER 1

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	2.1975
TOTAL ADVECTIVE FLUX RATE	320.62
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	322.82
RATE OF MASS DECAY AND TRANSFORMATION	132.74
NET RATE OF MATERIAL ACCUMULATION	322.82
MASS BALANCE ERROR	1.91084E-05
NORMALIZED MASS BALANCE ERROR	2.95960E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	1.22132E+05
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	2717.7

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	3.9408E-02	2	3.9408E-02	41	-1.0846E-22	42	3.8877E-23		

....
SUM OF ABOVE FLUX VALUES = 7.88150E-02
....

SPECIES COMPONENT NUMBER 2

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	7.88150E-02
TOTAL ADVECTIVE FLUX RATE	11.502
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	11.581
RATE OF MASS DECAY AND TRANSFORMATION	4.7602
NET RATE OF MATERIAL ACCUMULATION	11.581
MASS BALANCE ERROR	6.85536E-07
NORMALIZED MASS BALANCE ERROR	2.95979E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	1.22256E+05
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	2804.3

*** NODAL DISPERSIVE FLUX VALUES ***

NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX	NODE	DISP. FLUX
1	0.4311	2	0.4311	41	-5.2940E-23	42	-1.8612E-22		

....
SUM OF ABOVE FLUX VALUES = 0.86228
....

SPECIES COMPONENT NUMBER 3

*** INCREMENTAL MASS BALANCE RESULTS OVER A TIME STEP ***

TOTAL DISPERSIVE FLUX RATE	0.86228
TOTAL ADVECTIVE FLUX RATE	141.24
TOTAL DISPERSIVE + ADVECTIVE FLUX RATE	142.10
RATE OF MASS DECAY AND TRANSFORMATION	-133.58
NET RATE OF MATERIAL ACCUMULATION	142.10
MASS BALANCE ERROR	8.41782E-06
NORMALIZED MASS BALANCE ERROR	2.96193E-08
RATE OF MASS ACCUMULATION DUE TO PRESSURE HEAD CHANGE	0.00000E+00

*** CUMULATIVE MASS BALANCE RESULTS ***

CUMULATIVE MATERIAL STORAGE	1.27274E+05
CUMULATIVE MASS DECAY AND TRANSFORMATION.....................	373.19

*** NODAL CONCENTRATIONS FOR SPECIES NO. 1 ***

1	0.6606	2	0.6606	3	0[illegible]33	4	0.5583	5	0.3414
6	0.3414	7	0.1298	8	0.[illegible]98	9	2.2278E-02	10	2.2278E-02
11	-1.9221E-03	12	-1.9221E-03	13	-9.9922E-04	14	-9.9922E-04	15	1.1751E-04
16	1.1751E-04	17	3.5509E-05	18	3.5509E-05	19	-1.0473E-05	20	-1.0473E-05
21	8.5914E-08	22	8.5914E-08	23	5.0882E-07	[illegible]	5.0882E-07	25	-1.2334E-07
26	-1.2334E-07	27	5.2021E-0[illegible]	28	5.2021E-09	[illegible]	5.0664E-09	30	5.0664E-09
31	-1.7698E-09	32	-1.7698E-09	33	2.7533E-10	34	2.7533E-10	35	7.1986E-12
36	7.1986E-12	37	-1.7562E-11	38	-1.7562E-11	39	5.8465E-12	40	5.8465E-12
41	-1.6906E-12	42	-1.6906E-12						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 2 ***

1	2.3698E-02	2	2.3698E-02	3	2.0027E-02	4	2.0027E-02	5	1.2246E-02
6	1.2246E-02	7	4.6557E-03	8	4.6557E-03	9	7.9921E-04	10	7.9921E-04
11	-6.8954E-05	12	-6.8954E-05	13	-3.5846E-05	14	-3.5846E-05	15	4.2155E-06
16	4.2155E-06	17	1.2738E-06	18	1.2738E-06	19	-3.7570E-07	20	-3.7570E-07
21	3.0830E-09	22	3.0830E-09	23	1.8253E-08	24	1.8253E-08	25	-4.4246E-09
26	-4.4246E-09	27	1.8664E-10	28	1.8664E-10	29	1.8174E-10	30	1.8174E-10
31	-6.3485E-11	32	-6.3485E-11	33	9.8771E-12	34	9.8771E-12	35	2.5795E-13

36	2.5795E-13	37	-6.2989E-13	38	-6.2989E-13	39	2.0971E-13	40	2.0971E-13
41	-6.0650E-14	42	-6.0650E-14						

*** NODAL CONCENTRATIONS FOR SPECIES NO. 3 ***

1	0.3051	2	0.3051	3	0.2590	4	0.2590	5	0.1599
6	0.1599	7	6.2076E-02	8	6.2076E-02	9	1.1419E-02	10	1.1419E-02
11	-6.1727E-04	12	-6.1727E-04	13	-4.7705E-04	14	-4.7705E-04	15	3.7662E-05
16	3.7662E-05	17	1.7772E-05	18	1.7772E-05	19	-3.9761E-06	20	-3.9761E-06
21	-1.6916E-07	22	-1.6916E-07	23	2.2251E-07	24	2.2251E-07	25	-4.1523E-08
26	-4.1523E-08	27	-7.2897E-10	28	-7.2897E-10	29	2.2639E-09	30	2.2639E-09
31	-6.0383E-10	32	-6.0383E-10	33	6.4729E-11	34	6.4729E-11	35	1.0834E-11
36	1.0834E-11	37	-6.8526E-12	38	-6.8526E-12	39	1.7479E-12	40	1.7479E-12
41	-3.3729E-13	42	-3.3729E-13						

*** OBSERVATION NODE INFORMATION ***

NODAL VALUES OF DEPENDENT VARIABLE OVER TIME

OBSERVED NODE NUMBER: 19 SPECIES COMPONENT NUMBER : 1

TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION
0.1820E+02	0.3203E+00	0.3640E+02	0.5229E+00	0.5460E+02	0.6454E+00	0.7280E+02	0.7168E+00
0.9100E+02	0.7552E+00	0.1092E+03	0.7725E+00	0.1274E+03	0.7764E+00	0.1456E+03	0.7715E+00
0.1638E+03	0.7612E+00	0.1820E+03	0.7475E+00	0.2002E+03	0.7316E+00	0.2184E+03	0.7145E+00
0.2366E+03	0.6967E+00	0.2548E+03	0.6787E+00	0.2730E+03	0.6606E+00		

OBSERVED NODE NUMBER: 19 SPECIES COMPONENT NUMBER : 2

TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION
0.1820E+02	0.3979E-02	0.3640E+02	0.1255E-01	0.5460E+02	0.1959E-01	0.7280E+02	0.2391E-01
0.9100E+02	0.2623E-01	0.1092E+03	0.2732E-01	0.1274E+03	0.2767E-01	0.1456E+03	0.2760E-01
0.1638E+03	0.2727E-01	0.1820E+03	0.2680E-01	0.2002E+03	0.2624E-01	0.2184E+03	0.2563E-01
0.2366E+03	0.2499E-01	0.2548E+03	0.2435E-01	0.2730E+03	0.2370E-01		

OBSERVED NODE NUMBER: 19 SPECIES COMPONENT NUMBER : 3

TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION	TIME	CONCENTRATION
0.1820E+02	0.7936E-03	0.3640E+02	0.1828E-02	0.5460E+02	0.4732E-02	0.7280E+02	0.1168E-01
0.9100E+02	0.2339E-01	0.1092E+03	0.3953E-01	0.1274E+03	0.5927E-01	0.1456E+03	0.8171E-01
0.1638E+03	0.1060E+00	0.1820E+03	0.1314E+00	0.2002E+03	0.1573E+00	0.2184E+03	0.1833E+00
0.2366E+03	0.2091E+00	0.2548E+03	0.2344E+00	0.2730E+03	0.2590E+00		

***** VAM2D HAS FULLY EXCECUTED *****

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13. ABSTRACT (200 words or less)

This report documents a two-dimensional finite element model, VAM2D, developed to simulate water flow and solute transport in variably saturated porous media. Both flow and transport simulation can be handled concurrently or sequentially. The formulation of the governing equations and the numerical procedures used in the code are presented. The flow equation is approximated using the Galerkin finite element method. Nonlinear soil moisture characteristics are treated using Picard and Newton-Raphson iterations. Hysteresis effects and anisotropy in unsaturated hydraulic conductivity can be taken into account if needed. The contaminant transport simulation can account for advection, hydrodynamic dispersion, linear equilibrium sorption, and first-order degradation. Transport of a single component or a multi-component decay chain can be handled. The transport equation is approximated using an upstream weighted residual method. Several test problems are presented to verify the code and demonstrate its utility. These problems range from simple one-dimensional to complex two-dimensional and axisymmetric problems.

This document has been produced as a user's manual. It contains detailed information on the code structure along with instructions for input data preparation and sample input and printed output for selected test problems. Also included are instructions for job set up and restarting procedures.

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