UNSAT-H Version 2.0: Unsaturated Soil Water and Heat Flow Model

**M. J. Fayer
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April 1990

**Prepared for the U.S. Department of Energy
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UNSAT-H VERSION 2.0:
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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

This report documents UNSAT-H Version 2.0, a model for calculating water and heat flow in unsaturated media. The documentation includes the bases for the conceptual model and its numerical implementation, benchmark test cases, example simulations involving layered soils and plant transpiration, and the code listing.

Waste management practices at the Hanford Site have included disposal of low-level wastes by near-surface burial. Predicting the future long-term performance of any such burial site in terms of migration of contaminants requires a model capable of simulating water flow in the unsaturated soils above the buried waste. The model currently used to meet this need is UNSAT-H (Fayer, Gee, and Jones 1986). This model was developed at Pacific Northwest Laboratory to assess water dynamics of near-surface, waste-disposal sites at the Hanford Site. The code is primarily used to predict deep drainage (i.e., the downward redistribution of water below the root zone) as a function of such environmental conditions as climate, soil type, and vegetation. UNSAT-H is also used to simulate the effects of various practices to enhance isolation of wastes (e.g., placing surface barriers over waste sites).

UNSAT-H Version 2.0 is an upgrade of Version 1.0. Version 1.0 simulates the dynamic processes of infiltration, drainage, redistribution, evaporation, and uptake of water from soil by plants. Version 2.0 additionally includes options to calculate soil heat flow, surface-energy balance, and actual evaporation (without resorting to the concept of potential evapotranspiration). The modifications improve the accuracy of the evaporation calculation and provide soil temperature estimates that can support potential future model upgrades, such as the ability to simulate mechanistic plant growth, snowmelt, and soil freezing. The mathematical bases of Version 2.0 are Darcy's law, as extended by Richards (1931) to liquid water flow in unsaturated media, Fick's law of diffusion for the flow of water vapor, Fourier's law of heat conduction, and the theory of coupled water and heat flow in soils proposed by Philip and de Vries (1957).

This report includes six examples of the use of UNSAT-H. The first example, a verification test case, compares the results of UNSAT-H simulations of infiltration with analytic and numerical solutions. The comparisons showed excellent agreement for the specific test case, providing evidence that the infiltration portion of the UNSAT-H model has been correctly coded. The second example compares results obtained from UNSAT-H with the results of a drainage scenario by Kool, Parker, and van Genuchten (1985). The comparison shows close agreement. The third example, a verification test, compares results of UNSAT-H simulations with an analytic solution of a heat-flow problem. The fourth and fifth examples include simulations of water flow in a layered soil and plant transpiration, respectively. The sixth example is a repeat of the fourth, but with the addition of heat flow.

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1.0 INTRODUCTION

One waste management practice at the Hanford Site has been disposal of low-level waste by burial in the thick zone of unsaturated soil above the water table. If buried waste is contacted by soil water, the potential exists for soluble contaminants to be leached and transported to the water table. The acceptability of disposal in the unsaturated zone is contingent on suitable methods being developed to ensure that recharge rates to the water table are less than those that would transport sufficient quantities of leachable contaminants to create an environmental hazard; i.e., the recharge rates must be negligible. Earlier it was believed that there was no significant recharge of ground water near the burial sites; however, recent field investigations indicate that the rate and quantity of recharge are strongly dependent on specific site characteristics (Gee and Kirkham 1984; Gee and Heller 1985; Gee 1987).

Because low rates are extremely difficult to measure and monitor, and because the time period of interest is large (thousands of years), these recharge rates will have to be estimated using the simulation results from numerical models. U.S. Department of Energy order 5820.2A (DOE 1988a) and draft order 5400.xy (DOE 1988b) indicate that the use of models in assessing performance of radioactive waste sites will be required.

This report documents UNSAT-H Version 2.0, including the bases for the conceptual model and its numerical implementation, benchmark test cases, example simulations involving layered soils and plants, and the code listing. As UNSAT-H Version 2.0 is used and evaluated, the documentation of this report will provide the basis for further evaluations (e.g., Baca and Magnuson 1990) and potential enhancements.

The UNSAT-H model was developed at Pacific Northwest Laboratory for assessing the water dynamics of arid sites used or proposed for near-surface waste disposal. Version 2.0 is an enhanced-capability update of UNSAT-H Version 1.0 (Fayer, Gee, and Jones 1986). Version 2.0 allows the code user to calculate soil heat flow, evaporation (explicitly), energy balance at the soil surface, and nonisothermal vapor flow.

Section 2.0 provides an overview of the model, including its objectives, history, and applications. Section 3.0 presents the conceptual model of water and heat flow in near-surface sediments at the Hanford Site. Section 4.0 presents the mathematical model that quantifies the conceptual model that is portrayed by UNSAT-H Version 2.0. Section 5.0 details the numerical implementation of the mathematical model. Section 6.0 outlines the code design, including input/output file structure and model flow charts. Section 7.0 is the user's manual; it discusses problem formulation, input requirements, and code use.

Section 8.0 contains six examples of the use of the model. The first three examples are designed to verify the infiltration, drainage, and heat-flow portions of the model. The second three examples are designed to demonstrate the simulation of the water balance in a layered soil system (e.g., a protective barrier), the water balance in a field lysimeter located in the 200 East Area of the Hanford Site, and the water and heat balance of the layered soil in example four. Appendix A lists the code for the main programs and all subroutines. Appendix B lists the formats for input to the code, Appendix C lists the glossary of terms used in the text and the UNSAT-H code, and Appendix D lists the input and output files for the example problems in Section 8.0.

2.0 MODEL OVERVIEW

The use of numerical models to predict water flow in unsaturated sediments at the Hanford Site began in the early 1960s (Reisenauer 1963). Since then, there have been several efforts to develop models suitable for solving contemporary problems. A detailed discussion of model development at the Hanford Site and a brief description of the models are contained in Appendix A of Fayer, Gee, and Jones (1986).

2.1 HISTORY

The model described by this report is UNSAT-H Version 2.0. Version 1.0 of UNSAT-H was derived from the UNSAT model of Gupta et al. (1978). The objective of the UNSAT model was to predict the water dynamics of agricultural land. UNSAT-H Version 1.0 was developed to suit the needs of waste management at the Hanford Site. Although most of the mathematical and numerical formulations of the UNSAT model related to liquid water flow were retained in UNSAT-H Version 1.0, the model was changed to include isothermal vapor flow, an empirical cheatgrass-transpiration algorithm, and additional hydraulic property functions.

New capabilities incorporated into UNSAT-H Version 2.0 allow the model user to

- calculate soil heat flow
- calculate nonisothermal vapor flow
- calculate actual evaporation directly
- represent soil hydraulic properties with the van Genuchten water retention function and the Mualem conductivity function
- process output to provide data as a function of depth.

For the remainder of this report, comments concerning UNSAT-H will refer to Version 2.0, unless stated otherwise.

2.2 OBJECTIVES

The two major objectives of UNSAT-H are to estimate recharge rates (which can then be used in contaminant transport analyses) and assist in optimizing barrier design. For UNSAT-H to accomplish these objectives, the model must be able to predict the long-term water balance (particularly deep drainage) at waste burial sites for current and postulated future climatic conditions.

2.3 CODE SUMMARY

The UNSAT-H computer code simulates water and heat flow in unsaturated soils and sediments. The model is mechanistic in that it is based on Richards' equation for liquid water flow in unsaturated systems (Richards 1931), Fick's law of diffusion for vapor flow and evaporation (Hillel 1980), and Fourier's law of heat conduction for soil heat flow (Campbell 1985). UNSAT-H can simulate the isothermal flow of liquid water and water vapor, the nonisothermal flow of water vapor, the flow of heat, the surface energy balance, and soil-water extraction by plants. The basic numerical scheme used in UNSAT-H is the Crank-Nicholson method. The code listings are given in Appendix A.

The input data required by UNSAT-H can be divided into five categories: 1) program control variables, 2) soil properties, 3) initial conditions, 4) plant data, and 5) boundary conditions. The format for entering the data is listed in Appendix B. Instructions for formulating a problem to be solved and running the code are given in Section 7.0.

The first category of input, the set of program control variables, formulates the problem in terms of options and parameter values chosen, maximum allowable mass-balance error, time-step control, amount of output data saved, and simulation time. This input category also includes specification of elevation and material type for each node.

The second category of input, soil properties, includes water content as a function of water potential (i.e., the soil water characteristic or desorption curve) and hydraulic conductivity as a function of water potential.

These properties can be entered as one of several functional relationships and need to be provided for each soil material in the problem description. If heat flow is being modeled, information on the thermal conductivity function, volumetric heat capacity, and vapor enhancement factor for each soil must be provided.

The third category, initial conditions, consists of the day on which end-of-day initial conditions are provided, followed by suction head values for each node and, if heat is being modeled, temperature values for each node. The fourth category, plant data, includes mature root-length distribution, leaf area index (LAI) either as a function of time or germination and harvesting dates, and fraction of unvegetated surface area.

The final category of input is the boundary conditions. For water flow at the lower boundary of the model domain, input can be specified as a unit gradient, constant head, or daily flux values (such as drainage measured with a lysimeter). For heat flow at the lower boundary, a specified temperature gradient, constant temperature, or constant flux can be specified. For water flow at the upper boundary (the soil surface), either a constant head or flux values (daily or hourly) can be specified or calculated. The flux values can be a specified precipitation rate, a specified evaporation rate based on an input value of potential evapotranspiration, or, if heat flow is being modeled, a rate that is calculated based on the weather (i.e., solar radiation, air temperature, wind speed, and atmospheric vapor density) and the water and temperature status of the soil surface. For heat flow at the upper boundary, a constant or sinusoidally varying surface temperature can be specified, a constant flux can be specified, or the heat-flow rate at the soil surface can be calculated directly using weather data and the water and temperature status of the soil surface.

The file containing the input data is read using the program DATAINH. This program processes the data and creates a binary file that serves as the actual input file for UNSAT-H. Only one output file from UNSAT-H exists, and it is also in binary form. This output file can be read using the program DATAOUT. The output file contains daily (and less-than-daily if selected by the user) summaries of water content, water potential, water flow,

temperature, heat flow, and plant water use as a function of depth. The file also contains cumulative totals of the water and heat balance components (e.g., storage, precipitation, evaporation, transpiration, drainage, net radiation, and the sensible, latent, and soil heat fluxes). The binary output file contains information that can serve as input to a solute-transport code that requires estimates of water flux.

2.4 APPLICATIONS AND GENERAL LIMITATIONS

UNSAT-H Version 2.0 can be used to solve a variety of water and heat flow problems in unsaturated soils and sediments. Precipitation, evaporation, transpiration, soil water redistribution, and the surface energy balance at the Hanford Site can all be simulated, thus providing an estimate of the recharge rate to the underlying ground water. With proper accounting for the soil and plant characteristics at a specific site, recharge can be estimated as a function of a variable climate (e.g., the effect on recharge of precipitation changes for a given climate-change scenario can be evaluated). The effects of variations in soil type or layering, and in plant cover and type, can also be simulated by the model for various soil and plant configurations. UNSAT-H can also be applied to sites other than the Hanford Site, provided that appropriate plant algorithms are used to simulate evapotranspiration.

Version 1.0 of the UNSAT-H model was developed by Fayer, Gee, and Jones (1986). Fayer et al. (1985) and Fayer (1987) used UNSAT-H Version 1.0 to simulate the water balance of multilayer barriers. These simulations were made to help illustrate how protective barrier design (e.g., soil type, layer thickness) and changes in weather could affect recharge to the ground water. Work not yet published focuses on comparing model output with data collected at the Hanford Site during a 1.5-year period from a non-vegetated silt loam located in the 200 Area and during an 11-year period from a non-vegetated sand located in the 300 Area of the Hanford Site.

General limitations of UNSAT-H include assumptions of one-dimensionality, use of empirical plant transpiration algorithms, and lack of algorithms for hysteresis and snowmelt, freezing soil, and the temperature dependence of

soil properties. As mentioned above, Fayer et al. (1985) simulated flow through layered barriers, specifically through the central portion of the barriers where flow was assumed to be strictly vertical. The one-dimensional limitation of UNSAT-H precluded its use for describing flow at the lateral boundaries of the barrier. Although the one-dimensional nature of the model constitutes a well-defined limitation on the types of problems that can be solved, the other limitations listed above do not. The severity of each of these limitations with respect to the intended uses of the code has yet to be evaluated by validation testing, which is the process by which model predictions are objectively compared to field or laboratory data. Until UNSAT-H is validated, the reliability of UNSAT-H predictions cannot be quantitatively evaluated.

2.5 SYSTEM REQUIREMENTS

The UNSAT-H code is written in VAX FORTRAN Version 4.7, which is based on American National Standard FORTRAN-77 (ANSI X3.9-1978).^(a) Although extensions to FORTRAN-77 are available in VAX FORTRAN, limited use has been made of them to keep UNSAT-H close to standard FORTRAN-77 form. As configured, UNSAT-H will run on VAX and MicroVAX computers^(b) using the VMS operating system. UNSAT-H will run on the CRAY X-MP computer^(b) using the UNICOS operating system and the Sun workstation^(b) using the UNIX operating system with minimal modification.

The source codes listed in Appendix A require 179 kilobytes of storage. The executable images require 126 kilobytes of storage. The storage required for a given output file depends on the number of nodes and length of time

-
- (a) "Programming in VAX FORTRAN." 1984. AA-D034D-TE. Digital Equipment Corporation, Maynard, Massachusetts.
 - (b) VAX and MicroVAX computers are products of the Digital Equipment Corporation, Maynard, Massachusetts. The Cray X-MP computer is a product of Cray Research, Inc., Mendota Heights, Minnesota. The Sun workstation is a product of Sun Microsystems, Inc., Mountain View, California. References to these computers should not be regarded as an endorsement.

simulated. For the 250-node CLAY example in Section 8.1, the output file required 169 kilobytes of storage for the 41-day simulation using daily output.

3.0 CONCEPTUAL MODEL

The conceptual model identifies which processes are thought to significantly influence the flow of water in soil at the Hanford Site. The development of a site-specific conceptual model for water flow in unsaturated soil was begun by formulating a site-specific water balance equation to partition the water at a site into three categories: input, output, and storage. The water balance equation that forms the basis of the UNSAT-H conceptual model is

$$\Delta S_w = P - E - T - D \quad (3.1)$$

where ΔS_w is the change in water storage during an interval of time. Water storage is calculated as the average volumetric water content of the soil times the depth of soil. The water balance equation simply states that the increase or decrease in the amount of water stored in the soil profile is equal to the total precipitation, P , minus the amount of water lost to evaporation, E , transpiration, T , and drainage, D .

The second step in developing the conceptual model was to identify the environmental processes and physical principles controlling each term in Equation (3.1). For example, the flow of heat to the soil surface affects the rate of evaporation. Based on the interrelationships among terms in Equation (3.1), any attempt to solve for the value of one term will be limited by the accuracy of the other terms.

3.1 PRECIPITATION

Annual precipitation at the Hanford Site averages about 16 cm and ranges from less than 8 cm to 28 cm (Stone et al. 1983). In addition to low annual rates, precipitation at the Hanford Site is highly seasonal, with an average of 60% of the annual total coming between October and February. During these months, a significant percentage of precipitation may occur as snow. In fact, snow typically accounts for over 25% of the annual precipitation and 38% of the winter total.

The seasonal character of precipitation and the significant proportion as snow raise two issues that must be addressed by the conceptual model. The first issue is whether to explicitly account for snowfall and snowmelt, or to treat snow as an equivalent amount of rain. Snow covers the ground at the Hanford Site an average of 19 days per year, but may range from 0 to 54 days. The presence of a snow cover may both delay the entry of water into the soil and affect evaporation rates. The present conceptual model incorporated into UNSAT-H, however, views snow as an equivalent amount of rain. The UNSAT-H model does not attempt to simulate snowmelt or the effects of snow cover on evaporation, nor does it account for sublimation.

The second issue related to winter precipitation is how frozen soil affects infiltration, redistribution, evaporation, and runoff. If the climate at the Hanford Site were such that precipitation were negligible during winter months, then the effects of soil freezing would likely be small. However, the presence of significant precipitation during winter months means that frozen soil may need to be considered. The monthly weather records for the Hanford Site indicate that average temperatures at the 38-cm depth have been as low as -3.6°C . With the addition of heat flow to Version 2.0, potential future modifications of UNSAT-H (e.g., to simulate snowmelt and frozen soil) are facilitated. The need for such modification is being investigated.

A water balance component that was not included in Equation (3.1) is overland flow (i.e., runoff/runon). When the precipitation rate exceeds the infiltration rate, water begins to accumulate on the soil surface. Overland flow occurs when the soil's water-detention capacity is exceeded and the surface is slightly sloped. Overland flow is unlikely to occur during rainfall at the Hanford Site because the infiltration capacities of most of the soils exceed several centimeters per hour, in contrast to the 1000-year storm intensity of less than 3 cm per hour for 1 hr (Stone et al. 1983). Higher storm intensities are probable, but for shorter periods of time. Regardless of precipitation intensity, overland flow may occur when a snow cover melts quickly and the soil beneath is frozen (such that the soil's infiltrability is severely restricted). Localized overland flow has been observed at the Hanford Site under such conditions.

Overland flow is not addressed by the conceptual model for UNSAT-H, partly because the process occurs so rarely, but mostly because UNSAT-H is a one-dimensional model. When overland flow does occur, it is caused, in part, by variable surface topography. Overland flow is a multidimensional process that a one-dimensional model cannot describe. For a one-dimensional model to be applicable, the problem must be formulated such that water is applied uniformly over the surface. Therefore, UNSAT-H can be applied only to areas for which local runoff/runoff processes can be represented by a uniform precipitation rate over the entire area of interest, or to areas in which overland flow is prevented, such as in lysimeters.

3.2 EVAPORATION

Evaporation is the process of water loss from soil and/or plant surfaces to the atmosphere. Evaporation of water from the soil surface is controlled by the flow of heat to and from the soil surface, the flow of water to the soil surface from below, and the transfer of water vapor from the soil surface to the atmosphere (Hillel 1980). If one or more of these processes are altered, evaporation will be changed accordingly.

An integrated form of Fick's law of diffusion (the equation used to model vapor flow within the soil profile) addresses the interrelationships of these three processes and, therefore, has the structure necessary to predict evaporation. This form of Fick's law simply states that the evaporation rate is equal to the deficit in vapor density between the soil surface and the atmosphere divided by the atmospheric boundary-layer resistance. The atmospheric boundary layer is defined as the region of the atmosphere that is directly affected by the shearing forces originating at the surface. Rosenberg, Blad, and Verma (1983) refer to this layer as the turbulent surface layer. Air temperature, vapor density, and wind speed are measured within the atmospheric boundary layer.

The integrated form of Fick's law accounts for the potential effects that each of the three processes identified above may have on evaporation. For the first process, heat flow, rising soil-surface temperature causes the vapor density at the soil surface to increase. This increased vapor density,

in turn, increases the vapor density deficit between the soil surface and the atmosphere, and a higher evaporation rate thus ensues. Falling surface temperature has the opposite effect of reducing the deficit, thus lowering the evaporation rate. For the second process, water flow, a decrease in the supply of water to the surface leads to surface drying. A drier surface has a lower vapor density; hence, the vapor density deficit is smaller and evaporation is reduced. An increased supply of water to the soil surface would have the opposite effect.

The third process, transporting water vapor from the soil surface to the atmosphere, is controlled by both the atmospheric vapor density and the atmospheric boundary-layer resistance. Generally, the soil surface is wetter (higher vapor density) than the air. If the atmosphere is moist, however, such as during the early morning when temperatures approach the dew point or following precipitation, the increased atmospheric vapor density decreases the surface-air vapor deficit and, therefore, decreases evaporation. Another way that the transfer of water vapor from the soil surface to the atmosphere can be reduced is by decreased wind speed or reduced eddy diffusion caused by high atmospheric stability.

The diffusion equation can be shown to be equivalent to Penman-type equations. The Penman equation and its derivatives (Monteith 1980) are attempts to rewrite the diffusion equation to exclude the explicit dependence of the rate of diffusion on soil-surface temperature. Penman-type equations attempt to replace the need for data on soil surface temperature with information on net radiation and soil heat flux.

The option for using the Penman-type equations remains in Version 2.0 of UNSAT-H. When the soil surface is very wet, as immediately after a heavy rainfall, the evaporation rate will be at a maximum. This maximum rate, termed potential evaporation (PE), is determined largely by atmospheric parameters that control the supply of energy to and from the surface and the transport of water vapor away from the surface. The conceptual model in UNSAT-H Version 1.0 assumes that PE can be calculated solely based on atmospheric parameters, thus ignoring the effects of soil surface temperature and water content on the evaporation rate.

Given this conceptual model, the actual evaporation rate from a soil surface is the PE rate for only the few hours immediately following rainfall. More often, the evaporation rate is much lower than the PE rate because, as water evaporates from the soil, the soil profile begins to dry, particularly near the surface. Dry soil is a poor conductor of water and cannot readily transmit water from the moist, deeper layers to the evaporating surface at a rate sufficient to maintain the PE rate. Thus, drying of the soil limits actual evaporation to a rate that is generally a small fraction of the PE. Because of the dryness of Hanford Site soils, an important concept in this evaporation model is that the evaporation rate is limited primarily by soil conditions, rather than atmospheric conditions.

3.3 TRANSPIRATION

Transpiration is the evaporation of water from plants. When the soil surface is well vegetated with active plants, transpiration is usually the dominant mode of water loss from the soil profile. Even when the surface is only sparsely vegetated, transpiration can rival evaporation as the primary source of water loss from the soil. Exceptions to the above may occur during certain times of the year when plants are dormant or reacting to extreme water stress.

In a review of information on water flow in unsaturated soil at the Hanford Site, Gee and Heller (1985) reported that the plant community consists of a mixture of sagebrush and cheatgrass, with lesser amounts of bitterbrush, rabbitbrush, bluegrass, and Russian thistle. Rooting depths range from less than 100 cm for cheatgrass, to 200 cm for sagebrush, 220 cm for rabbitbrush, 240 cm for Russian thistle, and 300 cm for bitterbrush. Gee and Heller noted that areas of the Hanford Site disturbed by construction or brush fires tend to become colonized by a mixture of cheatgrass and Russian thistle. The exact proportion of the components of this mixture affects the water balance, because shallow-rooted cheatgrass does not remove as much water from the soil profile as deeper-rooted Russian thistle.

Annual water loss by transpiration at the Hanford Site is less than potential transpiration (PT), just as annual evaporation is less than PE. The

reduction of transpiration below the potential rate is caused primarily by two mechanisms. The first mechanism involves a decrease in plant biomass, primarily leaf area; the second mechanism involves stomatal closure.

When plants are stressed by lack of water, they may lose leaves, shoots, and roots. This reduction in plant tissue means that less water is necessary to maintain the remaining biomass. Reduction of plant biomass is a relatively slow mechanism that responds to climatic conditions averaged over weeks or months. On a short-term (e.g., hourly) basis, water loss can be reduced by stomatal closure. Closing of stomata (small openings in the leaves) drastically reduces plant water loss. In addition, closure of the stomata reduces carbon dioxide uptake, which limits photosynthesis and reduces overall plant metabolism.

The UNSAT-H conceptual model of transpiration relies on estimates of a potential evapotranspiration rate (PET) that is calculated from climate data. That potential rate is then modified by a "crop" coefficient that is a function of either leaf area or time of year. The resulting PT rate is applied to specific depths within the soil profile in proportion to the fraction of roots at these respective depths.

UNSAT-H currently allows for a fixed distribution of roots in the profile throughout the year and a variable maximum depth of root penetration. This conceptual model of transpiration offers some flexibility to vary transpiration during the simulation, but only in a predetermined way, and never solely in response to the conditions of the specific simulation. Some of the plant communities at the Hanford Site are mixed. That is, they include perennial as well as annual species, each with its own life cycle and rooting characteristics that influence the composite annual transpiration distribution. Caution should be exercised when the UNSAT-H model is applied to such plant communities until more information is available on the behavior of mixed plant communities.

3.4 DRAINAGE

The final term of Equation (3.1) is drainage, which is the movement of water downward through the bottom of the zone being simulated. Of particular

interest is the drainage water that reaches the water table. This specific type of drainage is known as ground-water recharge. As a practical matter, once water drains below the root zone, there is little chance of it being drawn upward again. Therefore, recharge is often defined as drainage below the root zone. Recharge is perhaps the water balance term of most interest for waste management because of its potential to move contaminants out of waste-disposal sites. A primary objective of any waste-disposal facility is to reduce recharge, and thus reduce the potential for drainage of water through the waste material.

Drainage results from the redistribution of water through a soil system in response to gradients in the energy state of the water. Other mechanisms that might induce water redistribution, such as geothermal gradients and barometric pressure fluctuations, have been shown to be minor contributors to water flow in soils at the Hanford Site (Reisenauer et al. 1975; Jones 1978; Gee and Simmons 1979). The energy state of water is expressed as a potential energy, commonly assumed to consist of a gravitational potential, pressure or matric potential, and solute potential. All of these potentials are expressed relative to the energy state of pure water at atmospheric pressure and a reference elevation.

Pressure or matric potential describes the water pressure difference from atmospheric pressure. When the water pressure is greater than the atmospheric pressure, the soil is saturated and the term pressure potential is used. When the water pressure is less than the atmospheric pressure, the soil is unsaturated and the term matric potential is used. Nearly all applications of UNSAT-H will be for unsaturated problems; consequently, the convention is to use matric potential.

The solute potential, which is the drop in potential energy caused by the presence of solutes, is effective in contributing to water flow only when there is a differential restriction of solute movement relative to water. In the absence of a semipermeable membrane, the solute potential is commonly neglected. In the conceptual model, therefore, the energy state of water is described by the sum of the gravitational and matric potentials; the sum is

usually called the hydraulic potential. Water continually redistributes from areas of high hydraulic potential to areas of low hydraulic potential, regardless of direction.

A question that must be addressed by the conceptual model is whether to include the flow of water vapor in the redistribution and drainage calculations. The above discussion of water redistribution in response to potential gradients applies mainly to water in the liquid phase. In unsaturated soils, water is also present in the vapor phase. Water vapor moves and redistributes within the soil in response to vapor pressure gradients. These vapor pressure gradients can arise from matric and osmotic potential gradients in the liquid phase and from temperature gradients within the soil. In the absence of a semipermeable membrane that could produce osmotic potential gradients, osmotic potential is not part of the UNSAT-H conceptual model. Water vapor flow induced by matric potential gradients is known as isothermal vapor flow. Vapor flow induced by thermal gradients is known as nonisothermal flow.

Analyses like that of Campbell (1985) imply that isothermal vapor flow can affect the near-surface (top 10 cm) water-content profile, although it is unclear how this would affect long-term simulations of the water balance. Nonisothermal vapor flow affects evaporation when the surface soil is dry and steep thermal gradients are present, a condition that occurs frequently at the semiarid Hanford Site. Hammel, Papendick, and Campbell (1981) reported that exclusion of nonisothermal vapor flow resulted in a higher predicted evaporative loss and poorer agreement between measured and predicted moisture profiles in a seed zone. Therefore, UNSAT-H Version 2.0 considers vapor flow to be a nonisothermal process.

Water redistribution (and thus drainage) is dependent on the description of soil hydraulic properties. Hysteresis, which is a nonuniqueness of properties, has been shown to affect soil water flow in some situations (Gillham, Klute, and Heermann 1976; Kool and Parker 1987). Attempts to simulate hysteresis have been at least partially successful (Gillham, Klute, and Heermann 1979; Kaluarachchi and Parker 1987). Currently, however, the soil properties of the UNSAT-H conceptual model are unique (i.e., they exhibit no hysteresis).

Soil hydraulic properties and the diffusion coefficient of water vapor through air are somewhat dependent on temperature. Nimmo and Miller (1986) determined that the temperature dependence of water potential is much greater than that which would result from just the dependence of surface tension on temperature. Currently, however, the soil properties of the UNSAT-H conceptual model are assumed to be independent of temperature.

Deep below the soil surface, temperature gradients are assumed to have negligible effect on redistribution of water. Near the soil surface, however, steep temperature gradients can exist and be the dominant cause of water vapor diffusion. Heat flow near the surface also plays a major role in determining the evaporation rate. Heat may be transferred within the soil by different mechanisms. Heat transported by conduction or by convection within moving liquid, vapor, or air is known as sensible heat. Heat associated with a phase change is known as latent heat. The latent heat associated with the phase change between liquid and vapor may be transported convectively or diffusively by water vapor. The latent heat associated with melting ice can be transported convectively by moving liquid water. Heat can also be transmitted through radiative transfer. All material at a temperature above absolute zero radiates energy in the form of heat.

The current conceptual model of heat flow within the soil includes the conduction and convection of sensible heat and the diffusive transport of latent heat of vaporization. The UNSAT-H conceptual model does not address the convective transport of latent heat associated with soil freezing or thawing, radiative heat transfer within the soil profile, or ice formation. The contribution from these processes to the soil energy balance is assumed to be small. At the soil surface, convective and radiative heat flow processes between the soil and atmosphere are considered in the conceptual model.

4.0 MATHEMATICAL MODEL

The mathematical model consists of a set of differential equations and boundary conditions that describe the processes depicted in Equation (4.1) and portrayed by the conceptual model. In this section, the mathematical models for unsaturated liquid water flow, vapor flow, heat flow, evaporation, and transpiration are presented.

In discussions of soil water flow for unsaturated conditions, hydraulic potential is calculated as the sum of the gravitational and matric potentials. The fundamental expression of potential is in terms of energy per unit mass. It is much more convenient and common, however, to replace the term potential with head, which is energy per unit weight and has units of centimeters. Therefore, the total potential is given as the hydraulic head, H , the gravitational potential as the gravitational head, Z , and the matric potential as the matric head, ψ .

4.1 UNSATURATED LIQUID WATER FLOW

The differential equation for liquid water flow is a modified form of Richards' equation (Richards 1931). This equation describes the change in water storage, redistribution, and plant water uptake at every point within the soil profile. Flow of water across the boundaries of the profile is represented by specifying a flux (e.g., precipitation, evaporation, or drainage) or by calculating a flux either directly (e.g., evaporation as a diffusive flux) or indirectly (e.g., holding the value of the boundary-node head constant for such boundary conditions as a ponded surface, evaporation, or a water table).

The development of the modified Richards' equation begins with Darcy's law. In its original form, Darcy's law represented an empirical relationship between the rate of flow in saturated sand and the hydraulic head gradient. The one-dimensional differential form of Darcy's law (Hillel 1980) is

$$q_1 = - K_s \frac{\partial H}{\partial z} \quad (4.1)$$

where q_1 is flux density of water, cm hr^{-1} ; K_s is saturated hydraulic conductivity, cm hr^{-1} ; and z is depth below the soil surface. Darcy's law can be extended to unsaturated flow by replacing the saturated conductivity term with liquid conductivity, K_L , as a function of matric head, yielding

$$q_1 = - K_L(\psi) \frac{\partial H}{\partial z} \quad (4.2)$$

Equation (4.2) must be combined with the continuity equation to describe transient flow. The continuity equation states that the change in water content of a volume of soil must equal the difference between flux into and out of the soil volume. For one-dimensional flow, the continuity equation is

$$\frac{\partial \theta}{\partial t} = - \frac{\partial q_1}{\partial z} \quad (4.3)$$

where θ is the volumetric water content, $\text{cm}^3 \text{ cm}^{-3}$; and t is time, hr . Combining Equations (4.2) and (4.3) yields

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[K_L(\psi) \frac{\partial H}{\partial z} \right] \quad (4.4)$$

UNSAT-H has two sign conventions that relate to heads. The first convention concerns gravitational head. With the soil surface as the reference elevation, the gravitational head at a point in the soil is the elevation of the point with respect to the soil surface and thus is negative. Because depth measured from the surface is positive, the gravitational head equals the negative of soil depth. Therefore, in UNSAT-H, z is replaced with $-z$. The second convention concerns matric head, which is a negative number for unsaturated soil conditions. In UNSAT-H, matric head is replaced with suction head, h , which is the negative of matric head. Thus, a positive suction head represents a matric head, and a negative suction head represents a pressure head. The calculation of hydraulic head then changes from $H = \psi + Z$ to the UNSAT-H form

$$H = - (h + z) \quad (4.5)$$

Using the chain rule of differentiation, $\partial\theta/\partial t$ in Equation (4.4) can be replaced by $C(h) (\partial h/\partial t)$, where $C(h)$ represents $\partial\theta/\partial h$ (i.e., the negative of the specific moisture capacity). With this manipulation and the incorporation of the identity $h = -\phi$, Equation (4.4) becomes

$$C(h) \frac{\partial h}{\partial t} = \frac{\partial}{\partial z} \left[K_L(h) \frac{\partial H}{\partial z} \right] \quad (4.6)$$

Combining Equations (4.5) and (4.6) and adding a sink term, S , for water uptake by plants gives

$$C(h) \frac{\partial h}{\partial t} = - \frac{\partial}{\partial z} \left[K_L(h) \left(\frac{\partial h}{\partial z} + 1 \right) \right] - S(z,t) \quad (4.7)$$

where $S(z,t)$ indicates that the sink term is a function of depth and time. With slight rearrangement, Equation (4.7) is the same as that in Gupta et al. (1978), Gee and Simmons (1979), and Simmons and Gee (1981).

To solve the flow equation for liquid, UNSAT-H must be supplied with relationships for both hydraulic conductivity and water content as functions of suction head. The capacity term can be calculated by UNSAT-H from the soil water-retention curve. Together, these two functions comprise the set of hydraulic properties required by UNSAT-H. The UNSAT-H code contains four options for describing the soil hydraulic properties: polynomials (Bond, Cole, and Gutknecht 1984), Haverkamp functions (Haverkamp et al. 1977), Brooks-Corey functions (Corey 1977), and van Genuchten functions (van Genuchten 1978).

The polynomial option allows up to four polynomials of the forms

$$\theta = a + b \log(h) + c \log^2(h) + d \log^3(h) + e \log^4(h)$$

and

$$\log K_L = a + b \log(h) + c \log^2(h) + d \log^3(h) + e \log^4(h)$$

to be used to describe each soil property for different ranges of h . Bond, Cole, and Gutknecht (1984) developed a computer program that can be used to fit polynomials to measured soil hydraulic data and to ensure that the fit is continuous at each matching point. Two major advantages of this option are that the user can easily fit polynomials to any data set and can extend the polynomials into the high suction-head range. Disadvantages of the polynomial option are that it requires many parameter inputs and consumes slightly more computer time for representing soil properties than the other options.

The second option uses the Haverkamp functions (Haverkamp et al. 1977) to describe soil properties by equations of the forms

$$\theta = \theta_r + \alpha (\theta_s - \theta_r) / (\alpha + |h|^\beta) \quad (4.8)$$

and

$$K_L = K_s A / (A + |h|^B)$$

where θ_r is the residual water content measured in $\text{cm}^3 \text{ cm}^{-3}$, θ_s is the saturated water content measured in $\text{cm}^3 \text{ cm}^{-3}$, and α , β , A , and B are curve-fitting parameters. The option exists in UNSAT-H to replace the h term in Equation (4.8) with $\ln(h)$. McKeon et al. (1983) developed two programs that can be used to fit the Haverkamp functions to measured soil hydraulic data.

The third option uses the Brooks-Corey functions (Corey 1977) to describe soil properties with equations of the forms

$$\begin{aligned} \theta &= \theta_r + (\theta_s - \theta_r) (h_e/h)^{(1/b)} && \text{with } \theta = \theta_s \text{ for } h \leq h_e \\ \text{and} & & & \\ K_L &= K_s (h_e/h)^{(2 + b'/b)} && \text{with } K_L = K_s \text{ for } h \leq h_e \end{aligned}$$

where h_e represents the air-entry suction head (the point at which the soil begins to desaturate) and b is a curve-fitting parameter. For the Burdine conductivity model, b' represents $1 + \ell$, where ℓ is the exponent (usually 2)

of the pore interaction term. For the Mualem model, b' represents $2 + \ell$, where ℓ is usually 0.5. The term θ_r was not included in UNSAT-H Version 1.0.

The fourth option uses the van Genuchten (1978) functions to describe soil properties with equations of the forms

$$\theta = \theta_r + (\theta_s - \theta_r)[1 + (ah)^n]^{-m}$$

where a , m , and n are curve-fitting parameters, and where it is assumed that $m = 1 - 1/n$, and

$$K_L = K_S \frac{\{1 - (ah)^{n-2}[1 + (ah)^n]^{-m}\}}{[1 + (ah)^n]^{\ell m}}$$

where the conductivity function is based on the Burdine conductivity model (Burdine 1953), or

$$K_L = K_S \frac{\{1 - (ah)^{n-1}[1 + (ah)^n]^{-m}\}^2}{[1 + (ah)^n]^{\ell m}}$$

where the conductivity function is based on the Mualem conductivity model (Mualem 1976).

To arrive at Equation (4.7), it was assumed that the

- fluid is incompressible
- air phase is continuous
- air phase is at constant pressure
- flow is one-dimensional
- liquid water flow is isothermal
- vapor flow is negligible.

The first three assumptions are routinely made for modeling of soil water under unsaturated conditions and are considered valid for the Hanford Site. The fourth assumption, one-dimensional flow, is considered valid for most near-surface modeling efforts, provided the surface is uniform and nearly level, no overland flow exists, and soil properties are homogeneous

and isotropic within each defined soil layer. The fifth assumption, isothermal liquid flow, is considered valid for the Hanford Site. The final assumption, that vapor flow can be ignored, is not considered valid. Soils at the Hanford Site dry out significantly during the summer and liquid-water conductivities decrease dramatically, to a point at which diffusion of water vapor from the soil to the atmosphere can be the dominant mode of water loss. For this reason, nonisothermal vapor flow has been incorporated into the UNSAT-H conceptual model. The inclusion of nonisothermal vapor flow is an enhancement of the capabilities of UNSAT-H Version 1.0.

4.2 VAPOR DIFFUSION

The fundamental equation used to calculate the diffusion of water vapor in soils is Fick's law of diffusion, which can be written as

$$q_v = - \frac{D}{\rho_w} \frac{\partial \rho_v}{\partial z} \quad (4.9)$$

where q_v = flux density of water vapor, cm hr⁻¹

ρ_w = density of liquid water, g cm⁻³

D = vapor diffusivity in soil, cm² hr⁻¹

ρ_v = vapor density, g cm⁻³.

When applying Fick's law to soils, adjustments must be made to account for the tortuous diffusion path and the reduced cross-sectional area available for flow. The need for both adjustments arises from the three-phase nature of soils. The usual way these adjustments are included in Equation (4.9) is to write the diffusivity term as

$$D = \alpha(\theta_s - \theta)D_a \quad (4.10)$$

where α is the tortuosity factor; D_a is the diffusivity of water vapor in air, cm² s⁻¹; and the quantity $(\theta_s - \theta)$ represents the air-filled porosity. Many variations of Equation (4.10) exist (Marshall 1959; Currie 1965; Troeh, Jabro, and Kirkham 1982); however, they generally treat α as a constant or as

a function of air-filled porosity. The most common formulation is to set α equal to 0.66 (Penman 1940; van Bavel 1952).

Fick's law can be written to explicitly include gradients for suction head and temperature by using the chain rule of differentiation to rewrite the vapor density gradient. Equation (4.9) becomes

$$q_v = - \frac{D}{\rho_w} \frac{\partial \rho_v}{\partial h} \frac{\partial h}{\partial z} - \frac{D}{\rho_w} \frac{\partial \rho_v}{\partial T} \frac{\partial T}{\partial z} \quad (4.11)$$

where T is the temperature, K.

The vapor density at a specific point in the soil can be related to the saturated vapor density, ρ_{vs} , and relative humidity, RH, by

$$\rho_v = \rho_{vs} \text{ RH} \quad (4.12)$$

Because water vapor density is a function of relative humidity and temperature, Equation (4.11) can be rewritten. Combining Equations (4.11) and (4.12), using the product rule for differentiation and assuming $\partial \text{RH} / \partial T = 0$ (Philip and de Vries 1957), Fick's law can be written as

$$q_v = - \frac{D}{\rho_w} \rho_{vs} \frac{\partial \text{RH}}{\partial z} - \frac{D}{\rho_w} \text{RH} \frac{d\rho_{vs}}{dT} \frac{\partial T}{\partial z} \quad (4.13)$$

Equation (4.13) explicitly includes the effect of soil temperature on vapor diffusion. The first term represents isothermal vapor diffusion. The second term represents thermal vapor diffusion. The empirical equation used by Doorenbos and Pruitt (1977) to calculate saturated vapor pressure (mb) from temperature was modified to provide vapor density (g cm^{-3}). The modified empirical equation is

$$\rho_{vs} = \exp[46.440973 - (6790.4985/T) - 6.02808 \ln(T)]$$

such that

$$d\rho_{vs}/dT = \rho_{vs} [-6.02808 + 6790.4985/T]/T$$

From the soil suction head (Campbell 1985), the relative humidity can be determined using

$$RH = \exp \left[\frac{-hMg}{RT} \right]$$

where M is the molecular weight of water, $g \text{ mole}^{-1}$; g is the gravitational constant, $cm \text{ s}^{-2}$; and R is the gas constant, $erg \text{ mole}^{-1} \text{ K}^{-1}$.

Much work has been published that evaluates the validity of Equation (4.13), particularly the thermal vapor diffusion term. Experimental measurements show that Equation (4.13) underpredicts water vapor flow. This deficiency is particularly apparent when temperature gradients are present (Gurr, Marshall, and Hutton 1952; Taylor and Cavazza 1954; Philip and de Vries 1957; Cassel, Nielsen, and Biggar 1969; Cass, Campbell, and Jones 1984). Most researchers have assumed that the problem is with the thermal vapor diffusion term of Equation (4.13); however, Scotter (1976) presents evidence that the isothermal term is also incomplete.

The most widely accepted explanation of why Equation (4.13) fails is given by Philip and de Vries (1957). They suggest two features that could be responsible for vapor diffusion greater than that predicted by Fick's law. The first is that the measured temperature gradient in a soil underestimates the temperature gradient within the air phase of the soil pores, and this "microscopic" temperature gradient is the more appropriate value to use in Fick's law. Secondly, Philip and de Vries (1957) propose that vapor is effectively transported through the liquid phase by condensation and evaporation processes operating within individual pores. These processes would have the effect of increasing the cross-sectional area available for vapor diffusion to a value larger than that for air-filled porosity, and of decreasing the tortuosity or path length for diffusion. Philip and de Vries (1957) proposed adding an enhancement factor, η , to the thermal vapor diffusion term in Equation (4.13) to account for these two processes.

Substituting the enhancement factor into Equation (4.13) and expressing the RH gradient in terms of the gradient in h gives the following formulation of Fick's law:

$$q_v = \frac{D}{\rho_w} \rho_{vs} \frac{Mg}{RT} RH \frac{\partial h}{\partial z} - \frac{D}{\rho_w} \eta RH \frac{d\rho_{vs}}{dT} \frac{\partial T}{\partial z} \quad (4.14)$$

This law explicitly accounts for the effect of temperature gradients and enhanced vapor diffusion in soil.

The first term on the right-hand side of Equation (4.14) is referred to as the isothermal vapor flux density, q_{vh} . The term is nearly equivalent to Equation (3.12) of Fayer, Gee, and Jones (1986) (i.e., UNSAT-H Version 1.0). The only exception is that Equation (4.14) allows for the saturated vapor density throughout the soil to vary according to the simulated soil temperature, rather than being a constant based on a fixed value of soil temperature. The second term on the right-hand side of Equation (4.14) is referred to as the thermal vapor flux density, q_{vT} . The term q_{vT} is new to the UNSAT-H model.

The q_{vh} and q_{vT} terms in Equation (4.14) are similar to the flux equation for liquid flow. As such, most of the parameters can be combined to yield vapor conductivity terms. The isothermal vapor conductivity term, K_{vh} , is

$$K_{vh} = \frac{D \rho_{vs} M g}{\rho_w R T} RH$$

The thermal vapor conductivity term, K_{vT} , is

$$K_{vT} = \frac{D}{\rho_w} \eta RH \frac{d\rho_{vs}}{dT}$$

Equation (4.7) can now be rewritten to include the contribution of vapor flow

$$C(h) \frac{\partial h}{\partial t} = \frac{-\partial}{\partial z} \left[K_T(h) \frac{\partial h}{\partial z} + K_L(h) + q_{VT} \right] - S(z,t) \quad (4.15)$$

where K_T is $K_L + K_{vh}$. Equation (4.15) is the modified Richards' equation that serves as the primary differential equation solved by UNSAT-H; it describes changes in water storage, isothermal redistribution of liquid water, nonisothermal redistribution of water vapor, and water uptake by plants. This equation is applied at every point in the interior of the soil profile.

4.3 EVAPORATION

An equation that integrates the three processes of heat and water flow to the soil surface and transport of water vapor to the atmosphere is an integrated form of Fick's law of diffusion (Campbell 1977)

$$e = \frac{c_e (\rho_{vss} - \rho_{va})}{\rho_w r_v} \quad (4.16)$$

where e = evaporation flux density, cm hr^{-1}
 c_e = units conversion factor, $\text{cm s m}^{-1} \text{hr}^{-1}$
 ρ_{vss} = vapor density at soil surface, -g cm^{-3}
 ρ_{va} = atmospheric vapor density, g cm^{-3}
 r_v = boundary layer resistance to vapor transport, s m^{-1} .

Equation (4.16) is an integrated form of Fick's law because it is the result of integrating the differential equation form of Fick's law (Equation 4.9) over the atmospheric boundary-layer distance. The result is a vapor density difference divided by a resistance, rather than a diffusivity times a vapor density gradient. This approach is advantageous in that the thickness of the atmospheric boundary layer does not appear explicitly in the equation, but rather is contained implicitly in the resistance term. Use of Equation (4.16) to represent the evaporative-flux boundary condition at the soil surface, rather than treating the atmospheric boundary layer as a separate region and applying the differential form of Fick's law to that region, assumes that diffusive transport of water vapor in the atmospheric

boundary layer is sufficiently rapid (compared to that in the soil) that a quasi-steady-state water vapor profile exists within the layer, dependent only on ρ_{vss} and ρ_{va} .

Solution of Equation (4.16) requires that the values of three parameters be known. The vapor density at the soil surface is obtained from the suction head and temperature of the soil surface. The atmospheric water vapor density is obtained from meteorological data. The third parameter, the atmospheric boundary-layer resistance, is calculated as detailed in Campbell (1985). For bare soil, it is assumed that the exchange surface for heat and water are the same (i.e., the soil surface), and that heat and water are exchanged between the soil surface and the atmosphere by the same eddy-diffusion process. Therefore, the atmospheric boundary-layer resistance to heat and water vapor transport is

$$r_v = r_h = \frac{\ln \left[(z^T - d + z_h) / z_h \right] + \psi_h}{k U^*} \quad (4.17)$$

where r_h = boundary layer resistance to heat transfer, $s \, m^{-1}$

z^T = height of air temperature measurement, m

d = zero plane displacement, m

z_h = roughness height for sensible heat transport, m

ψ_h = atmospheric stability correction factor for sensible heat transport

k = von Karman's constant

U^* = friction velocity, $m \, s^{-1}$.

The friction velocity in Equation (4.17) is calculated using

$$U^* = \frac{k u}{\ln \left[(z^u - d + z_m) / z_m \right] + \psi_m} \quad (4.18)$$

where u = wind speed, m s^{-1}

z^u = height of wind speed measurement, m

z_m = roughness height for momentum transfer, m

ψ_m = atmospheric stability correction factor for momentum transfer.

The atmospheric stability parameters required for Equations (4.17) and (4.18) are calculated differently, depending on the direction of the sensible heat flux (Bussinger 1975; Campbell 1985). For stable conditions when the surface temperature is lower than the air temperature and sensible heat flux is from the atmosphere to the soil

$$\psi_m = \psi_h = 4.7 \xi$$

where

$$\xi = \frac{-k z^T_g H}{C_{ha} T U^3}$$

where ξ is the stability parameter, H is the sensible heat flux, $\text{J m}^{-2} \text{s}^{-1}$; C_{ha} is the volumetric heat capacity of air, $\text{J m}^{-3} \text{K}^{-1}$; and T_a is the air temperature, K.

For unstable conditions when the surface temperature is higher than the air temperature and the sensible heat flux is from the soil to the atmosphere, there is a greater potential for eddy diffusion and atmospheric turbulence. For these conditions, the stability parameters are calculated using

$$\psi_h = -2 \ln \left[\frac{1 + (1 - \frac{16 \xi}{2})^{1/2}}{2} \right]$$

and

$$\psi_m = 0.6 \psi_h$$

Note that the atmospheric boundary-layer resistance (Equation 4.17) depends on the stability parameters, which depend on the sensible heat flux, which, in turn, depends on the boundary layer resistance. Therefore, the

atmospheric boundary-layer resistance is calculated using the iterative technique described by Campbell (1985).

4.4 HEAT FLOW

Calculation of soil temperature requires solving the energy balance equations in much the same manner that the soil water-balance equations are solved to obtain soil water potential. The constitutive equation describing the conduction of sensible heat is Fourier's law of heat conduction

$$q_h = -k_h \frac{\partial T}{\partial z} \quad (4.19)$$

where q_h is the heat flux density, $J\ cm^{-2}\ hr^{-1}$; and k_h is the thermal conductivity of soil, $J\ cm^{-1}\ hr^{-1}\ K^{-1}$.

The latent heat transported by vapor flow is equal to the product of the latent heat of vaporization and the flux density of water vapor, which is calculated using Equation (4.14). The heat convected by water flow is equal to the product of the heat capacity of water, the flux density of water, and the soil temperature. Adding latent and convective heat transport to Equation (4.19) gives the steady-state heat flux density (Jury 1973):

$$q_h = -k_h \frac{\partial T}{\partial z} + L_o q_v + C_{hv}(T - T_o)q_v + C_{hw}(T - T_o)q_l \quad (4.20)$$

where L_o is the volumetric latent heat of vaporization of water, $J\ cm^{-3}$, at the reference temperature T_o , and C_{hv} and C_{hw} are the volumetric heat capacities of water vapor and liquid, $J\ cm^{-3}\ K^{-1}$.

Relative to the reference temperature, the storage of heat (S_h) in the soil is

$$S_h = C_{hs}(T - T_o) + L_o\theta_v + C_{hv}(T - T_o)\theta_v + C_{hw}(T - T_o)\theta$$

where C_{hs} is the volumetric heat capacity of soil, $J\ cm^{-3}\ K^{-1}$, and θ_v is the volumetric vapor content expressed as an equivalent water content, cm. The equation of continuity for the conservation of energy in one dimension is (Jury 1973)

$$\frac{\partial S_h}{\partial t} = - \frac{\partial q_h}{\partial z}$$

Combining the continuity equation with Equation (4.20) gives the soil temperature equation to be solved by UNSAT-H:

$$\begin{aligned} C_h \frac{\partial T}{\partial t} + L_o \frac{\partial \theta_v}{\partial t} + C_{hv}(T - T_o) \frac{\partial \theta_v}{\partial t} + C_{hw}(T - T_o) \frac{\partial \theta}{\partial t} = \\ - \frac{\partial}{\partial z} \left[-k_h \frac{\partial T}{\partial z} + L_o q_v + C_{hv}(T - T_o) q_v + C_{hw}(T - T_o) q_l \right] \end{aligned} \quad (4.21)$$

where $C_h = C_{hs} + C_{hv}\theta_v + C_{hw}\theta$ and represents the volumetric heat capacity of soil, $J\ cm^{-3}\ K^{-1}$. The contributions of air and organic matter to C_h are considered negligible.

As stated previously, Equations (4.20) and (4.21) describe soil heat flow by accounting for conduction and convection of sensible heat and transfer of latent heat of vaporization by diffusion of water vapor. Heat balance processes that are assumed by Equation (4.21) to be negligible include 1) convective transfer of the latent heat of melting ice by liquid water, 2) convective transfer of sensible heat by the soil gas phase, 3) heat transfer by radiation, and 4) heat of wetting effects.

In Equation (4.21), thermal conductivity of soil, k_h , is a function of water content. Cass, Campbell, and Jones (1981) measured values of k_h for a soil from the Hanford Site. They used the relationship

$$k_h = A + B \frac{\theta}{\theta_s} - (A - D) \exp \left[\left(-C \frac{\theta}{\theta_s} \right)^E \right] \quad (4.22)$$

to express k_h , $J s^{-1} m^{-1} K^{-1}$, as a function of water content. Cass, Campbell, and Jones (1981) also measured the enhancement factor [η in Equation (4.14)]: for the same soil. They then used Equation (4.22) to represent η as a function of water content, substituting η for k_h in Equation (4.22). Equation (4.22) is the only option available in UNSAT-H Version 2.0 for describing these two soil properties.

4.5 TRANSPIRATION

The mathematical model of transpiration is the same in UNSAT-H Version 2.0 as in Version 1.0. Because this model is based on the concept of potential evapotranspiration, its use is constrained to problems that do not require heat flow to be modeled.

The removal of water from soil by transpiring plants is treated as a sink term in the flow equation. The calculation of the sink term is accomplished in three steps. First, PET is partitioned into PT and PE, subject to the constraint

$$PET = PT + PE$$

In the second step, PT is distributed over the root zone in proportion to the relative root density at each depth. This effectively establishes a potential sink term for each depth. The final step is to modify the potential sink term of each node, based on water content, to arrive at the actual sink term. Calculation of the sink term in this manner was proposed by Feddes, Kowalik, and Zaradny (1978).

Two methods are used to partition PET in the UNSAT-H code. In the first method, PT is calculated from the leaf area index (LAI) using the equation

$$PT = PET[-0.21 + 0.70 (LAI^{1/2})] \text{ for } 0.1 \leq LAI \leq 2.7 \quad (4.23)$$

developed by Ritchie and Burnett (1971) for cotton and grain sorghum. Ritchie (1972) noted that PET in Equation (4.23) is actually net radiation and not PET in the sense of that calculated by the Penman combination

equation (Doorenbos and Pruitt 1977). Seasonal LAI data are not currently available for the plant communities at the Hanford Site; hence, this option has not been tested using Hanford Site data.

The second method for partitioning PET uses local cheatgrass data. Hinds (1975) conducted field experiments with cheatgrass growing in micro-lysimeters in the Arid Lands Ecology (ALE) Reserve of the Hanford Site. During April and May 1972, Hinds measured total and net short-wave radiation, soil heat flux, evaporation, and transpiration; and calculated net long-wave radiation with an empirical equation. Hinds then related transpiration to the total net radiation and computed a ratio that could be termed a "crop coefficient." The ratio of transpiration to net radiation applies to the 2 months of Hinds' experiment. The shaded portion of Figure 4.1 represents this ratio for the 2-month period.

According to Klemmedson and Smith (1964), cheatgrass usually germinates in the fall, remains dormant during the winter, resumes growth in early spring, and flowers and dies of either maturity or lack of soil moisture by

FIGURE 4.1. Relationship Between the Ratio of Transpiration to Net Radiation and Day of the Year

early June. To use UNSAT-H to simulate the phenology of cheatgrass, the transpiration/net radiation relationship (shown as a cross-hatched area in Figure 4.1) has been extended throughout the growing season. The code user can do this by choosing two dates. The first date is assigned as the day cheatgrass seeds germinate. The second date is assigned as the day cheatgrass plants cease transpiring because of senescence. Because the dates for these two parameters depend on the conditions of the simulation, they are left as variables for the code user. As seen in Figure 4.1, the ratio of transpiration to net radiation increases linearly between germination and the first day of maximum transpiration (day of the year 90), and then decreases linearly from the last day of maximum transpiration (day of the year 151) to zero as the plant senesces.

From year to year, plant biomass production (and thus transpiration) varies because of weather conditions and water and nutrient availability. The exact relationship between biomass and transpiration has not yet been established for cheatgrass or other common plant species at the Hanford Site. Therefore, an empirical relationship is used to estimate the effect of increased biomass on transpiration. Hinds (1975) measured 220 g/m^2 of plant biomass during the course of his experiment. If a direct relationship between biomass and transpiration is assumed, the transpiration ratio within UNSAT-H can be altered by specifying a value for biomass other than 220. For example, specifying a biomass of 440 g/m^2 results in doubling the transpiration/net radiation ratio, with the constraint that the ratio must be between 0.0 and 1.0.

Once PT is determined, the transpiration demand is applied to the root zone using the volumetric sink term of Equation (4.15). The sink term of each node in the model domain is assigned a fraction of the transpiration demand, with the fraction calculated as the root-length density of the node divided by the total root length within the soil profile. Cline, Uresk, and Rickard (1977) have measured end-of-growing-season distributions of below-ground biomass (both living and dead tissue) in two plant communities on the ALE Reserve. Figure 4.2 shows the total root biomass distributions for an annual grass community (mostly cheatgrass) at the 1000-ft elevation, and for a perennial grass community (mostly bluebunch wheatgrass) at the 1200-ft

FIGURE 4.2. Root Mass at the End of the 1974 Growing Season in Cheatgrass and Bluebunch Wheatgrass Communities of the Hanford Site

elevation. The cheatgrass root biomass was mostly in the top 30 cm (0 to 3 dm) of soil, in contrast to the deeper distribution for the bluebunch wheatgrass.

The cheatgrass root biomass data of Figure 4.2 were normalized (Table 4.1). Assuming that the normalized total root biomass is directly related to root-length density (RLD), the RLD can be related to the depth, z , below the surface by

$$\text{RLD} = a \exp(-bz) + c \quad (4.24)$$

TABLE 4.1. Cheatgrass Root-Biomass Data, Root-Length Density (RLD), and Root Density Function (RDF)

Depth Interval, cm	Root Biomass, g/m ²	Normalized Biomass	RLD cm root/cm soil	RDF, cm ⁻¹ Roots Penetrate to	
				80 cm	20 cm
0-10	499.4	0.630	0.630	0.0629	0.0770
10-20	145.5	0.184	0.188	0.0188	0.0230
20-30	51.1	0.065	0.066	0.0066	--
30-40	31.5	0.040	0.033	0.0033	--
40-50	25.6	0.032	0.024	0.0024	--
50-60	15.7	0.020	0.021	0.0021	--
60-70	11.8	0.015	0.020	0.0020	--
70-80	11.8	0.015	0.020	0.0020	--
Total	792.4				

where a , b , and c are coefficients that optimize the fit to the normalized biomass data ($a = 1.163$, $b = 0.129$, and $c = 0.020$). The units of RLD are cm roots/cm soil. To calculate the root-density function (RDF), the values of RLD are multiplied by their respective depth intervals to obtain the total root length. Each RLD value is then divided by the total root length to obtain the RDF value for each depth. Table 4.1 contains the RDF values calculated for two depths of root penetration.

After PT is distributed throughout the root zone, the final step is to calculate the actual transpiration or sink term at each depth. This is done by multiplying the potential sink term, S_{pot} , of each node by α_f , a factor that is less than, or equal to, 1.0 and is a function of the soil water content of the respective node. The factor α_f relates the transpiration rate to the water status in the root zone. The relationship between α_f and water content is shown in Figure 4.3. When the soil water content of a node is greater than θ_n , α_f equals zero (because anaerobic conditions prevail and the plant ceases withdrawal of water from that node). When the soil water content is between θ_d and θ_n , α_f is 1.0 and the rate of withdrawal is equal to S_{pot} . If the soil water content is between θ_w and θ_d , the rate of withdrawal is reduced linearly from 1.0 to 0.0 as the water content decreases. When the soil water content is less than θ_w , α_f equals zero to indicate that the plant has stopped withdrawing water from that node.

FIGURE 4.3. The Factor α_f as a Function of Water Content

4.6 BOUNDARY CONDITIONS

The above discussion of the flow equations and the plant sink term apply to points in the interior of the modeled soil profile. The flow of water and heat across the surface and lower boundary of the soil column of interest is determined by boundary condition specifications.

For infiltration events, the upper boundary condition for water flow can be either a flux or constant head. The flux boundary can be specified as an hourly flux that is equivalent to a precipitation rate. If the suction head of the surface node should become less than the minimum suction head, the upper boundary becomes a constant head that is equivalent to the minimum suction head. During this condition, infiltration is calculated as the sum of the change in storage of the surface node and the flux between the surface node and the node below it. The constant head condition continues until the precipitation rate becomes less than the potential infiltration rate, and the suction head of the surface node exceeds the minimum suction head. At that time, the upper boundary of the domain reverts to being a flux boundary.

The second surface-boundary option is to specify a constant head, such as a depth of ponding. The surface water flux then becomes equivalent to the flux between the first and second nodes.

Similarly, the surface boundary condition during evaporation is either a flux or a constant head. The input required for the evaporative-flux boundary condition is either daily weather data or daily PET values. The daily weather data consist of

- maximum and minimum air temperatures
- average wind speed
- solar radiation
- average vapor density
- cloud cover (if available).

The average wind speed and vapor density are used as daily constants. The maximum and minimum air temperatures are used to calculate a sinusoidal variation in air temperature, T_a , throughout the day, using

$$T_a = T_{\text{mean}} + T_{\text{amp}} \cos(2\pi(t_d - 15)/24) \quad (4.25)$$

where T_{mean} is the average of maximum and minimum air temperatures, K; T_{amp} is the air temperature amplitude, K and t_d is the time of day, hr. Equation (4.25) assumes the daily minimum temperature occurs at 0300 hr and the daily maximum temperature occurs at 1500 hr.

Before 0300 hr, the maximum air temperature from the previous day is used in Equation (4.25). After 1500 hr, the minimum air temperature from the next day is used in Equation (4.25). This arrangement ensures that air temperature has no discontinuity at midnight.

When heat flow is being modeled, the surface boundary condition for water flow will be an evaporative flux that is calculated using Equation (4.16). When heat flow is not being modeled, the boundary condition will be a function of the PE rate. The PE rate can be either input directly as a daily value or calculated as a daily value using the form of Penman equation reported by Doorenbos and Pruitt (1977)

$$PE = \frac{s R_{ni}}{s + \gamma} + \frac{\gamma}{s + \gamma} 0.27 \left(1 + \frac{U}{100}\right) (e_a - e_d)$$

where s = slope of the saturation vapor pressure-temperature curve, mb K^{-1}

R_{ni} = isothermal net radiation, mm d^{-1}

γ = psychrometric constant, mb K^{-1}

U = 24-hr wind run, km d^{-1}

e_a = saturation vapor pressure at the mean air temperature, mb

e_d = actual vapor pressure, mb.

The units used by Doorenbos and Pruitt (1977) were retained for this option.

Whether input or calculated, the PE value is distributed during the day according to the input of the code user or a sine function. The sine function approximates the daily variation of solar radiation, with the maximum value occurring at 1200 hr. This option allows 88% of the daily PE to be applied sinusoidally between 0600 and 1800 hr. During the remaining time, hourly PE rates are 1% of the daily value.

As long as the suction head of the surface node does not exceed the maximum suction head (a value that corresponds to air-dry soil), evaporation will proceed at the PE rate. When the maximum suction head is exceeded, the simulation continues with a constant head boundary in which the suction head of the surface node is equal to the maximum head. For such conditions, the evaporation rate is always less than the PE rate and is calculated as the sum of the change in storage of the surface node and the flux between the surface node and the node below it.

When heat flow is modeled, the surface boundary condition for heat flow can be a calculated heat flux, constant temperature, variable temperature, or constant flux. With the first option, the heat flux results from normal exposure of the soil surface to the atmosphere. For this condition, the flux of heat into or out of the surface node is

$$G = R_n - H - LE \quad (4.26)$$

where G = surface heat flux density, $J s^{-1} m^{-2}$

R_n = net radiation, $J s^{-1} m^{-2}$

H = sensible heat flux density, $J s^{-1} m^{-2}$

LE = latent heat flux density, $J s^{-1} m^{-2}$.

In Equation (4.26), the net radiation, R_n , is calculated from Campbell (1985) using

$$R_n = (1 - \alpha_s)S_t + \epsilon_a \sigma T_a^4 - \epsilon_s \sigma T_s^4 \quad (4.27)$$

where α_s = surface albedo

S_t = short-wave radiation, $J s^{-1} m^{-2}$

ϵ_a = atmospheric emissivity

σ = Stephan-Boltzmann constant, $J s^{-1} m^{-2} K^{-4}$

T_a = air temperature, K

ϵ_s = soil emissivity

T_s = soil surface temperature, K.

The calculation of net radiation requires estimates of the surface albedo, the atmospheric and soil emissivities, and short-wave (i.e., solar) radiation. Representative estimates of surface albedo are found in Campbell (1977); however, Hillel (1977) concluded that simulating the change in surface albedo during surface drying was important. Therefore, the relationship (van Bavel and Hillel 1976)

$$\alpha_s = 0.10 + (0.25 - \theta_1)$$

was incorporated in which θ_1 is the water content at the surface. The albedo value thus calculated is constrained to between 0.10 and 0.25.

Campbell (1985) recommends that atmospheric emissivity be calculated based on cloud cover. For clear skies, Campbell recommends the formula of Brutsaert (1975)

$$\epsilon_a = 1.56 (\rho_{va})^{1/7}$$

where ρ_{va} is the atmospheric vapor density. For cloudy skies, Campbell recommends the formula of Monteith (1975)

$$\epsilon_{ac} = (1 - 0.84c) \epsilon_a + 0.84c \quad (4.28)$$

where ϵ_a is the clear-sky emissivity and c is the fractional cloud cover. Although the emissivity of the soil surface could be estimated as a constant (Campbell 1977), ϵ_s is dependent to some degree on the wetness of the soil surface. Therefore, the relationship (van Bavel and Hillel 1976)

$$\epsilon_s = 0.90 + 0.18\theta_1$$

is included in which the emissivity is not allowed to exceed unity.

The daily solar radiation is converted into fluxes that are a function of the time of day. The first step is to calculate the transmission coefficient, T_t , which is the ratio of measured solar radiation to potential solar radiation. Potential daily solar radiation, Q_o , is a function of latitude, ϕ , and the solar declination angle, δ , which varies throughout the year. The potential daily solar radiation is calculated from (Campbell 1985)

$$Q_o = \frac{117.5}{\pi} (h_s \sin \phi \sin \delta + \cos \phi \cos \delta \sin h_s)$$

where h_s is $\cos^{-1}(-\tan \phi \tan \delta)$. The sine of the solar declination angle is calculated as

$$\sin \delta = 0.3985 \sin [4.869 + 0.0172J + 0.03345 \sin(6.224 + 0.0172J)]$$

where J is the day of the year from 1 to 365. The arguments of the trigonometric functions are in radians. If cloud data are unavailable, the fractional cloud cover, c , of Equation (4.28) is that of Campbell (1985)

$$c = 2.33 - 3.33 T_t$$

The value of c is constrained to be between the values of zero and one.

The measured daily solar radiation is converted to fluxes throughout the day using the transmission coefficient and

$$S_t = S_{\text{ext}} T_t \sin(e)$$

where S_{ext} is the solar constant (i.e., the flux density of solar radiation at the outside edge of the earth's atmosphere on a plane normal to the flux of solar radiation). The last term, $\sin(e)$, is the sine of the solar elevation angle, sometimes referred to as the solar altitude. The solar elevation angle is a function of latitude and time of day and year. The sine of the solar elevation angle is

$$\sin(e) = \sin \phi \sin \delta + \cos \phi \cos \delta \cos(2\pi(t_d - t_o)/24)$$

where t_d is the hour of the day, and t_o is solar noon, specified in UNSAT-H Version 2.0 to be 1200 hr.

The sensible heat flux is the loss or gain of heat by conduction and convection through the atmospheric boundary layer. The equation of choice is an integrated form of Fourier's law of conduction that closely resembles the integrated form of Fick's law used to calculate evaporation (Equation 4.16)

$$H = \frac{C_{ha} (T_s - T_a)}{r_h} \quad (4.29)$$

In a manner similar to that of the evaporation model, Equation (4.29) is used to represent the sensible heat flux such that the atmospheric boundary layer is not treated as a separate region in which the differential form of Fourier's law applies. Rather, Equation (4.29) assumes that the heat flux across the boundary layer is sufficiently rapid (compared to that in the soil) that a quasi-steady-state temperature profile exists within the layer and is dependent only on T_s and T_a .

The latent heat term in Equation (4.26) is the product of the latent heat of vaporization, L , and the evaporation rate, E . The evaporation rate is calculated from Equation (4.16). Using Equations (4.27), (4.29), and (4.16), heat flux, G , at the soil surface can be calculated using Equation (4.26).

When the surface boundary condition for heat flow is constant temperature, the heat flux at the surface is equated to the heat flux between the surface node and the node below it. When the surface temperature is allowed to vary sinusoidally during the course of a day, the heat flux at the surface is equivalent to the flux between the surface node and the node below it, plus the change in heat storage at the surface node. For the last option, a constant heat flux is specified.

The second boundary to be specified is the lower boundary. The four options for flow of water across this boundary are 1) unit gradient, 2) constant head, 3) specified daily flux, and 4) impermeable boundary (i.e., zero flux). The unit gradient option corresponds to gravity-induced drainage and is most appropriate when applied to soil profiles that extend below the root zone and in which drainage is not impeded. With the unit gradient condition, the calculated drainage flux depends on the liquid water conductivity of the lower boundary node. The constant head option is most often chosen when the soil profile being simulated extends to a static water table, in which case the constant head value would be zero. Whenever drainage fluxes are known, they can be input directly using the flux option. Finally, the impermeable lower boundary condition can be used when drainage is restricted (e.g., in closed-bottom lysimeters).

For heat flow, the three options for the lower boundary condition are 1) constant gradient, 2) constant temperature, and 3) constant flux. For the constant gradient option, the heat flux across the lower boundary is a function of the chosen gradient, the thermal conductivity of the lower boundary node, and the thermally induced vapor flux. For the constant temperature option, the heat flux across the lower boundary is equal to the flux between

the lower boundary node and the node above it. For the third option, a constant heat flux is specified. A value of zero can be used to model a boundary impermeable to heat flow.

5.0 NUMERICAL IMPLEMENTATION

The equations used to represent the conceptual model are solved numerically with a Crank-Nicholson finite difference scheme. In this scheme, the mathematical equations are approximated with finite difference equations in which a finite grid represents both the space and time derivatives. Some error is associated with this approximation, but the error can be minimized by decreasing the size of the space and/or time grid intervals. The finite difference equations can be formed into a matrix that is amenable to an iterative solution scheme.

5.1 FINITE DIFFERENCE APPROXIMATION OF WATER FLOW

With the Crank-Nicholson method, the time derivatives are evaluated at the midpoint of the time step. Thus, Equation (4.15) is approximated in the computer code as

$$C_i^{j-1/2} \frac{h_i^j - h_i^{j-1}}{t^j - t^{j-1}} = \frac{-2}{z_{i+1} - z_{i-1}} \left[q_{i+1/2}^{j-1/2} - q_{i-1/2}^{j-1/2} \right] - S_i^{j-1/2} \quad (5.1)$$

where

$$C_i^{j-1/2} = \frac{C_i^j + C_i^{j-1}}{2}$$

and

$$q_{i+1/2}^{j-1/2} = \frac{q_{i+1/2}^j + q_{i+1/2}^{j-1}}{2}$$

The subscript i denotes the node at depth z_i . The superscript j denotes the time, t^j , for which the solution will be determined. The sink term, S_i , is directly calculated in the code as a function of the time of day and the water content, $\theta_i^{j-1/2}$.

The flux terms at the midpoints between nodes are approximated by

$$q_{i+1/2}^j = K_{T_{i+1/2}}^j \left(\frac{h_{i+1}^j - h_i^j}{z_{i+1} - z_i} \right) + G K_{L_{i+1/2}}^j - K_{VT_{i+1/2}}^j \left(\frac{T_{i+1}^{j-1} - T_i^{j-1}}{z_{i+1} - z_i} \right) \quad (5.2a)$$

and

$$q_{i-1/2}^j = K_{T_{i-1/2}}^j \left(\frac{h_i^j - h_{i-1}^j}{z_i - z_{i-1}} \right) + G K_{L_{i-1/2}}^j - K_{VT_{i-1/2}}^j \left(\frac{T_i^{j-1} - T_{i-1}^{j-1}}{z_i - z_{i-1}} \right) \quad (5.2b)$$

When the fluxes are evaluated at time $j - 1$, the other parameters in Equations (5.2a,b) are evaluated at time $j - 1$, including the temperatures (i.e., the temperatures at time $j - 1$ are used in the calculation at both times, j and $j - 1$). During the water flow calculation, soil temperatures are assumed to remain constant at T_i^{j-1} during the time step.

The G term in Equations (5.2a,b) is the gravity-induced flow factor. When G has a value of 0, the gravity-induced contribution to flow is neglected, thus allowing for simulation of horizontal flow. When G is 1, the gravity-induced contribution to flow is included.

In Equations (5.2a,b,c), the hydraulic conductivity between nodes can be calculated as the arithmetic mean, with an option for weighting the arithmetic mean to the upstream or downstream flow direction, the harmonic mean, or the geometric mean. The appropriate equations are

$$K_{L_{i+1/2}}^j = UP K_{L_i}^j + DOWN K_{L_{i+1}}^j \quad (5.3a)$$

and

$$K_{L_{i+1/2}}^j = 2 \left(\frac{1}{K_{L_i}^j} + \frac{1}{K_{L_{i+1}}^j} \right)^{-1} \quad (5.3b)$$

$$K_{L_{i+1/2}}^j = \left(K_{L_i}^j K_{L_{i+1}}^j \right)^{0.5} \quad (5.3c)$$

for the arithmetic (where UP + DOWN = 1), harmonic, and geometric means, respectively. Values of K_L are calculated from the input soil properties based on the head value of the corresponding node.

The isothermal vapor conductivity, K_{vh} , [which is part of K_T in Equation (5.2)] for the midpoint is calculated in the same manner as the liquid conductivity at the midpoint (i.e., using equations similar to Equations (5.3a,b,c)]. The value of K_{vh} for a particular node is calculated from

$$K_{vh_i}^j = \frac{aD_a Mg \rho_{vs_i}^{j-1}}{\rho_w RT_i^{j-1}} (\theta_s - \theta_i^j) \exp \left[\frac{-h_i^j Mg}{RT_i^{j-1}} \right]$$

based on Equation (4.10) and the first term on the right side of Equation (4.14). In Equations (5.2a,b), the total conductivity applicable to a water potential gradient at a midpoint is thus

$$K_{T_{i+1/2}}^j = K_{L_{i+1/2}}^j + K_{vh_{i+1/2}}^j$$

In Equations (5.2a,b), the midpoint value of the nonisothermal vapor conductivity is also calculated using equations similar to Equations (5.3a,b,c). From Equation (4.10) and the second term on the right side of Equation (4.14), the nonisothermal vapor conductivity for each node is calculated using

$$K_{vT_i}^j = \frac{aD_a}{\rho_w} (\theta_s - \theta_i^j) \eta_i^j \exp \left[\frac{-h_i^j Mg}{RT_i^{j-1}} \right] \frac{d\rho_{vs_i}^{j-1}}{dT_i^{j-1}}$$

5.1.1 Interior Nodes

Equation (5.1) is rearranged to solve for the head values at the end of a time step, with the general form of the rearranged equation being

$$A_i^* h_{i-1}^j + B_i^* h_i^j + C_i^* h_{i+1}^j = D_i^* \quad (5.4)$$

For the boundary nodes, the exact form of the coefficients in Equation (5.4) depends on the boundary conditions chosen. For all interior nodes, however, the coefficients for nodes $i = 2, n - 1$ are

$$A_i^* = K_{T_{i-1/2}}^j / \left[(z_{i+1} - z_{i-1})(z_i - z_{i-1}) \right]$$

$$B_i^* = \frac{C_i^{j-1/2}}{t_i^j - t_{i-1}^{j-1}} - \left[K_{T_{i+1/2}}^j / (z_{i+1} - z_i) + K_{T_{i-1/2}}^j / (z_i - z_{i-1}) \right] / (z_{i+1} - z_{i-1})$$

$$C_i^* = K_{T_{i+1/2}}^j / \left[(z_{i+1} - z_{i-1})(z_{i+1} - z_i) \right]$$

$$\begin{aligned} D_i^* = & \frac{C_i^{j-1/2} h_i^{j-1}}{t_i^j - t_{i-1}^{j-1}} - S_i^{j-1/2} - \frac{G}{z_{i+1} - z_{i-1}} (K_{L_{i+1/2}}^j - K_{L_{i-1/2}}^j) \\ & - \frac{1}{z_{i+1} - z_{i-1}} \left[K_{T_{i+1/2}}^{j-1} \left(\frac{h_{i+1}^{j-1} - h_i^{j-1}}{z_{i+1} - z_i} \right) - K_{T_{i-1/2}}^{j-1} \left(\frac{h_i^{j-1} - h_{i-1}^{j-1}}{z_i - z_{i-1}} \right) \right] \\ & + G \left(K_{L_{i+1/2}}^{j-1} - K_{L_{i-1/2}}^{j-1} \right) - \left(K_{VT_{i+1/2}}^j + K_{VT_{i+1/2}}^{j-1} \right) \left(\frac{T_{i+1}^{j-1} - T_i^{j-1}}{z_{i+1} - z_i} \right) \\ & + \left(K_{VT_{i-1/2}}^j + K_{VT_{i-1/2}}^{j-1} \right) \left(\frac{T_i^{j-1} - T_{i-1}^{j-1}}{z_i - z_{i-1}} \right) \end{aligned}$$

5.1.2 Surface Boundary Node

By convention, the surface boundary node in UNSAT-H is node 1. The values of coefficients assigned to node 1 will depend on which surface boundary condition is chosen. One option in UNSAT-H is to specify a constant head for node 1. The resulting solution equation for node 2 (the node below node 1) is

$$B_2^* h_2^j + C_2^* h_3^j = D_2^* - A_2^* h_1^j$$

In this case, the number of equations in the solution matrix is reduced by one because h_1 is already known.

Another surface boundary option in UNSAT-H specifies a surface flux, either as evaporation or precipitation. The special form of Equation (5.4) for this case looks like

$$B_1^* h_1^j + C_1^* h_2^j = D_1^*$$

where $A_1^* = 0$

$$B_1^* = C_1^{j-1/2} / (t^j - t^{j-1}) - K_{T3/2}^j / (z_2 - z_1)^2$$

$$C_1^* = K_{T3/2}^j / (z_2 - z_1)^2$$

$$D_1^* = \frac{C_1^{j-1/2} h_1^{j-1}}{t^j - t^{j-1}} - S_1^{j-1/2} - \frac{1}{z_2 - z_1} \left[-2q_1^{j-1/2} + G K_{L3/2}^j \right. \\ \left. + K_{T3/2}^{j-1} \left(\frac{h_2^{j-1} - h_1^{j-1}}{z_2 - z_1} \right) + G K_{L3/2}^{j-1} - \left(K_{vT3/2}^j + K_{vT3/2}^{j-1} \right) \left(\frac{\tau_2^{j-1} - \tau_1^{j-1}}{z_2 - z_1} \right) \right]$$

Note that the flux, $q_{1/2}^{j-1/2}$, is either specified by the user or calculated directly (e.g., the evaporative flux). The program checks during each time step to determine if the head value at the soil surface exceeds the range of values permitted (being either too wet or dry). If it does, then the head at the surface boundary is reset to the appropriate limit and the problem is re-solved for that time step for the remaining nodes. At the start of the next time step, the program will again assume a surface flux condition.

When evaporation and heat flow are simulated, the evaporation rate is calculated using Equation (4.16):

$$e = c_e \left[\frac{\rho_{va} - \frac{\rho_{vss}^j + \rho_{vss}^{j-1}}{2}}{\rho_w r_h^{j-3/2}} \right]$$

Because of the dependence of e on ρ_{vss} , the evaporation rate is a nonlinear function of the suction head, h_1 , of the surface node. A fraction of the dependence of e on h_1 can be represented by expanding the exponential in Equation (4.16) and moving the linear h_1 term to the left-hand side of the matrix by modifying B_1 and D_1 . The identity used to expand the exponential is

$$\exp(f(h_1)) = 1 + f(h_1) + \frac{f(h_1)^2}{2!} + \frac{f(h_1)^3}{3!} \dots = [\exp(f(h_1)) - f(h_1)] + f(h_1)$$

where $f(h_1) = -h_1 M g / R T$. The modifications to the coefficients are

$$B_1^* = B_1^* - \frac{\rho_{vs} h_1^j M g}{r_h^{j-3/2} \rho_w R T_1^{j-1} (z_2 - z_1)}$$

$$D_1^* = D_1^* - \frac{\rho_{vs} h_1^j M g}{r_h^{j-3/2} \rho_w R T_1^{j-1} (z_2 - z_1)}$$

where B_1^* and D_1^* on the right-hand side represent the unmodified version calculated previously.

5.1.3 Lower Boundary Node

Of the four options for determining the lower boundary condition, one is a fixed-head option. For this option, the user specifies in the initial conditions what the head value of the node will be. The solution equation for node $n - 1$ changes to

$$A_{n-1}^* h_{n-2}^j + B_{n-1}^* h_{n-1}^j = D_{n-1}^* - C_{n-1}^* h_n^j$$

and the number of equations to be solved is reduced by one. The user can specify a constant water table condition by using this fixed-head option and setting h_n to zero.

The three other options are flux options. The general form of Equation (5.4) that is pertinent to all three options is

$$A_n^* h_{n-1}^j + B_n^* h_n^j = D_n^*$$

where

$$A_n^* = K_{T_{n-1/2}}^j / (z_n - z_{n-1})^2$$

$$B_n^* = \frac{C_n^{j-1/2}}{t_n^j - t_{n-1}^{j-1}} - K_{T_{n-1/2}}^j / (z_n - z_{n-1})^2$$

$$C_n^* = 0$$

$$D_n^* = \frac{C_n^{j-1/2} h_n^{j-1}}{t_n^j - t_{n-1}^{j-1}} - \frac{1}{z_n - z_{n-1}} \left[2q_{n+1/2}^{j-1/2} - K_{T_{n-1/2}}^{j-1} \left(\frac{h_n^{j-1} - h_{n-1}^{j-1}}{z_n - z_{n-1}} \right) \right]$$

$$- G K_{L_{n-1/2}}^{j-1} - G K_{L_{n-1/2}}^j + \left(K_{VT_{n-1/2}}^j + K_{VT_{n-1/2}}^{j-1} \right) \left(\frac{T_n^{j-1} - T_{n-1}^{j-1}}{z_n - z_{n-1}} \right) \Bigg]$$

For the impermeable boundary option, the time-averaged flux, $q_{n+1/2}$, is set equal to zero. For the specified flux boundary, $q_{n+1/2}$ is set equal to values specified by the code user. For the unit-gradient boundary condition, the flux is calculated as

$$q_{n+1/2}^{j-1/2} = \frac{1}{2} \left(K_{L_n}^j + K_{L_n}^{j-1} \right)$$

5.1.4 Mass Balance Error

Two options exist for calculating the mass balance error in UNSAT-H. The first, which is identical to that used by Gupta et al. (1978), is to monitor the nodes for the largest fractional change in θ during each time step. This error is calculated as

$$\text{Error} = \text{MAX} \left| \frac{\theta_i^j - \theta_i^{j-1}}{\theta_i^{j-1}} \right|$$

Although not a true measure of error, this calculation does allow the user to monitor the system for the node with the largest change in water content. Generally, that node is assumed to be the source of the largest error.

The second option in UNSAT-H is to calculate an actual mass-balance error. First, soil-water storage at the end of a time step is calculated using

$$S_w^j = \theta_1^j \left(\frac{z_2 - z_1}{2} \right) + \theta_n^j \left(\frac{z_n - z_{n-1}}{2} \right) + \sum_{i=2}^{n-1} \theta_i^j \left(\frac{z_{i+1} - z_{i-1}}{2} \right)$$

Then, the mass balance error for the time step can be obtained using

$$\text{Error} = I^j - E^j - T^j - D^j - S_w^j$$

where the terms I^j , E^j , T^j , D^j , and S_w^j refer to the amounts of infiltration, evaporation, transpiration, drainage, and change in storage, respectively, that have occurred during the time step.

5.2 TIME STEPS

Time steps must be kept small to solve the system of nonlinear equations with a minimum of error associated with the time discretization. Ideally, the optimal size of the time steps would be infinitesimally small. Practically, however, their size must be sufficiently large that a solution can be reached in a reasonable amount of computer time. In UNSAT-H, the time step is allowed to vary between specified minimum and maximum values. The actual size of the time step used depends on assessment of the mass-balance error. Additional options for controlling the time step are available. These options allow the code user to specify the sizes of the initial time step, the time step at the start of an infiltration event, and the maximum allowable change in head per time step.

During simulations, time-step adjustments are carried out as follows. After solving the water flow equations to determine the head, an error is calculated and compared to the allowable limit. If the limit is exceeded, the calculations are rejected, the time step is reduced by a factor between 0.5 and 1.0 (depending on the degree to which the error exceeds the assigned limit), and the coefficient matrix is recalculated and solved. This process continues until either the error is within the allowable limit or the time step is reduced below the minimum allowable value. At this point, the program will accept the solution and its error, and proceed with the simulation using the user-prescribed minimum time step.

When the error is within the allowable limit, the next time step is increased relative to the one previously used. The size of each successive time-step can be increased until the maximum allowable time step, as defined

by the user, is reached. From then on, as long as the error criteria are satisfied, the time-step size will be set to the maximum value.

Once a head solution is obtained in which the mass-balance error criterion is met, the program proceeds to solve for temperature if the heat flow option is chosen. The heat flow calculations do not affect the size of the time step.

5.3 FINITE DIFFERENCE APPROXIMATION OF HEAT FLOW

In the Crank-Nicholson method, the time derivatives are evaluated at the midpoint of the time step. Thus, Equation (4.21) is approximated in the computer code as

$$\begin{aligned}
 & C_{h_i}^{j-1/2} \frac{T_i^j - T_i^{j-1}}{t^j - t^{j-1}} + C_{v_i}^{j-1/2} \frac{\theta_{v_i}^j - \theta_{v_i}^{j-1}}{t^j - t^{j-1}} + C_{\ell_i}^{j-1/2} \frac{\theta_i^j - \theta_i^{j-1}}{t^j - t^{j-1}} \\
 & = \frac{-2}{z_{i+1} - z_{i-1}} \left[q_{h_{i+1/2}}^{j-1/2} - q_{h_{i-1/2}}^{j-1/2} \right] \quad (5.5)
 \end{aligned}$$

where

$$C_{h_i}^{j-1/2} = \frac{C_{h_i}^j + C_{h_i}^{j-1}}{2}$$

$$C_{v_i}^{j-1/2} = \left[\left(L_o + C_{hv} (T_i^j - T_o) \right) + \left(L_o + C_{hv} (T_i^{j-1} - T_o) \right) \right] / 2$$

$$C_{\ell_i}^{j-1/2} = \left[C_{hw} (T_i^j - T_o) + C_{hw} (T_i^{j-1} - T_o) \right] / 2$$

and

$$q_{h_{i\pm 1/2}}^{j-1/2} = \frac{q_{h_{i\pm 1/2}}^j + q_{h_{i\pm 1/2}}^{j-1}}{2}$$

The subscript i denotes the node at depth z_i . The superscript j denotes the time, t^j , for which the equations are solved.

The flux terms at the midpoints between nodes are approximated by

$$q_{h_{i+1/2}}^j = -k_{h_{i+1/2}}^j \left(\frac{T_{i+1}^j - T_i^j}{z_{i+1} - z_i} \right) + \left[L_o + c_{hv} \left(\frac{T_{i+1}^j + T_i^j}{2} - T_o \right) \right] q_{v_{i+1/2}}^{j-1/2} \quad (5.6a)$$

$$+ c_{hw} \left(\frac{T_{i+1}^j + T_i^j}{2} - T_o \right) q_{l_{i+1/2}}^{j-1/2}$$

and

$$q_{h_{i-1/2}}^j = -k_{h_{i-1/2}}^j \left(\frac{T_i^j - T_{i-1}^j}{z_i - z_{i-1}} \right) + \left[L_o + c_{hv} \left(\frac{T_i^j + T_{i-1}^j}{2} - T_o \right) \right] q_{v_{i-1/2}}^{j-1/2} \quad (5.6b)$$

$$+ c_{hw} \left(\frac{T_i^j + T_{i-1}^j}{2} - T_o \right) q_{l_{i-1/2}}^{j-1/2}$$

The thermal conductivity values in Equations (5.6a,b) are calculated using an arithmetic mean. The q_v term in Equations (5.6a,b) is the sum of q_{vh} and q_{vT} , and is obtained from solution of the water flow equation. Within a time step, the effect of any temperature change on q_v is assumed to be negligible. When the fluxes are evaluated at time $j-1$, the other parameters in Equations (5.6a,b) are evaluated at time $j-1$, except q_v and q_l .

5.3.1 Interior Nodes

Equation (5.5) is rearranged to solve for the temperature values at the end of a particular time step, with the general form of the rearranged equation being

$$A_i^* T_{i-1}^j + B_i^* T_i^j + C_i^* T_{i+1}^j = D_i^* \quad (5.7)$$

For the boundary nodes, the exact form of the coefficients in Equation (5.7) depends on the boundary conditions chosen. For all interior nodes, however, the coefficients for nodes $i = 2, n-1$ are

$$A_i^* = \frac{1}{(z_{i+1} - z_{i-1})} \left[\frac{-k_{hi-1/2}^j}{(z_i - z_{i-1})} - \frac{C_{hv}}{2} q_{vi-1/2}^{j-1/2} - \frac{C_{hw}}{2} q_{li-1/2}^{j-1/2} \right]$$

$$B_i^* = \frac{C_{hi}^{j-1/2}}{t^j - t^{j-1}} + \frac{1}{(z_{i+1} - z_{i-1})} \left[\frac{k_{hi+1/2}^j}{(z_{i+1} - z_i)} + \frac{k_{hi-1/2}^j}{(z_i - z_{i-1})} \right]$$

$$+ \frac{C_{hv}}{2} \left[\frac{\theta_{vi}^j - \theta_{vi}^{j-1}}{t^j - t^{j-1}} + \frac{q_{vi+1/2}^{j-1/2} - q_{vi-1/2}^{j-1/2}}{(z_{i+1} - z_{i-1})} \right]$$

$$+ \frac{C_{hw}}{2} \left[\frac{\theta_{li}^j - \theta_{li}^{j-1}}{t^j - t^{j-1}} + \frac{q_{li+1/2}^{j-1/2} - q_{li-1/2}^{j-1/2}}{(z_{i+1} - z_{i-1})} \right]$$

$$C_i^* = \frac{1}{(z_{i+1} - z_{i-1})} \left[\frac{-k_{hi+1/2}^j}{(z_{i+1} - z_i)} + \frac{C_{hv}}{2} q_{vi+1/2}^{j-1/2} + \frac{C_{hw}}{2} q_{li+1/2}^{j-1/2} \right]$$

$$D_i^* = \frac{C_{hi}^{j-1/2} T_i^{j-1}}{t^j - t^{j-1}} - \frac{1}{z_{i+1} - z_{i-1}} \left[-k_{hi+1/2}^{j-1} \left(\frac{T_{i+1}^{j-1} - T_i^{j-1}}{z_{i+1} + z_i} \right) + k_{hi-1/2}^{j-1} \left(\frac{T_i^{j-1} - T_{i-1}^{j-1}}{z_i - z_{i-1}} \right) \right]$$

$$+ \left(L_o + C_{hv} \left(\frac{T_i^{j-1}}{2} - T_o \right) \right) \left(\frac{\theta_{vi}^j - \theta_{vi}^{j-1}}{t^j - t^{j-1}} \right) - \frac{1}{z_{i+1} - z_{i-1}} \left[(L_o - C_{hv} T_o) \right.$$

$$\left. \left(q_{vi+1/2}^{j-1/2} - q_{vi-1/2}^{j-1/2} \right) + \left[L_o + C_{hv} \left(\frac{T_{i+1}^{j-1} + T_i^{j-1}}{2} - T_o \right) \right] q_{vi+1/2}^{j-1/2} \right]$$

$$- \left[L_o + c_{hv} \left(\frac{T_i^{j-1} + T_{i-1}^{j-1}}{2} - T_o \right) \right] q_{v,i-1/2}^{j-1/2} - c_{hw} \left(\frac{T_i^{j-1}}{2} - T_o \right)$$

$$\frac{\theta_i^j - \theta_i^{j-1}}{t^j - t^{j-1}} = \frac{1}{z_{i+1} - z_{i-1}} \left[c_{hw} \left(\frac{T_{i+1}^{j-1} + T_i^{j-1}}{2} - T_o \right) q_{l,i+1/2}^{j-1/2} \right. \\ \left. - c_{hw} \left(\frac{T_i^{j-1} + T_{i-1}^{j-1}}{2} - T_o \right) q_{l,i-1/2}^{j-1/2} - c_{hw} T_o \left(q_{l,i+1/2}^{j-1/2} - q_{l,i-1/2}^{j-1/2} \right) \right]$$

5.3.2 Surface Boundary Node

The values of the coefficients assigned to node 1 (the surface node) depend on the option chosen for the surface boundary condition for heat flow. Two of these options in UNSAT-H Version 2.0 permit specification of either a constant or variable temperature for node 1. The resulting equation for heat flow at node 2 (the node below node 1) is

$$B_2^* T_2^j + C_2^* T_3^j = D_2^* - A_2^* T_1^j$$

In this case, the number of equations in the solution matrix is reduced by one because T_1 is already known.

The remaining two options for the surface boundary condition for heat flow in UNSAT-H Version 2.0 are to treat the surface boundary as a heat flux. The special form of Equation (5.7) for this option looks like

$$B_1^* T_1^j + C_1^* T_2^j = D_1^*$$

$$A_1^* = 0$$

$$\begin{aligned}
B_1^* &= \frac{C_{h1}^{j-1/2}}{t^j - t^{j-1}} + \frac{k_{h3/2}^j}{(z_2 - z_1)^2} \\
&+ \frac{C_{hv}}{2} \left[\frac{\theta_{v1}^j - \theta_{v1}^{j-1}}{t^j - t^{j-1}} + \frac{q_{v3/2}^{j-1/2}}{(z_2 - z_1)} \right] - C_{hw} \frac{q_{v1/2}^{j-1/2}}{(z_2 - z_1)} \\
&+ \frac{C_{hw}}{2} \left[\frac{\theta_1^j - \theta_1^{j-1}}{t^j - t^{j-1}} + \frac{q_{13/2}^{j-1/2} - q_{11/2}^{j-1/2}}{(z_2 - z_1)} \right]
\end{aligned}$$

$$C_1^* = \frac{1}{(z_2 - z_1)^2} \left[-k_{h3/2}^j + \frac{C_{hv}}{2} q_{v3/2}^{j-1/2} + \frac{C_{hw}}{2} q_{13/2}^{j-1/2} \right]$$

$$\begin{aligned}
D_1^* &= \frac{C_{h1}^{j-1/2} T_1^{j-1}}{t^j - t^{j-1}} - \frac{1}{(z_2 - z_1)} \left[-k_{h3/2}^{j-1} \left(\frac{T_2^{j-1} - T_1^{j-1}}{z_2 + z_1} \right) - q_{h1/2}^{j-1/2} \right] \\
&+ \left(L_o + C_{hv} \left(\frac{T_1^{j-1}}{2} - T_o \right) \right) \left(\frac{\theta_{v1}^j - \theta_{v1}^{j-1}}{t^j - t^{j-1}} \right) - \frac{1}{z_{i+1} - z_{i-1}} \left[(L_o - C_{hv} T_o) q_{v3/2}^{j-1/2} \right. \\
&+ \left. \left[L_o + C_{hv} \left(\frac{T_2^{j-1} + T_1^{j-1}}{2} - T_o \right) \right] q_{v3/2}^{j-1/2} - C_{hw} T_o q_{v1/2}^{j-1/2} \right. \\
&- \left. C_{hv} \left(T_1^{j-1} - T_o \right) q_{v1/2}^{j-1/2} \right] - C_{hw} \left(\frac{T_i^{j-1}}{2} - T_o \right) \\
&\frac{\theta_1^j - \theta_1^{j-1}}{t^j - t^{j-1}} - \frac{1}{z_2 - z_1} \left[C_{hw} \left(\frac{T_2^{j-1} + T_1^{j-1}}{2} - T_o \right) q_{13/2}^{j-1/2} \right.
\end{aligned}$$

$$- C_{hw} \left(\frac{T_1^{j-1} + T_a^{j-1/2}}{2} - T_o \right) q_{l1/2}^{j-1/2} - C_{hw} T_o \left(q_{l3/2}^{j-1/2} - q_{l1/2}^{j-1/2} \right) \Big]$$

According to the option chosen, the time-averaged flux, q_h , across the soil surface can be calculated (using Equation (4.26)) as a function of weather and soil parameters, or specified by the code user. When evaporation occurs, $q_{v1/2} < 0$ and $q_{l1/2} = 0$. When precipitation occurs, $q_{l1/2} = 0$ and $q_{l1/2} > 0$.

5.3.3 Lower Boundary Node

Of the three options for determining the lower boundary condition, one is a constant temperature option. For this option, the user specifies in the initial conditions what the temperature value of the node will be. The solution equation for node $n - 1$ changes to

$$A_{n-1}^* T_{n-2}^j + B_{n-1}^* T_{n-1}^j = D_{n-1}^* - C_{n-1}^* T_n^j$$

and the number of equations to be solved is reduced by one.

The two other options are flux options. The general form of Equation (5.7) pertinent to these two options is

$$A_n^* T_{n-1}^j + B_n^* T_n^j = D_n^*$$

where

$$A_n^* = \frac{1}{(z_n - z_{n-1})^2} \left[-k_{h_{n-1/2}}^j - \frac{C_{hv}}{2} q_{v_{n-1}}^{j-1/2} - \frac{C_{hw}}{2} q_{l_{n-1}}^{j-1/2} \right]$$

$$B_n^* = \frac{C_{h_n}^{j-1/2}}{t^j - t^{j-1}} + \frac{k_{h_{n-1}}^j}{(z_n - z_{n-1})^2}$$

$$+ \frac{C_{hv}}{2} \left[\frac{\theta_v^j - \theta_v^{j-1}}{t^j - t^{j-1}} - \frac{q_{v,n-1/2}^{j-1/2}}{(z_n - z_{n-1})} \right]$$

$$+ \frac{C_{hw}}{2} \left[\frac{\theta_n^j - \theta_n^{j-1}}{t^j - t^{j-1}} + \frac{q_{1,n+1/2}^{j-1/2} - q_{1,n-1/2}^{j-1/2}}{(z_n - z_{n-1})} \right]$$

$$C_n^* = 0$$

$$D_n^* = \frac{C_{hn}^{j-1/2} T_n^{j-1}}{t^j - t^{j-1}} - \frac{1}{z_{i+1} - z_{i-1}} \left[2 q_{h,n+1/2}^{j-1/2} + k_{h,i-1/2}^{j-1} \left(\frac{T_i^{j-1} - T_{i-1}^{j-1}}{z_i - z_{i-1}} \right) \right]$$

$$+ \left(L_o + C_{hv} \left(\frac{T_n^{j-1}}{2} - T_o \right) \right) \left(\frac{\theta_v^j - \theta_v^{j-1}}{t^j - t^{j-1}} \right) - \frac{1}{z_{i+1} - z_{i-1}} \left[- (L_o - C_{hv} T_o) q_{v,n-1/2}^{j-1/2} \right.$$

$$\left. - \left[L_o + C_{hv} \left(\frac{T_n^{j-1} + T_{n-1}^{j-1}}{2} - T_o \right) \right] q_{v,n-1/2}^{j-1/2} \right] - C_{hw} \left(\frac{T_n^{j-1}}{2} - T_o \right)$$

$$\frac{\theta_n^j - \theta_n^{j-1}}{t^j - t^{j-1}} - \frac{1}{z_n - z_{n-1}} \left[C_{hw} \left(\frac{T_b^{j-1} + T_n^{j-1}}{2} - T_o \right) q_{1,n+1/2}^{j-1/2} \right.$$

$$\left. - C_{hw} \left(\frac{T_n^{j-1} + T_{n-1}^{j-1}}{2} - T_o \right) q_{1,n-1/2}^{j-1/2} - C_{hw} T_o \left(q_{1,n+1/2}^{j-1/2} - q_{1,n-1/2}^{j-1/2} \right) \right]$$

One of the two flux options specifies a temperature gradient (∇T_n) for the lower boundary condition. For this option, the flux is calculated as

$$q_{h_{n+1/2}}^{j-1/2} = \frac{1}{2} \left(k_{h_n}^j + k_{h_n}^{j-1} \right) \nabla T_n$$

The second flux option specifies a constant heat flux. With this option, the flux can be set equal to zero to simulate a boundary impermeable to heat flow. When $q_{1_{n+1/2}} \neq 0$, $T_b = T_n + (z_n - z_{n-1}) \nabla T_n$. A vapor flux across the lower boundary is not permitted.

5.3.4 Heat Balance Error

Once a temperature solution has been obtained, a heat balance error (HBE) is calculated. First, the change in heat storage (ΔS_h) of the soil during the time step is calculated using

$$\begin{aligned} S_h = & \left(\frac{z_2 - z_1}{2} \right) \Delta T_1 C_{h_1}^{j-1/2} + (L_o + C_{hv} \tilde{T}_1) (\theta_{v_1}^j - \theta_{v_1}^{j-1}) + C_{hw} \tilde{T}_1 (\theta_1^j - \theta_1^{j-1}) \\ & + \left(\frac{z_n - z_{n-1}}{2} \right) \Delta T_n C_{h_n}^{j-1/2} + (L_o + C_{hv} \tilde{T}_n) (\theta_{v_n}^j - \theta_{v_n}^{j-1}) + C_{hw} \tilde{T}_n (\theta_n^j - \theta_n^{j-1}) \\ & + \left(\frac{z_{i+1} - z_{i-1}}{2} \right) \Delta T_i C_{h_i}^{j-1/2} + (L_o + C_{hv} \tilde{T}_i) (\theta_{v_i}^j - \theta_{v_i}^{j-1}) + C_{hw} \tilde{T}_i (\theta_i^j - \theta_i^{j-1}) \end{aligned}$$

where $\Delta T_i = T_i^j - T_i^{j-1}$

$$\tilde{T}_i = \frac{T_i^j + T_i^{j-1}}{2} - T_o$$

Then, the heat balance error for the time step can be obtained using

$$HBE^j = R_n^j - LE^j - H^j - QH_n^j - \Delta S_h^j$$

where the terms R_n^j , LE^j , H^j , and QH_n^j refer to the net radiation, latent heat, sensible heat, and lower-boundary heat flows that have occurred during the time step. The calculated HBE^j value is an informative index of the heat flow calculations and does not affect the calculation of water or heat flow or the time-step size. Individual HBE^j values are summed during each output cycle.

6.0 CODE DESIGN

The UNSAT-H model consists of three main programs: DATAINH, UNSATH, and DATAOUT. The interconnections among these programs, as well as the file specifications and subroutine calls, are illustrated in Table 6.1. The symbol "*" in the file names is a "wildcard character" that can be replaced by any problem name. For example, the input file for a drainage problem might be called DRAIN.INP. The three-character ending of the file names (e.g., BIN, RES) is called the "file name extension." BIN is a convention in the UNSAT-H model that indicates a binary input file, INP an ASCII input file, RES a binary results file, and LIS and OUT are ASCII results files.

6.1 DATAINH

The purpose of DATAINH is to process the input data that are destined for the UNSATH program. Having DATAINH preprocess the data lessens the likelihood that UNSATH will fail to run because of input errors. Thus, jobs (program runs) submitted to run overnight have a greater likelihood of running successfully, given that the input data have already been checked by DATAINH.

TABLE 6.1. Data Flow, Program Tasks, and Subroutines

<u>Input Files</u>	<u>Program</u>	<u>Purpose</u>	<u>Output Files or Device</u>	<u>Subroutines and Functions</u>
*.INP (ASCII format)	DATAINH	Process input data	*.BIN (binary format), printer, screen	CALPET, MYHRLY, POLYCH, POLYKH, POLYTH, RLD, THERMK
*.BIN (binary format)	UNSATH	Model calculations	*.RES (binary format)	B L R, DELCHK, HDRYCALC, HEATFLOW, NETRAD, POLYCH, POLYKH, POLYTH, RLD, THERME, THERMK, TRIDAG
*.RES (binary format)	DATAOUT	Process output data	*.LST, *.PRO, *.OUT, TOSS.OUT (ASCII format), printer, screen	DDSUM, HARDCOPY, INITSUM, LISTDATA, PROFILER, READREC, REINIT, SCAN, SUMMARY

The DATAINH program is run interactively. The program reads the data contained in the specified *.INP file, checks for errors, performs calculations (such as unit conversions), and then writes the data in binary form to a file with the same name as the input file, but with the extension BIN. The error checking done by DATAINH consists mostly of determining whether the choices for various options exist (e.g., if an option three was chosen when only two options exist), whether array dimensions are exceeded, and whether rainfall dates are listed in chronological order.

Whenever estimates of soil hydraulic properties are required, DATAINH calls the subroutines POLYCH, POLYKH, and POLYTH to calculate capacity, hydraulic conductivity, and water content, respectively. Subroutine THERMK is called to calculate thermal conductivities, heat capacities, and volumetric vapor contents. Plant root distribution is calculated using the function RLD. The UNSATH program uses the identical function. Hourly factors to distribute daily PET are calculated by the subroutine MYHRLY. Subroutine CALPET processes daily weather data into PET values using the Penman equation of Doorenbos and Pruitt (1977).

All data required by UNSATH are output to a *.BIN file in the format shown in Figure 6.1. Dimensions and variable type for each parameter are shown in the code listings (Appendix A).

```

WRITE(LUB) IPLANT, LOWER, NDAYS, NDAY, NPRINT, ITOPBC, HTOP, TGRAD,
!      KOPT, KEST, UP, DOWN, IVAPOR, DAYEND, NYEARS, ISWDIF,
!      MATN, NPT, NGRAY, MAXSUB, MAXPOL, NSURPE, NSOW, NHRVST,
!      INC, MXROOT, NWATER, DV, STOPHR, ET_OPT, SH_OPT, INMAX,
!      INHMAX, IHEAT, UPPERH, LOWERH, GRAV, TSWEAN, TSAMP, IFILE
WRITE(LUB) DMAXBA, DELMAX, DELMIN, RAINIF, RFACT, HIRRI, HDRY, SATK,
!      DRYK, SATC, DRYC, SATTH, DRYTH, AA, B1, B2, TMOIST, LOG10E,
!      DHMAX, DHFACT, ICONVH, QHTOP, QUTTIM
WRITE(LUB) TITLE, (Z(I), H(I), NTRoot(I), THETA(I), KL(I), C(I),
!      T(I), CHSOIL(I), I=1, NPT), THETAW, THETAD, THETAN, RDF, FPET,
!      MGR, VC, TSOIL, PTRANS, PEVAP0, QWLEAK, QHLEAK
WRITE(LUB) MAT, IHY, SINLAT, COSLAT, TANLAT, TPIY, PI, DAYSOLAR, SB, CHW,
!      ZU, ZH, ZW, ZT, D, VK, SEXT, CHA, LHV, ICLOUD, TCON, CHS, EF, WATDEN,
!      LVHD, CHV, TO
IF (ET_OPT .EQ. 0) THEN
  WRITE(LUB) IRDAY, IRTYPE, EFICEN, NP,
!      (RTIME(J), AMOUNT(J), J=1, NP)
ELSE
  WRITE(LUB) (METDAT(J, I), J=1, 7), IRTYPE, EFICEN, NP,
!      (RTIME(J), AMOUNT(J), J=1, NP)
ENDIF

```

FIGURE 6.1. Format of the *.BIN File Created by DATAINH For Input to UNSATH. LUB is a logical name for the binary output file.

6.2 UNSATH

The UNSATH program is the heart of the UNSAT-H model. The *.BIN file created by DATAINH serves as the input file for UNSATH. The major steps executed within UNSATH are illustrated in Figures 6.2 and 6.3. The steps start with data input and end with the final summary output of the simulation to file *.RES.

FIGURE 6.2. Operations Flow of UNSATH

FIGURE 6.3. Operations Flow of DELSUB Loop Within UNSATH

While executing, UNSATH calls the subroutines POLYCH, POLYKH, and POLYTH whenever information on soil hydraulic properties is needed. When the effects of plants are simulated, function RLD is called to calculate the root density. Subroutine TRIDAG is called to solve the matrix of flow equations. Subroutine DELCHK is called at the end of every time step. If the solution from TRIDAG for a particular time step is identified by UNSATH as unsuccessful (e.g., the mass-balance error is too large), the solution is rejected, DELCHK decreases the time-step size and the problem is re-solved. Conversely, if the solution

is acceptable, DELCHK increases the time-step size for the next step. The new time-step size is bounded by user-determined maximum and minimum limits. If heat flow is being simulated, subroutine HEATFLOW is called after DELCHK. HEATFLOW calls subroutines THERME and THERMK for soil thermal properties, B_L_R and NETRAD for boundary layer resistance and net radiation if evaporation is being simulated, and TRIDAG to solve the matrix of heat flow equations.

Simulation data that are output to the *.RES file include initial conditions, DELSUB and day-end values for head, water content, water and heat flow, temperatures, plant-sink terms, water and heat-balance terms, and at the end of the file, the simulation-end results. The *.RES format is shown in Figure 6.4; the dimensions and variable type of each parameter are shown in the code listings in Appendix A. Each parameter is defined in Appendix C.

```

C**  Output of simulation parameters to first record of *.RES file
      WRITE(LUB,REC=1) NPT,IPLANT,(Z(I),I=1,NPT),DAYEND,NPRINT,NSURPE,
      !      NTOTAL,IFILE,SDATE,STIME,UV,DAYBEG,STOPHR,TITLE,IHEAT,ICLOUD,
      !      ET_OPT,SH_OPT,UPPER,UPPERH,LOWER,LOWERH

C**  Output of daily values at the end of each simulated day
C**  (format for DELSUB totals is identical)
      IF (IPLANT .EQ. 0) THEN
        IF (IHEAT .EQ. 0) THEN
          !      WRITE(LUB,REC=2) IDAY, HOUR, (H(J),THETA(J),DAYQ(J),
          !      J=1,NPT),DAYINF,DAYRAN,DAYE,DAYTRA,DAYRUN,
          !      TPREV,TWOIST,DAYSTP,PE,PT,DAYTIM,DAYAST,DAYUBC,RHMEAN,
          !      TMEAN,HDRY,DAYRN,DAYSHF,DAYSEN,DAYHBE,
          !      TA,TMAX,TMIN,VO_A,WIND,CLOUD,SR_MEAS,DAYLE,DAYS DH
          ELSE
            !      WRITE(LUB,REC=2) IDAY, HOUR, (H(J),THETA(J),DAYQ(J),
            !      T(J),DAYQH(J),J=1,NPT),DAYINF,DAYRAN,DAYE,DAYTRA,DAYRUN,
            !      TPREV,TWOIST,DAYSTP,PE,PT,DAYTIM,DAYAST,DAYUBC,RHMEAN,
            !      TMEAN,HDRY,DAYRN,DAYSHF,DAYSEN,DAYHBE,
            !      TA,TMAX,TMIN,VD_A,WIND,CLOUD,SR_MEAS,DAYLE,DAYS DH
          ENDIF
        ELSE
          !      WRITE(LUB,REC=IREC) IDAY, HOUR, (H(J),THETA(J),DAYQ(J),
          !      DAYS NK(J),J=1,NPT),DAYINF,DAYRAN,DAYE,DAYTRA,
          !      DAYRUN,TPREV,TWOIST,DAYSTP,PE,PT,DAYTIM,
          !      DAYAST,DAYUBC,RHMEAN,TMEAN,HDRY,DAYS DH
          ENDIF
      ENDIF

C**  Output of simulation totals at the conclusion of the simulation
      WRITE(LUB,REC=IREC) IDAY,G,IPLANT,TPET,TPT,TTRA,TPE,TE,TETRAN,
      !      TRUNDF,TINF,TTIM,TRAIN,APPLIED,TTIRRI,TWOIST,TERR,TSTP,
      !      (TQ(I),TQH(I),I=1,NPT),TAST,TUBC,TRN,TSHF,TSEN,TLE,THBE,TS DH

```

FIGURE 6.4. Format of the *.RES Output File Created by UNSATH. LUB is a logical name for the binary output file.

6.3 DATAOUT

The purpose of DATAOUT is to process the UNSATH output data. Specifically, DATAOUT converts the binary output data into ASCII format so that the results can be sent to either a screen for viewing or to a printer or file for permanent record. The program DATAOUT, which is run interactively, reads the first record of the data file and uses the subroutine READREC to read the DELSUB and daily summaries. The subroutines INITSUM and DDSUM are used to output the initial condition and DELSUB/daily summaries, respectively. The subroutine SUMMARY is used to read and write the simulation-end summary. The main program, DATAOUT, uses the five subroutines described in Table 6.2 to write the data.

TABLE 6.2. DATAOUT Subroutines that Provide Output Options

Subroutine	Function
REINIT	Creates an output file (called TOSS.OUT) containing the simulation head values for the end of any user-chosen DELSUB period or day in a format ready for inclusion in a *.INP file. The TOSS.OUT file can serve as the initial condition for simulating the next year.
SCAN	Allows the user to see on the screen a summary of the initial conditions, any DELSUB period or day of the simulation, or the final simulation results. No hardcopy listings are created.
HARDCOPY	Creates a *.OUT file. Two choices exist for what goes into the file: a summary of the first and last simulation days and the simulation summary; or a summary of every DELSUB period and day, as well as the simulation summary.
LISTDATA	Enables the code user to view (on the screen) head, water content, infiltration, fluxes, and storage as a function of time. The code user has the option of routing the data to a separate file for subsequent printing or plotting.
PROFILER	Enables the code user to view (on the screen) head, water-content, water flow, temperature, or heat flow data as a function of depth in the soil profile. The code user has the option of routing the data to a separate file for subsequent printing or plotting.

7.0 CODE USE

The UNSAT-H Version 2.0 model uses two basic steps to solve a problem. First, the problem must be formulated in terms of the conceptual model and available site characterization data, and the resulting information assembled in a form that can be used by the computer code. Second, the computer code is run and the results processed for eventual analysis.

7.1 PROBLEM FORMULATION

Application of the UNSAT-H model to a particular problem requires the problem to be formulated in terms understood by the numerical model. Problem formulation entails discretizing the spatial and temporal domain of interest, assigning soil and plant properties, defining the boundary conditions, and specifying program control options.

As an example, assume that the water-balance dynamics of the site illustrated in Figure 7.1a are to be simulated. The problem can be modeled in one dimension in the vertical direction and, therefore, requires discretization (i.e., nodal spacing) as shown in Figure 7.1b. The nodal spacing should be very small near the surface and become progressively larger downward through the profile. The smaller node spacing near the surface is necessary for a correct solution because very large and rapid changes in suction head are expected as the surface dries and wets in response to evaporation and precipitation. Therefore, nodal spacing of 0.1 cm near the surface is commonly used. For conditions in which head changes at the surface are less dramatic, such as for constant ponding, the node spacing can be increased. By convention, the first node (node 1) is at the surface and the last node is at the bottom of the soil profile to be simulated.

Other things being equal, a larger number of nodes provides a more accurate solution, but requires more computer time. Uncertainties regarding the sufficiency of the number of nodes for a particular problem may require repetition of the simulation with more nodes to check the prior solution. If the solution remains essentially the same, additional nodes are not

FIGURE 7.1. Example Problem Formulation: a) Site Description, b) Model Representation

necessary. If the solution changes significantly, then the original number of nodes may have been insufficient (i.e., the node spacing was too large). In that case, repetition of the simulation with smaller node spacings is needed until the solution does not change appreciably.

In the example shown in Figure 7.1a, the soil type changes at the midpoint of the profile. This kind of change may make the solution difficult if the hydraulic properties of the two soils are significantly different. Therefore, the node spacing near the interface of two soils should be decreased (i.e., more nodes in that vicinity), until the solution does not change.

After discretizing the spatial domain, the next step is to assign soil properties. In the example of Figure 7.1a, there are two soil types. Nodes within each soil are assigned the properties of that soil. In other instances, soil layering may be less clearly defined. In those cases, the dominant soil types are identified and soil properties assigned accordingly.

Once soil properties have been assigned, initial conditions must be specified (i.e., specify the head values at the start of the simulation period). If heat flow is being modeled, the temperature values must also be specified. In most instances, soil characterization data consists of neutron probe measurements of water content at several depths within the profile. Based on these measurements, water contents must be assigned to each node. Unfortunately, the measurement depths are unlikely to coincide with the nodal depths. Therefore, values must be interpolated. The nodal water contents must then be converted to head values (the initial conditions required by UNSAT-H) according to the soil hydraulic properties assigned to the respective node.

The next stage in problem formulation is to describe the plant community, if one is present. Required plant data include fraction of surface covered by plants, dates of germination and death, rooting depths, and responses to moisture-related stress.

The lower and upper boundary conditions must be identified next. In Figure 7.1b, the lower boundary is known to be permeable, but measurements of the drainage rate are not available, and the head at the lowest node is not likely to remain constant for long periods of time. As an approximation, a unit gradient can be assumed to exist at the lower boundary because the boundary is well below the root zone. In the absence of heat flow measurements, a rough estimate of the geothermal gradient can be used.

For the surface boundary, daily weather data must be provided if heat flow and evaporation are being modeled. Daily weather data must also be provided if evaporation is being modeled using the PET concept and the code is to calculate the daily PET. Otherwise, daily PET values that are calculated external to the UNSAT-H code, using programs such as FAOPET (Doorenbos and Pruitt 1977), must be provided. Precipitation rates can be entered directly.

Program control variables that can be adjusted include length of time to be simulated, whether hourly or daily data are to be output, maximum and minimum time-step size, and the mass-balance error limit. Some of these choices affect the amount of computer time necessary to solve the problem. For instance, reducing the size of the maximum time step or using very small mass-balance error limits increase the computer time. However, such choices may yield a more accurate solution. Because of the tradeoff between benefits and their costs, program control variables should be chosen carefully. Several trial runs may be needed to optimize both solution accuracy and computer time. (See Section 5.2 for a discussion of time steps.)

When a problem is to be solved using UNSAT-H Version 2.0, the necessary data must be collected into a *.INP file in the format required by the pre-processor program, DATAINH. That format is specified in Appendix B.

7.2 CODE OPERATION

The UNSAT-H code is run on MicroVAX II and VAX 11/780 computers.^(a) The discussion of code operation that follows pertains to those computers. Code operation on other computers may be different.

The three main programs that constitute UNSAT-H are DATAINH, UNSATH, and DATAOUT. These programs input and output data at several points in the program's operation. Their operations involve particular logical units as specified in BVAR.INC and BOUT.INC. The current assignments are listed in Table 7.1. Before running the model, the user must ensure that these logical units have not been redefined.

(a) The MicroVAX II and VAX 11/780 are products of the Digital Equipment Corporation, Maynard, Massachusetts. References to MicroVAX and VAX computers should not be regarded as an endorsement.

TABLE 7.1. Logical Unit Assignments

Logical Unit	Variable	Description
1	LUI	Binary input file unit (input to UNSATH and DATAOUT)
2	LUB	Binary output file unit from DATAINH and UNSATH
5	LUR	Read (interactive input)
6	LUS	Screen (interactive output)
7	Luw	ASCII output file from DATAOUT

The first step in running UNSAT-H is to create the executable files for DATAINH, UNSATH, and DATAOUT. These files can be created by compiling the main programs and their subroutines (listed in Table 6.1) into object files and then linking the appropriate object files. The result should be three executable files, DATAINH.EXE, UNSATH.EXE, and DATAOUT.EXE. When compiling DATAINH and UNSATH, the user must ensure that the files BARRAY.INC, BMET.INC, BSOIL.INC, BTIME.INC, and BVAR.INC are present in the default directory. These *.INC files contain the variable and array declaration statements and are included in the codes by using the FORTRAN "INCLUDE" statement. To redimension UNSATH, the user must modify the statements in the appropriate *.INC file and recompile both programs. DATAOUT and its subroutines use a single *.INC file called BOUT.INC. If DATAINH and UNSATH are redimensioned, the user must ensure that DATAOUT is also redimensioned (within BOUT.INC).

The next step in running the UNSAT-H code is to process the input data (located in a *.INP file) by typing the command RUN DATAINH (assuming DATAINH.EXE is in the default directory). The user will then be queried for the input file name and the desired level of DATAINH output. Output from DATAINH allows the user to verify that input data were read correctly.

The UNSATH program is designed to be run in the batch mode by a command file that instructs the system on file location and provides answers to program queries. Figure 7.2 is a listing of a typical command file. (This file was used to run one of the two simulations described in Section 8.1.) The default directory is established on the first line of the command file.


```

$ SET DEFAULT $DISK3:[HCODE.UNSATH_VERS20]
$ TYPE CLAY.COM
$ TYPE CLAY.INP
$ RUN UNSATH
CLAY
$ COST

```

FIGURE 7.2. Listing of Sample Command File (CLAY.COM) for Running UNSATH in the Batch Mode

Unless instructed otherwise, the system assumes that the input file (*.BIN) and the results file (*.RES) are to be located in the default directory.

The next two lines of the command file are optional, but their use is strongly recommended because they cause copies of the command and ASCII input files to be inserted into the *.LOG file of a simulation. These copies serve as a quality assurance record of the files used.

The RUN UNSATH command (the fourth line of Figure 7.2) initiates actual code operation. If the UNSATH.EXE file is not in the default directory, the RUN UNSATH command must be altered to indicate the directory in which the file is located. For example, the command RUN DISK0:[TRIAL]UNSATH indicates that the file UNSATH.EXE is in the main directory TRIAL, which is located in DISK0. Having only one copy of the code on the computer at a given time saves storage space and ensures that all code users are using the same version.

The fifth line of the command file serves as an answer to an UNSAT-H query for the name of the binary input file (*.BIN, with BIN indicating binary form). No dollar sign appears at the start of this line because the line is a response to a program query, rather than a system command.

The sixth line causes a cost summary of the simulation run to be written to the *.LOG file.

To run the code in the batch mode, the appropriate command file must be submitted to the batch queue. Assuming that the command file CLAY.COM (Figure 7.2) is in the current directory, typing the command

```
SUBMIT/NOPRINTER/LOG=[] CLAY
```


will send the command file to the SYS\$BATCH queue to be processed. Batch jobs normally generate a *.LOG file that contains program output and a summary of the run characteristics (e.g., total time spent in the queue and computer run time). The *.LOG file is automatically printed once the job has finished. With the NOPRINTER option, however, the *.LOG file remains in the user's main directory with the command file name and a *.LOG extension. With the LOG=[] option, the *.LOG file goes to the default directory specified in the command file (Figure 7.2).

The command file shown in Figure 7.2 generates two files: the binary output file, CLAY.RES, and the program *.LOG file, CLAY.LOG. The *.LOG file is in ASCII format and can easily be read, but the *.RES file is binary and, therefore, can only be read by running the program DATAOUT. To run DATAOUT, the user must type the command RUN DATAOUT (assuming the file DATAOUT.EXE is located in the default directory). The user will be asked for the name of the results file to be processed, followed by questions regarding the form of output desired.

When the command file is processed, a batch
normally generates a *.LOG file containing program output and a
copy of the characteristics (e.g., total time spent in the queue and
other run times). The *.LOG file is automatically printed once the job has
finished. With the REPORTING option, however, the *.LOG file residing in the
user's work directory with the command file name and a *.LOG extension, with
the LOG file option, the *.LOG file goes to the default directory specified in
the command file (Figure 2).

The command file shown in Figure 2 generates two files: the binary
output file, EXE.RES, and the program *.LOG file, EXE.LOG. The *.LOG file
is in ASCII format and can easily be read, but the *.EXE file is binary and
therefore, can only be read by running the program DATOUT. To run DATOUT,
the user must type the command RUN DATOUT (assuming the file DATOUT.EXE is
located in the default directory). The user will be asked for the name of
the results file to be processed, followed by questions regarding the form of
output desired.

8.0 EXAMPLE SIMULATIONS

Six examples are provided in this section to illustrate how various UNSAT-H options work. These examples are verification tests of the 1) infiltration, 2) drainage, and 3) heat flow portions of the UNSAT-H code, 4) a simulation of a layered soil system, 5) a simulation that includes the effects of plant transpiration, and 6) a repeat of part of example four but with the addition of heat flow.

8.1 VERIFICATION OF INFILTRATION

Haverkamp et al. (1977) performed several infiltration simulations using different models based on the nonlinear flow equation. One of those models, the head-based implicit model (No. 4 in the Haverkamp paper), is the same as that used in UNSAT-H. To simultaneously verify the infiltration component of UNSAT-H and provide an example of how UNSAT-H works, the Haverkamp et al. (1977) infiltration problem was simulated with UNSAT-H. The UNSAT-H results are compared with those of Haverkamp et al. and with an approximate analytic solution derived by Philip (1969).

8.1.1 Problem Description

Haverkamp et al. (1977) used two soil types: a sand and a clay (Yolo light clay). In UNSAT-H, the sand and clay were described by setting KOPT equal to 2 and 4, respectively, to indicate the type of soil property descriptions. The various coefficients and input parameters used are listed in Table 8.1.

The soil profile depths were 90 and 250 cm for the sand and clay, respectively. Depth increments were 1.0 cm. For the lower boundary, the head at the bottom node was held constant at the initial value of 61.4 cm for the sand and 600 cm for the clay. For the upper boundary, the head at the surface node was held constant at 20.73 cm for the sand and 0.0 cm for the clay. The minimum and maximum time steps were 0.0125 and 0.15 hr, respectively. The complete input file for the clay simulation is shown in Appendix D, Figure D.1.

TABLE 8.1. Coefficients and Parameters Used in the Infiltration Simulations (UNSAT-H symbols are defined in Appendix C)

UNSAT-H Symbols	Sand	Clay	Haverkamp Symbols	Units
THET	0.287	0.495	θ_s	$\text{cm}^3 \text{ cm}^{-3}$
THTR	0.075	0.124	θ_r	$\text{cm}^3 \text{ cm}^{-3}$
A	1.611×10^6	739.0	α	cm^{-1}
B	3.96	4.00	β	--
AIRINT	1.0	1.0	--	cm
SK	34.0	4.428×10^{-2}	K_s	cm hr^{-1}
ALPHA	1.175×10^6	124.6	A	cm^{-1}
BETA	4.74	1.77	B	--
AIRINK	1.0	1.0	--	cm

8.1.2 Results

Figure 8.1 illustrates the results obtained by Haverkamp et al. (1977, Figure 6). Also shown is Philip's (1969) quasi-analytic series solution. According to Haverkamp et al. (1977), the series solution is valid (i.e., the solution converges) only for times less than 600 hr for the clay and 0.29 hr for the sand. The UNSAT-H results are shown as dotted lines in Figure 8.1. For both soils, the agreement among the results of UNSAT-H, Haverkamp et al., and Philip is excellent. This agreement indicates that the infiltration component of UNSAT-H performs satisfactorily for this type of problem. The UNSAT-H output file is shown in Appendix D, Figure D.2. The sand and clay simulations required 0.03 and 1.36 hr of processing time, respectively, on a MicroVAX II.

8.2 VERIFICATION OF DRAINAGE

Kool, Parker, and van Genuchten (1985) used the parameter estimation program ONESTEP to fit drainage data from an outflow experiment. The program estimated values for three parameters of the van Genuchten hydraulic property

FIGURE 8.1. Infiltration Rate and Cumulative Infiltration Versus Time as Determined Using Philip's Solution, the Numerical Code of Haverkamp et al., and UNSAT-H

functions. The Kool, Parker, and van Genuchten (1985) experiment was simulated with UNSAT-H, using their fitted parameters, to verify the drainage component of UNSAT-H and the implementation of the van Genuchten hydraulic property model.

8.2.1 Problem Description

Kool, Parker, and van Genuchten sampled an undisturbed core of silty loam soil from a field in Virginia. They equilibrated the core at zero suction in a Tempe pressure cell with a ceramic plate located at the bottom. The soil core was 3.95 cm long and 5.4 cm in diameter. The porous ceramic plate was 0.57 cm thick and had a K_s value of 0.003 cm/hr. After a complete cycle of drying and wetting, the core was subjected to a pressure of 1000 cm and the drainage that resulted was monitored over time.

Kool, Parker, and van Genuchten measured the parameters θ_s and K_s in the laboratory. The three parameters that were adjusted to optimize the fit to the laboratory drainage data were α , n , and θ_r . Kool, Parker, and van Genuchten chose to simulate the ceramic plate using a constant K_s and a specific capacity of zero. For the UNSAT-H simulation, all materials were described using the same hydraulic property model. Therefore, a set of van Genuchten parameters were derived that would allow the simulated plate to remain nearly saturated at suctions up to 1000 cm. These parameters are included in Table 8.2. The spatial discretization and initial conditions are specified in Table 8.3. At time zero, the head at node 12 was increased to 1000 cm. The complete input file for the drainage simulation is shown in Appendix D, Figure D.3.

TABLE 8.2. Hydraulic Property Parameters for Silt Loam Soil and Ceramic Plate

Parameter	Silt Loam	Ceramic Plate
θ_s (cm ³ cm ⁻³)	0.388	0.388
θ_r (cm ³ cm ⁻³)	0.17321	0.387
α (cm ⁻¹)	0.04705	4.705×10^{-6}
n	1.46097	3.0
K_s (cm hr ⁻¹)	5.4	0.003

TABLE 8.3. Space Discretization and Initial Conditions for the Drainage Simulation

<u>Node</u>	<u>Depth, cm</u>	<u>Suction Head, cm</u>	<u>Material</u>
1	0.0	2.0	Silt Loam
2	0.5	1.5	Silt Loam
3	1.0	1.0	Silt Loam
4	1.5	0.5	Silt Loam
5	2.0	0.0	Silt Loam
6	2.5	-0.5	Silt Loam
7	3.0	-1.0	Silt Loam
8	3.5	-1.5	Silt Loam
9	3.75	-1.75	Silt Loam
10	3.9	-1.9	Silt Loam
11	4.0	-2.0	Ceramic Plate
12	4.52	-2.52	Ceramic Plate

To obtain frequent simulation output during the first 16 hr and less frequent output during the remainder of the simulation, three separate simulations were conducted. The first simulation, using the input file VGTESTA.INP, generated output every 0.002 hr for a 0.5-hr period. This input file is shown in Figure D.3. The second simulation generated output every 0.1 hr for a 15.5-hr period. The third simulation generated output every 24 hr for a 984-hr period. The drainage results from all three simulations were then combined.

One aspect of the work of Kool, Parker, and van Genuchten that cannot be duplicated by UNSAT-H is the approximation used for describing flow in portions of the core that remained saturated during the very early times of drainage. This difference between the two models should not significantly affect the comparison of results because saturated conditions in the simulated core disappeared after less than 0.01 hr.

8.2.2 Results

The results of the first simulation are contained in the output file VGTESTA.OUT shown in Appendix D, Figure D.4. The cumulative drainage results from UNSAT-H simulations are shown in Figure 8.2, along with the simulation results and laboratory measurements from Kool, Parker, and van Genuchten (1985). The close agreement among the two code solutions and the measurements indicates that UNSAT-H simulates drainage correctly. The agreement also indicates that the soil hydraulic property model of van Genuchten has been implemented correctly in UNSAT-H. This simulation required 0.95 hr of processing time on a MicroVAX II.

FIGURE 8.2. Cumulative Drainage Versus Time as Determined by Kool, Parker, and van Genuchten, and by UNSAT-H

8.3 VERIFICATION OF HEAT FLOW

Campbell (1977) reported an analytic solution to a heat conduction problem in which the temperature at the soil surface varies by

$$T(z,t) = \bar{T} + A(0) \sin(\omega t)$$

where $\bar{T}$ = mean surface temperature, K

$A(0)$ = amplitude of surface temperature, K

ω = angular frequency of the temperature oscillation, hr^{-1}

t = time, hr.

Assuming the soil is uniform and infinitely deep, the solution (Campbell 1977) is

$$T(z,t) = \bar{T} + A(0)e^{-z/D} \sin(\omega t_d - z/D) \quad (8.1)$$

where

$$\omega = 2\pi/24$$

and

$$D = \left[\frac{2 k_h}{\omega C_h} \right]^{1/2}$$

For this case, the angular frequency yields a complete surface temperature cycle in 24 hr. To specify that the peak temperature occur at noon, as is done for this example, the t_d value in Equation (8.1) is modified by subtracting 6 hr. The parameter, D , in Equation (8.1) is the damping depth, which is the depth at which the temperature fluctuation has been reduced to 37% (i.e., $1/e$) of its surface value.

8.3.1 Problem Description

A 1-m-deep soil profile is subjected to a temperature variation of 10 K from a mean surface temperature of 288 K occurring at noon. A total of 101 nodes, evenly spaced 1 cm apart, are used to discretize the soil profile.

The soil type is a loamy sand known as lysimeter sand or L-soil (Rockhold, Fayer, and Gee 1988). The hydraulic properties are described using the Brooks-Corey functions, with $\theta_s = 0.4326$, $\theta_r = 0.0381$, $h_e = 9.4$ cm, $b = 1.2846$, and $K_s = 35.3$ cm/hr. The thermal properties are taken from Cass, Campbell, and Jones (1981). Specifically, the parameters listed in their Table 2 (Cass, Campbell, and Jones 1981) for lysimeter sand at 22.5°C were used. The initial temperature at all nodes is 288 K; the initial suction at all nodes is 100 cm ($\theta_i = 0.1007$).

A horizontal profile is simulated; vapor flow is neglected so that water contents and thermal conductivities remain constant during the simulation. The complete input file for the heat flow simulation is shown in Appendix D, Figure D.5. For the analytic solution, $k_h = 27.448$ J cm⁻¹ mole⁻¹ K⁻¹, $C_h = 1.1927$ J cm⁻³ K⁻¹, and $D = 13.26$ cm.

8.3.2 Results

A complete output file from UNSAT-H is shown in Appendix D, Figure D.6. Figure 8.3 contains soil temperature results from UNSAT-H for several depths over a 24-hr period. The analytic solution is included in Figure 8.3 for each depth. Figure 8.4 shows a similar comparison, but for all depths at selected times. The closeness of the match between the analytic solution and the simulated temperatures shown in Figures 8.3 and 8.4 indicates that UNSAT-H correctly solves the heat conduction equation. This simulation required 0.03 hr of processing time on a MicroVAX II.

8.4 LAYERED SOIL SIMULATION

The UNSAT-H model will be used to simulate the water balance of various protective barrier designs. In this example, the functioning of a specific barrier design was simulated for weather conditions in 1962.

8.4.1 Problem Description

The concept of protective barrier design is illustrated in Figure 8.5. The top 30 cm of material is composed of the Composite soil described by Fayer et al. (1985) and gravel 0.5 to 1.0 cm in diameter (15% by weight). The material between the 30- and 150-cm depths is Composite soil. Below the

FIGURE 8.3. Soil Temperature Versus Time as Determined Using an Analytic Solution and UNSAT-H

150-cm depth is gravel 0.6 to 1.3 cm in diameter. The hydraulic properties of all three materials were represented with polynomials given in Fayer et al. (1985). Those same polynomials were used in this simulation (see Appendix D, Figure D.7). Vapor flow was also included. Initial head values for each node were obtained from the output of a previous simulation for the year 1961.

A unit hydraulic gradient was chosen as the lower boundary condition. This choice was reasonable because the lower boundary was located more than 5 m from the surface and well below the zone of possible upward water movement. For the upper boundary condition, hourly values of precipitation and daily values of PET were used. The precipitation data were obtained from the

FIGURE 8.4. Soil Temperature Versus Depth as Determined Using an Analytic Solution and UNSAT-H

Hanford Meteorological Station (HMS). The PET values were calculated using the Penman equation given by Doorenbos and Pruitt (1977) and meteorological data from the HMS. The upper and lower head limits for the surface boundary node were 100,000 and 1 cm, respectively.

8.4.2 Results

Output from this simulation is shown in Appendix D, Figure D.8. Drainage through the barrier amounted to 1.6 cm for the given barrier design and 1962 weather conditions. Annual evaporation was 13.3 cm, which is only 8% of the annual potential evaporation of 165.2 cm. This result is in accord with the conceptual model of Section 3.1 that indicated the rate of evaporation from dry soil would be much less than the potential rate. Clearly, potential

FIGURE 8.5. Conceptual Model of Protective Barrier

evaporation rates should not be used as indicators of actual evaporation. This simulation required 0.54 hr of processing time on a MicroVAX II.

8.5 TRANSPIRATION SIMULATION

A simulation was conducted of the 200 Area closed-bottom lysimeter for 1974 weather conditions to demonstrate how UNSAT-H might be used to model transpiration. Gee and Heller (1985) documented that Russian thistle plants were growing on the lysimeter during that year. Unfortunately, the plant

community was never quantitatively characterized. Consequently, various assumptions were made to provide the model with plant parameters. The data that are available for use in simulations by UNSAT-H are soil hydraulic properties, hourly precipitation, and weather data.

8.5.1 Problem Description

The lysimeter, which is 1829 cm (60 ft) deep, was represented with 43 nodes. The depths of those nodes are given in the input file RHOLYP74.INP listed in Appendix D, Figure D.9.

Laboratory data for the soil water-retention curve and saturated conductivity were taken from Finlayson, Nelson, and Baca (1978). The Brooks-Corey hydraulic property functions were fit to the data and both the laboratory data and the functions are shown in Figure 8.6. Initial conditions (i.e., initial head values) were obtained from the results file of a simulation for the year 1973. These values are shown in Appendix D, Figure D.9.

The plant data needed for the simulation include the LAI, fraction of the soil surface that is bare, rooting density and depth, and plant response to water content (the sink functions). The LAI and the maximum rooting depth are shown in Figure 8.7. Note in the figure that growth started on day 121 and stopped on day 274 of the simulation. In addition, roots were allowed to penetrate to the 3-m depth by day 244. The bare fraction of soil surface was 0.94. Rooting density was calculated using Equation (4.24) such that $a = 4.0$, $b = 0.034$, and $c = 1.0$. Finally, the sink function (Figure 4.3) was approximated with $\theta_w = 0.031$, $\theta_d = 0.0374$, and $\theta_n = 0.4125$.

8.5.2 Results

A year-end summary of the simulation is provided in Appendix D, Figure D.10. Note that although the simulated plants covered only 6% of the lysimeter surface, they were able to remove 2.3 cm of water from the lysimeter. This transpired water represents 17% of the precipitation for the year. Evaporation removed 16 cm of water, resulting in a total annual water loss of 18.3 cm. In other words, storage in the lysimeter decreased by

FIGURE 8.6. Soil Hydraulic Properties for 200 Area Lysimeter

FIGURE 8.7. Plant Parameters: a) Assumed Leaf Area Index, b) Assumed Maximum Rooting Depth

4.9 cm during the year, a condition that is not conducive to long-term deep drainage or recharge. This simulation required 0.98 hr of processing time on a MicroVAX II.

8.6 LAYERED SOIL SIMULATION WITH HEAT FLOW

The major feature added to Version 2.0 of the UNSAT-H model is heat flow. In this example, the functioning of a specific protective barrier design was simulated with concurrent water and heat flow for the weather conditions of days 144 to 146 of 1962. Precipitation on day 144 amounted to 1.30 cm; no precipitation occurred on days 145 and 146.

8.6.1 Problem Description

The problem is as described in Section 8.4. Modifications for this example include the addition of soil thermal properties, aerodynamic coefficients, time-stepping controls, and initial suction heads and temperatures for the end of day 143.

Thermal conductivity parameters for the barrier materials were taken from Cass, Campbell, and Jones (1984). For the Composite soil and the Composite-gravel mix, the parameters for the Portneuf silt loam at 32.5°C were used. For the gravel layer, the parameters for the Lysimeter sand at 22.5°C were used. Although provided by Cass, Campbell, and Jones (1984), parameters for the enhancement factor (η) were calculated to provide η values of 1 (i.e., no enhancement). A test run with actual η values yielded oscillating temperatures between the surface and the 0.2-cm depth, although the water balance results were similar to this example.

The measurement heights for temperature and wind speed were 0.914 and 15.24 m, respectively. Data from Ligothke (1988) indicate a roughness length for momentum of 4.9×10^{-4} m for a soil mix containing 70% silt loam and 30% 0.7-cm-diameter gravel. The roughness length for heat was assumed to equal that for momentum.

The minimum and maximum time-step sizes were reduced from 10^{-7} and 1.0 to 10^{-8} and 0.025 hr, respectively. The mass balance criterion was decreased from 10^{-4} to 10^{-5} cm. In addition, changes in head per time step were

limited to 2×10^4 cm; otherwise, the time step size was reduced by half. The iteration number for water flow was increased from 2 to 3. The iteration number for heat flow was 2. Hourly rather than daily output was specified.

Initial suction head values for the end of day 143 were obtained from the results of the simulation in Section 8.4. The lower head limit for the surface boundary node was 1 cm; no upper limit was specified. Initial soil temperature values for the end of day 143 were specified using the historical average for May for the 91.4-cm depth (Stone et al. 1983). That average, 15.9°C , was applied to all nodes. The complete input file is shown in Figure D.11, Appendix D.

8.6.2 Results

Output from this simulation is shown in Appendix D, Figure D.12. For the three-day period, the surface energy fluxes, suction heads of the top two nodes, and air and surface temperatures are plotted in Figure 8.8(a-c). (Note that the surface heat flux that is reported by UNSAT-H does not include the heat convected via water flow, e.g., precipitation and evaporation.)

In Figure 8.8a, the latent heat flux is small on day 144 because of the precipitation. The abrupt changes in soil heat flux on this day are caused by the intermittent nature of the precipitation (see Figure 8.8d). On day 145, the latent heat flux rises steadily during the day until 1400 hr. By that time, the surface node has dried to a suction head of 4.8×10^5 cm (Figure 8.8b). This surface dryness reduces the latent heat flux (i.e., the evaporation rate). On day 146, the surface node again dries to a high suction head (5×10^5) by midday. As on day 145, the dryness of the surface limits the latent heat flux during midday.

The results in Figure 8.8c show that the surface temperature remains higher than air temperature throughout the three-day period. For the rainy day 144 and the nighttime of days 145 and 146, the surface temperature is within 5K of air temperature. During the daytime of days 145 and 146, however, the surface temperature exceeds the air temperature by as much as 20K. Peak surface temperature occurs between the noon peak of net radiation and the 1500 hr peak of air temperature.

S9001001.1base

FIGURE 8.8. Selected Simulation Results for Water and Heat Flow in a Layered Soil a) energy fluxes at the soil surface, b) suction heads at and 0.1 cm below the soil surface, c) air and soil surface temperature, and d) precipitation

Total evaporation for this three-day period was 0.564 cm, compared to 0.386 cm for the same period for the simulation in Section 8.4. Because of the time-step differences between the two simulations, the isothermal problem in Section 8.4 was repeated with time-step information identical to the problem described in this section. The results from this third simulation show total evaporation to be 0.375 cm. Results such as these will be compared with hourly weighing lysimeter data to verify the efficacy of the code for simulating daily evaporation rates. These comparisons will be published elsewhere in 1990. This simulation of heat flow in layered soil required 0.35 hr of processing time on a MicroVAX II.

FIGURE 8.4. Selected simulation results for heat and mass flow in a layered soil: (a) energy fluxes at the soil surface; (b) another view of (a); (c) precipitation at the soil surface. (a) and (b) are energy fluxes at the soil surface; (c) is precipitation at the soil surface.

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APPENDIX A

CODE LISTINGS

APPENDIX A

CODE LISTINGS

This appendix lists the programs, subroutines, and functions that comprise the UNSAT-H model. The UNSAT-H code is written in VAX FORTRAN Version 4.0, which is based on American National Standard FORTRAN-77 (ANSI X3.9-1978). Extensions to FORTRAN-77 are available in VAX FORTRAN, although limited use is made of them. The extensions include the system subroutines DATE and TIME, the FORTRAN statement INCLUDE, format specifiers, and non-standard variable names. Calls to the system subroutines DATE and TIME return the date and time, respectively. The "INCLUDE" statement, when embedded within a program, will "include" a designated external file program when it is compiled. The format specifiers "\$", "<", and ">" are used to facilitate program input and output. Finally, some variable names are longer than six characters and some use the "_" character.

The first codes to be listed are the *.INC files: BARRAY.INC, BMET.INC, BOUT.INC, BSOIL.INC, BTIME.INC, and BVAR.INC. The *.INC files contain the variable type declarations, array dimensions, data statements, and common blocks that are shared by different programs and subroutines.

After the *.INC files, each program, subroutine, and function is listed separately. The listing starts with DATAINH followed by each of its subroutines, then UNSAT-H followed by each of its subroutines, and finally DATAOUT followed by each of its subroutines. Although some subroutines or functions may be used by more than one main program, they are listed only once.

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C-----
C   File BARRAY.INC: Arrays
C   Program Units: DATAINH,HEATFLOW,HDRYCALC,UNSATH
C-----
      REAL KL(M1),KKHMID(M1)
      COMMON /ARRAY/Z(M1),H(M1),NTR00T(M1),HH(M1),ROF(M1),
!      THETA(M1),TTHETA(M1),C(M1),CC(M1),T(M1),TT(M1),
!      FPET(24),THETAW(5),THETAD(5),THETAN(5),KKHMID,QT(M1),
!      PTRANS(368),PEVAPO(368),QWLEAK(368),CCH(M1),QV(M1),
!      THICK(M1),ZZ(M1),QH(M1),SUBQH(M1),DAYQH(M1),TQH(M1),
!      QL(M1),TTHETA(M1),THETA(M1)

C-----
C   File BMET.INC: Meteorological parameters
C   Program Units: B_L_R,DATAINH,CALPET,HEATFLOW,HDRYCALC,NETRAD,
C   UNSATH
C-----
      REAL LHV0,LHV,PET(368),LE,KKHNPT
      COMMON /MET/PET,DAYMET,ALT,PMB,ALBEDO,VK,PI,CHW,
!      ZH,ZM,ZT,ZU,D,CHA,SB,SEXT,DAYSXT,TAQ,GRAY,
!      SINDEC,COSDEC,SINLAT,COSLAT,TANLAT,TPIY,LHV,
!      RN,SUBSEN,SUBSHF,SUBRN,SUBLE,SUBHBE,VD_A,SR_FRAC,
!      TMAX,TMIN,TMEAN,TA,SR_MEAS,WIND,CLOUD,EMISS_A,WATDEN,
!      TSMEAN,TSAMP,KKHNPT,INHMAX,RHMEAN,METDAY,QHTCP,QHLEAK,
!      SENFLX,LHV0,T0,CHV
      EQUIVALENCE (T(1),TS)

C-----
C   File BOUT.INC: Variables, Arrays, and Common Blocks
C   Program Units: DATAOUT,HARDCOPY,LISTDATA,PROFILER,READREC,
C   REINIT,SCAN,SUMMARY
C-----
      CHARACTER*80 IFILE,OFILE,BFILE,RFILE,TMFILE,RFILEN
      CHARACTER*80 STIME*8,SDATE*9,TITLE*80
      INTEGER DAYBEG,DAYEND,DAYSTP,TSTP,DAYAST,TAST,DAYUBC,TUBC,ET_OPT,
!      SH_OPT,UPPER,UPPERH,LOWERH,DAYS DH,TS DH
      REAL LE
      PARAMETER (M1=250)
      DIMENSION DAYQ(M1),DAYS NK(M1),H(M1),THETA(M1),Z(M1),TQ(M1),
!      NODE(7),T(M1),DAYQH(M1),TQH(M1)
      COMMON /INTEG/ DAYEND,DAYSTP,TSTP,LOUT,LUI,LUR,LUS,LUN,NPT,IPLANT,
!      NPRINT,NSURPE,NTOTAL,MAXREC,IREC,IERROR,NCHR,IDAY,DAYAST,TAST,
!      DAYUBC,TUBC,DAYBEG,ET_OPT,SH_OPT,IHEAT,ICLOUD,UPPER,UPPERH,
!      LOWERH,NDEPTH,DAYS DH,TS DH
      COMMON /REAL/ HOUR,DAYINF,DAYRAN,DAYE,DAYTRA,DAYRJN,TPREV,TMOIST,
!      PE,PT,DAYTIM,STOPHR,D0V,RHMEAN,TMEAN,HDRY,DAYRN,DAYS HF,DAYS EN,
!      DAYHBE,TA,TMAX,TMIN,VD_A,WIND,CLOUD,SR_MEAS,DAYLE
      COMMON /ARRAY/ DAYQ,DAYS NK,H,THETA,Z,TQ,NODE,T,DAYQH,TQH
      COMMON /CHAR/ IFILE,OFILE,BFILE,RFILE,STIME,SDATE,TITLE,RFILEN
      DATA LUI,LUR,LUS,LUN/1,5,6,7/

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C-----
C   File BS0IL.INC: Soil parameters
C   Program Units: DATAINH,HDRCALC,POLYCH,POLYKH,POLYTH,THERMP,
C   UNSATH
C-----

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PARAMETER (M2M3 = M2*M3, M2M3M4 = M2*M3*M4)
REAL KH(M1),IHY(7*M2+4*M2M3+2*M2M3M4)
COMMON /IHY/MAT(M1),IHY,TCON(M2,5),CHS(M2),
!     EF(M2,5),CHSOIL(M1),ENFACT(M1),CH(M1),KH
DIMENSION NSUBTH(M2),AIRINT(M2),THET(M2),THTR(M2),
!     NDEGTH(M2M3),XDIVTH(M2M3),CREGTH(M2M3M4),
!     NSUBKH(M2),AIRINK(M2),SK(M2),
!     NDEGKH(M2M3),XDIVKH(M2M3),CREGKH(M2M3M4),AMOUNT(24)
EQUIVALENCE (IHY(1),NSUBTH),
!     (IHY(1+M2),AIRINT),
!     (IHY(1+2*M2),THET),
!     (IHY(1+3*M2),THTR),
!     (IHY(1+4*M2),NDEGTH),
!     (IHY(1+4*M2+M2M3),XDIVTH),
!     (IHY(1+4*M2+2*M2M3),CREGTH),
!     (IHY(1+4*M2+2*M2M3+M2M3M4),NSUBKH),
!     (IHY(1+5*M2+2*M2M3+M2M3M4),AIRINK),
!     (IHY(1+6*M2+2*M2M3+M2M3M4),SK),
!     (IHY(1+7*M2+2*M2M3+M2M3M4),NDEGKH),
!     (IHY(1+7*M2+3*M2M3+M2M3M4),XDIVKH),
!     (IHY(1+7*M2+4*M2M3+M2M3M4),CREGKH)

```

```

C-----
C   File BTIME.INC: Time parameters
C   Program Units: DELCHK,UNSATH,HEATFLOW,NETRAD
C-----
COMMON /TIME/DELT,DIFMAX,DELSAV,ISWDIF,DELSUB,TSUB,TSTART,
!     IDAY,N,IG0150,RFACT,RTIME(24),HTIME,HOUR,DUTTIM

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C-----
C   File BVAR.INC: Real, Integer, and Logical Unit parameters
C   Program Units: B_L_R,CALPET,DATAINH,DELCHK,HEATFLOW,HDRYCALC,
C   NETRAD,POLYCH,POLYKH,POLYTH,UNSATH,
C-----
C   LOGICAL START,FINISH
C   REAL LOG10E,MGR,KMODEL
C   INTEGER DAYBEG,DAYEND,ET_OPT,SH_OPT,IHEAT,UPPERH
C   COMMON /RPARA/DMAXBA,DELMAX,DELMIN,HIRRI,HORY,TWOIST,LOG10E,MGR,
C   !   SATK,DRYK,SATC,DRYC,SATTH,DRYTH,AA,B1,B2,SSFLUX,QHLAST,TGRAD,
C   !   KMODEL
C   COMMON /IPARA/IPLANT,LOWER,NDAYS,NDAY,KOPT,IVAPOR,MATN,NPT,
C   !   NGRAY,MAXSUB,MAXPOL,MSURPE,INC,WXROOT,NWATER,
C   !   NPRINT,ET_OPT,SH_OPT,IHEAT,LOWERH,UPPERH,ICLOUD,ICONVH
C   COMMON /LOGIC/START
C
C   Logical unit assignments
C   LUI = binary input file unit (input to UNSATH)
C   LUB = binary output file unit from DATAINH;
C   !       binary output file unit from UNSATH
C   LUR = read (interactive input unit)
C   LUS = screen (interactive and additional output unit)
C
C   PARAMETER (LUI = 1,
C   !           LUB = 2,
C   !           LUR = 5,
C   !           LUS = 6)
C
C   Maximum dimension for nodal arrays
C
C   PARAMETER (M1 = 250)
C
C   Maximum dimension for soil types
C
C   PARAMETER (M2 = 5)
C
C   Maximum dimension for MAXSUB (maximum number of polynomials
C   per soil type)
C
C   PARAMETER (M3 = 4)
C
C   Maximum dimension for MAXPOL (maximum number of coefficients
C   per soil function). For the polynomial and van Genuchten
C   functions, M4 must be exactly 5. For the Haverkamp and Brooks-
C   Corey functions, M4 must be at least 3.
C
C   PARAMETER (M4 = 5)

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0001      PROGRAM DATAINH
0002      C-----
0003      C      Version 2.0
0004      C
0005      C      Calls CALPET, MYHRLY, POLYCH, POLYKH, POLYTH, RLD, and THERMK
0006      C
0007      C      Reads the data file *.INP, checks the data and performs
0008      C      some calculations, then writes the necessary information to
0009      C      the binary output file *.BIN, which serves as the input
0010      C      file to UNSAT-H
0011      C-----
0012      INCLUDE 'BYAR.INC/NOLIST'
0013      DATA DV/2.0/
0014      CHARACTER*80 FILE,IFILE,OFILE,TITLE,DUMMY*60,STIME*8,SDATE*9
0015      LOGICAL LUSLW
0016      REAL LAT,MOLAR,METDAT(8,366)
0017      INCLUDE 'BARRAY.INC/NOLIST'
0018      INCLUDE 'BSOIL.INC/NOLIST'
0019      INCLUDE 'BMET.INC/NOLIST'
0020      COMMON /MD/METDAT
0021      DIMENSION RTIME(24),NQLAK(366),QLEAK(366),
0022      | NGROW(36),FLAI(36),DLAI(366)
0023      FUNVD(TD) = EXP(46.440973D0-(6790.4985D0/TD)-6.02808D0*LOG(TD))
0024      C-----
0025      C      The following parameters are fixed within UNSAT-H:
0026      C      CHA = Volumetric specific heat of air      [J/m3/K]
0027      C      CHV = Volumetric specific heat of vapor    [J/cm3/K]
0028      C      CHW = Volumetric specific heat of water   [J/cm3/K]
0029      C      GASCON = Gas constant                      [erg/mole/K]
0030      C      GRAV = Gravity constant                   [m/s2]
0031      C      MOLAR = Molar mass of water               [g/mole]
0032      C      PI = Pi constant                          [-]
0033      C      LHV0 = Latent heat of vaporization at     [J/g]
0034      C      reference temperature T0
0035      C      SB = Stephan-Boltzman constant            [W/m2/K4]
0036      C      SEXT = Solar constant                    [W/m2]
0037      C      T0 = Reference temperature               [K]
0038      C      VK = von Karmans constant                [-]
0039      C      WATDEN = Density of water                [g/cm3]
0040      C-----
0041      DATA LHV0,MOLAR,GRAV,GASCON/2.5D3,18.D0,9.807D0,8.3143D7/
0042      DATA SB,PI,VK,SEXT,CHV,CHA/5.67D-8,3.1415926D0,0.4D0,1360.D0,1200.D0/
0043      DATA WATDEN,CHW,CHV,T0/1.D0,4.18D0,1.8D0,273.15D0/
0044      LHV0 = LHV0*WATDEN
0045      WRITE(LUS,9000)
0046      9000 FORMAT(' Results are based on the use of unverified software.',/,
0047      | ' No assurance is expressed or implied as to the accuracy.',/,
0048      | ' completeness or usefulness of this information.')
0049      LOG10E = LOG10(EXP(1.D0))
0050      LUSLW = .FALSE.
0051      NSTOP = 0
0052      CALL TIME(STIME)
0053      CALL DATE(SDATE)
0054      C
0055      C      IFILE = Input filename
0056      C
0057      WRITE(LUS,8) DV
0058      8 FORMAT(/,80(' '),//,T30' Program DATAINH',/,T32' Version',F4.1,
0059      | ' ',//,80(' '))
0060      20 WRITE(LUS,1010)
0061      READ(LUR,1000) FILE
0062      NCHR = INDEX(FILE,' ')
0063      FILE(NCHR:NCHR+3) = '.INP'
0064      OPEN(UNIT=LUI,FILE=FILE,STATUS='OLD',ERR=900)
0065      INQUIRE(UNIT=LUI,NAME=IFILE)
0066      NCHR = INDEX(IFILE,' ')

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0185     IF (NCHR .EQ. 0) THEN
0186         FILE = IFILE
0187     ELSE
0188         FILE = IFILE(NCHR+1:80)
0189     ENDIF
0190     NCHR = INDEX(FILE, ';')
0191     WRITE(LUS,1020)
0192     READ(LUR,*) IPRINT
0193     IF (IPRINT .GT. 0) THEN
0194         WRITE(LUS,1030)
0195         READ(LUR,*) IOUT
0196         IF (IOUT .EQ. 0) THEN
0197             LUW = LUS
0198         ELSE
0199             LUW = 7
0200             LUSLUW = .TRUE.
0201             FILE(NCHR-3:NCHR+4) = 'LIS'
0202             OPEN(UNIT=LUW,FILE=FILE,STATUS='NEW')
0203             INQUIRE(UNIT=LUW,NAME=OFILE)
0204             WRITE(LUS,1040) OFILE
0205         ENDIF
0206         WRITE(LUW,1050) DV,IFILE,SDATE,STIME
0207     ENDIF
0208     1010 FORMAT(/' Enter input filename (without ".INP" extension)',
0209             !      ' ==> ', $)
0210     1020 FORMAT(/' Output options in addition to creating < >.BIN:',/,
0211             !      '      (0) = no output',/,
0212             !      '      (1) = options, nodes, soil properties',/,
0213             !      '      and initial conditions',/,
0214             !      '      (2) = (1) plus PET and rain information',/,
0215             !      '      (3) = (2) plus meteorological, leaf, and bottom',/,
0216             !      '      boundary flux information',/,
0217             !      ' Enter choice ==> ', $)
0218     1030 FORMAT(/' Options for output device:',/,
0219             !      '      (0) screen',/,
0220             !      '      (1) file',/,
0221             !      ' Choose output device option ==> ', $)
0222     1040 FORMAT(/' The input summary filename is: '//1X,A79//)
0223     1050 FORMAT(/'//,80(' '),//,T30' Program DATAIN',//,T32,' Version'F4.1,
0224             !      '//,80(' '),//, ' Input Filename: ',A80,/,
0225             !      ' Date Processed: ',A9,/, ' Time Processed: ',A8,/)
0226     C*****
0227     C   OPTIONS, CONSTANTS, AND LIMITS
0228     C*****
0229     C
0230     C   Read TITLE
0231     C
0232     READ(LUI,1000) TITLE
0233     IF (IPRINT .GT. 0) WRITE(LUW,2000) TITLE
0234     C
0235     C   Read IPLANT,LOWER,NGRAV,ISWDIF,IHEAT,UPPERH,LOWERH
0236     C
0237     READ(LUI,1001) IPLANT,LOWER,NGRAV,ISWDIF,IHEAT,UPPERH,LOWERH
0238     IF (IPRINT .GT. 0) WRITE(LUW,2010) IPLANT,LOWER,NGRAV,ISWDIF,
0239     !     IHEAT,UPPERH,LOWERH
0240     2010 FORMAT(' Options chosen include: '//T2'IPLANT = ',I3,T22,
0241             !     'LOWER = ',I3,T42,'NGRAV = ',I3,T62,'ISWDIF = ',I3,T2,
0242             !     'IHEAT = ',I3,T22,'UPPERH = ',I3,T42,'LOWERH = 'I3)
0243     IF (IPLANT .EQ. 1 .AND. IHEAT .EQ. 1) THEN
0244         WRITE(LUS,2034)
0245         IF (LUSLUW) WRITE(LUS,2034)
0246         NSTOP = 1
0247     ENDIF
0248     2034 FORMAT(/' ERROR: IHEAT not allowed to be "1" while',
0249             !     ' IPLANT = 1'/)
0250     C

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0231 C      Read NPRINT, DAYEND, NDAYS, NYEARS, IRAIN, ICONVH, OUTTIM
0232 C
0233 READ(LUI,1005) NPRINT, DAYEND, NDAYS, NYEARS, IRAIN, ICONVH, OUTTIM
0234 IF (IPRINT .GT. 0) WRITE(LUW,2020) NPRINT, DAYEND, NDAYS, NYEARS,
0235 !      IRAIN, ICONVH
0236 2020 FORMAT(T2,NPRINT = ',I3,T22,'DAYEND = ',I3,T42,'NDAYS = ',I3,
0237 !      T82,'NYEARS = ',I3/T2,'IRAIN = ',I3,T22,'ICONVH = ',I3)
0238 LEAP = 0
0239 IF (NDAYS .EQ. 366) LEAP = 1
0240 IF (NDAYS .GT. 366) STOP ' Program stopped because NDAYS > 366'
0241 C
0242 C      Read NSURPE, NFHOUR, ITOPBC, ET_OPT, ICLOUD
0243 C
0244 READ(LUI,1001) NSURPE, NFHOUR, ITOPBC, ET_OPT, ICLOUD
0245 IF (IPRINT .GT. 0) WRITE(LUW,2030) NSURPE, NFHOUR, ITOPBC, ET_OPT,
0246 !      ICLOUD
0247 2030 FORMAT(' NSURPE = ',I3,T22,'NFHOUR = ',I3,T42,'ITOPBC = ',I3,
0248 !      T82,'ET_OPT = ',I3/, ' ICLOUD = 'I3)
0249 IF (ET_OPT .EQ. 0 .AND. (IHEAT .EQ. 1 .AND. UPPERH .EQ. 0)) THEN
0250 WRITE(LUS,2032)
0251 IF (LUSLW) WRITE(LUS,2032)
0252 NSTOP = 1
0253 ENDIF
0254 2032 FORMAT('/' ERROR: ET_OPT not allowed to be '0' while'/,
0255 !      ' IHEAT = 1 and UPPERH = 0 (surface temperature calculated)'/)
0256 C
0257 C      Read KOPT, KEST, IVAPOR, SH_OPT, INMAX, INHMAX
0258 C
0259 READ(LUI,1001) KOPT, KEST, IVAPOR, SH_OPT, INMAX, INHMAX
0260 IF (INMAX .LT. 2) INMAX = 2
0261 IF (INHMAX .LT. 1) INHMAX = 1
0262 IF (IPRINT .GT. 0)
0263 !      WRITE(LUW,2040) KOPT, KEST, IVAPOR, SH_OPT, INMAX, INHMAX
0264 2040 FORMAT(T2,KOPT = ',I3,T22,'KEST = ',I3,T42,'IVAPOR = ',I3,
0265 !      T82,'SH_OPT = ',I3/T2,'INMAX = ',I3,T22,'INHMAX = ',I3)
0266 C
0267 C      Read HIRRI, HDRI, HTOP, DHMAX
0268 C
0269 READ(LUI,1003) HIRRI, HDRI, HTOP, DHMAX
0270 IF (IPRINT .GT. 0) WRITE(LUW,2050) HIRRI, HDRI, HTOP, DHMAX
0271 2050 FORMAT(' HIRRI = ',1PQ10.3,T22,'HDRI = ',1PQ10.3,T42,'HTOP = ',
0272 !      Q10.3,T82,'DHMAX = 'Q10.3)
0273 C
0274 C      Read DMAXBA, DELMAX, DELMIN, STOPHR
0275 C
0276 READ (LUI,1003) DMAXBA, DELMAX, DELMIN, STOPHR
0277 IF (OUTTIM .EQ. 0) OUTTIM = DELMAX
0278 IF (OUTTIM .GT. 24.) OUTTIM = 24.0D0
0279 IF (NPRINT .EQ. 1) THEN
0280 IF (OUTTIM .GT. 1.) THEN
0281 TEST1 = 24.0D0-OUTTIM*NINT(24.0D0/OUTTIM)
0282 IF (TEST1 .NE. 0) THEN
0283 NSTOP = 1
0284 WRITE(LUS,*) ' OUTTIM does not divide 24 hours evenly'
0285 ENDIF
0286 ELSE
0287 TEST2 = 1.0D0-OUTTIM*NINT(1.0D0/OUTTIM)
0288 IF (TEST2 .NE. 0) THEN
0289 WRITE(LUS,*) ' WARNING: OUTTIM does not divide 1 hour'
0290 WRITE(LUS,*) ' evenly. Problems will occur if using hourly'
0291 WRITE(LUS,*) ' precipitation and/or potential evaporation.'
0292 ENDIF
0293 ENDIF
0294 ENDIF
0295 IF (DELMAX .GT. OUTTIM) THEN
0296 DELMAX = OUTTIM

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0297      WRITE(LUS,*) ' DELMAX reset equal to OUTTIM'
0298      ENDIF
0299      IF (IPRINT .GT. 0) WRITE(LUW,2060) DMAXBA,DELMAX,DELMIN,STOPHR,
0300      ! OUTTIM
0301      2060 FORMAT(T2'DMAXBA = ',1PG10.3,T22,'DELMAX = ',G10.3,T42,
0302      ! 'DELMIN = ',G10.3,T62'STOPHR = ',G10.3,/T2'OUTTIM = 'G10.3)
0303      C
0304      C      Read TORT,TSOIL,VAPDIF,QHTOP
0305      C
0306      C      TORT is pore tortuosity, which is usually reported as 0.66.
0307      C      TSOIL is the average soil temperature for the simulation period.
0308      C      For Hanford, the average annual soil temperature at the 90 cm
0309      C      depth is 15.3 C (288.46 K) for the years 1952-1988.
0310      C      VAPDIF is the diffusivity of water vapor in air,
0311      C      approximately 0.24 cm2/s
0312      C
0313      READ(LUI,1003) TORT,TSOIL,VAPDIF,QHTOP
0314      IF (IPRINT .GT. 0) WRITE(LUW,2061) TORT,TSOIL,VAPDIF,QHTOP
0315      2061 FORMAT(T2'TORT = ',1PG10.3,T22,'TSOIL = ',G10.3,T42,
0316      ! 'VAPDIF = ',G10.3,T62'QHTOP = ',G10.3)
0317      MGR = 1.02*MOLAR*GRAV/GASCON
0318      IF (IVAPOR .EQ. 1) THEN
0319          VAPDEN = FUNVD(TSOIL)
0320          VC = 3600.D0*VAPDIF*TORT/WATDEN
0321          IF (IPRINT .GT. 3)
0322              ! WRITE(LUW,4340) VAPDEN,MGR,VC
0323          ENDIF
0324      4340 FORMAT('/ IVAPOR = 1: This option allows vapor flow'1P/,
0325      ! ' Saturated vapor density (g/cm3)'/,
0326      ! ' of soil when soil temperature is'/,
0327      ! ' a constant equal to TSOIL = ',E10.3,/,
0328      ! ' 100*MOLAR*GRAV/GASCON (K/cm) = ',E10.3,/,
0329      ! ' VC (cm5/g/h) = ',E10.3)
0330      C
0331      C      When vapor flow is isothermal, VC is modified
0332      C
0333      IF (IVAPOR .EQ. 1 .AND. IHEAT .EQ. 0) THEN
0334          SVD = FUNVD(TSOIL)
0335          VC = VC*SVD*MGR/TSOIL
0336      ENDIF
0337      C
0338      C      Read TGRAD,TSMEAN,TSAMP,QHLEAK
0339      C
0340      READ(LUI,1003) TGRAD,TSMEAN,TSAMP,QHLEAK
0341      IF (IPRINT .GT. 0) WRITE(LUW,2069) TGRAD,TSMEAN,TSAMP,QHLEAK
0342      2069 FDRMAT(T2'TGRAD = ',1PG10.3,T22,'TSMEAN = ',G10.3,T42,
0343      ! 'TSAMP = ',G10.3,T62'QHLEAK = ',G10.3)
0344      C
0345      C      Read WTF,RFACT,RAINIF,DHFACT
0346      C
0347      READ(LUI,1003) WTF,RFACT,RAINIF,DHFACT
0348      IF (IPRINT .GT. 0) WRITE(LUW,2070) WTF,RFACT,RAINIF,DHFACT
0349      2070 FORMAT(T2'WTF = ',1PG10.3,T22,'RFACT = ',G10.3,T42,
0350      ! 'RAINIF = ',G10.3,T62,'DHFACT = ',G10.3)
0351      UP = WTF
0352      DOWN = 1.D0-UP
0353      C-----
0354      C      NDDE INFORMATION: Define geometric details of the problem
0355      C-----
0356      C
0357      C      Read MATN,NPT
0358      C
0359      READ(LUI,1001) MATN,NPT
0360      IF (IPRINT .GT. 0) WRITE(LUW,3000) MATN,NPT
0361      3000 FORMAT(T2'MATN = ',I3,T22,'NPT = ',I3)
0362      IF (NPT .GT. M1) STOP ' NPT exceeds node dimensions'

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0363 C
0364 C   Read MAT,Z:  Material type and depth below the surface
0365 C
0366 READ(LUI,3010) (MAT(I), Z(I),I=1,NPT)
0367 3010 FORMAT(4(I4,F10.0))
0368 DO 300 I=1,NPT-1
0369     ZZ(I) = Z(I+1)-Z(I)
0370 300 CONTINUE
0371     ZZ(NPT) = 0.D0
0372 C-----
0373 C   SOIL PROPERTY DESCRIPTION
0374 C-----
0375     MAXSUB = 1
0376     MAXPOL = M4
0377     INC = M4
0378     IF (KOPT .NE. 1) GO TO 400
0379 C
0380 C   KOPT = 1:  Polynomial functions
0381 C
0382 READ(LUI,1001) MAXSUB,MAXPOL
0383 IF (IPRINT .GT. 0) WRITE(LUW,4000) MAXSUB,MAXPOL
0384 IF (MAXSUB .GT. M3)
0385     ! STOP ' MAXSUB exceeds M3 dimensions in BVAR.INC'
0386 IF (MAXPOL .GT. M4)
0387     ! STOP ' MAXPOL exceeds M4 dimensions in BVAR.INC'
0388 INC = MAXSUB+MAXPOL
0389 DO 410 I=1,MATN
0390 READ(LUI,1000) DUMMY
0391 READ (LUI,4010) NSUBTH(I),AIRINT(I),THET(I)
0392 IF (IPRINT .GT. 0) WRITE(LUW,4020) I,DUMMY,NSUBTH(I),AIRINT(I),
0393     ! THET(I)
0394 DO 420 J=1,NSUBTH(I)
0395     ID = (I-1)*MAXSUB+J
0396     IP = (I-1)*INC+(J-1)*MAXPOL
0397 READ(LUI,4030) II,NDEGTH(ID),XX,XDIVTH(ID)
0398 IF (J .GT. 1) THEN
0399     IF (XDIVTH(ID) .LT. XDIVTH(ID-1)) THEN
0400         WRITE(LUS,4040) I,J,XDIVTH(ID),XDIVTH(ID-1)
0401         IF (LUSLUW) WRITE(LUW,4040) I,J,XDIVTH(ID),XDIVTH(ID-1)
0402         NSTOP = 1
0403     ENDIF
0404 ENDIF
0405 READ(LUI,4050) (CREGTH(IP+L),L=1,NDEGTH(ID))
0406 IF (IPRINT .GT. 0) WRITE(LUW,4060) ID,NDEGTH(ID),XDIVTH(ID),
0407     (CREGTH(IP+L),L=1,NDEGTH(ID))
0408 420 CONTINUE
0409 4000 FORMAT(/80(' ')/,
0410     ! ' KOPT = 1:  Polynomial functions for soil hydraulic'
0411     ! ' properties'//,
0412     ! ' MAXSUB = 'I1', MAXPOL = 'I1'/)
0413 4010 FORMAT(1X,I5,2F15.0)
0414 4020 FORMAT(/' THETA vs H, MAT 'I1':  'A60,/,
0415     ! ' NSUBTH = 'I1', AIRINT = 'F9.4', THET = 'F8.4//
0416     ! ' ID NDEGTH XDIVTH CREGTH'//,
0417     ! ' -----')
0418 4050 FORMAT(5F15.0)
0419 4030 FORMAT(1X,2I5,2F15.0)
0420 4060 FORMAT(0P,T2,I2,T8,I2,T14,1P,E12.4,(T20,E13.6))
0421 4040 FORMAT(' ERRDR:  Material No. 'I1', J = 'I3', XDIVTH(J) = ',
0422     ! E15.7' < XDIVTH(J-1) = 'E15.7)
0423 READ(LUI,1000) DUMMY
0424 READ(LUI,4010) NSUBKH(I),AIRINK(I),SK(I)
0425 IF (IPRINT .GT. 0)
0426     ! WRITE(LUW,4070) I,DUMMY,NSUBKH(I),AIRINK(I),SK(I)
0427 DO 430 J=1,NSUBKH(I)
0428     ID = (I-1)*MAXSUB+J

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0429      IP = (I-1)*INC*(J-1)*MAXPOL
0430      READ(LUI,4030) II,NDEGKH(ID),XX,XDIVKH(ID)
0431      IF (J .GT. 1) THEN
0432          IF (XDIVKH(ID) .LT. XDIVKH(ID-1)) THEN
0433              WRITE(LUS,4080) I,J,XDIVKH(ID),XDIVKH(ID-1)
0434              IF (LUSLOW) WRITE(LUW,4080) I,J,XDIVKH(ID),XDIVKH(ID-1)
0435              NSTOP = 1
0436          ENDIF
0437      ENDIF
0438      READ(LUI,4050) (CREGKH(IP+L),L=1,NDEGKH(ID))
0439      IF (IPRINT .GT. 0) WRITE(LUW,4060) ID,NDEGKH(ID),XDIVKH(ID),
0440      ! (CREGKH(IP+L),L=1,NDEGKH(ID))
0441      430 CONTINUE
0442      410 CONTINUE
0443      4080 FORMAT(' ERROR: Material No. 'I1', J = 'I3', XDIVKH(J) = ',
0444      ! E15.7' < XDIVKH(J-1) = ',E15.7)
0445      4070 FORMAT(/'      K vs H, MAT 'I1': 'A60/,
0446      ! ' NSUBKH = 'I1', AIRINK = 'F9.4', SK = 'I1,E12.4//
0447      ! ' ID NDEGKH      XDIVKH      CREGKH',
0448      ! ' -----')
0449      GO TO 440
0450      400 IF (KOPT .NE. 2) GO TO 450
0451      C
0452      C      KOPT = 2: Haverkamp functions
0453      C
0454      IF (IPRINT .GT. 0) WRITE(LUW,4100)
0455      DO 400 I=1,MATN
0456          READ(LUI,1000) DUMMY
0457          READ(LUI,1003) THET(I),THTR(I),AIRINT(I),ALPHA,BETA,RETOPT
0458          IF (IPRINT .GT. 0)
0459      !      WRITE(LUW,4110) I,DUMMY,AIRINT(I),RETOPT,THET(I),THTR(I),
0460      !      ALPHA,BETA
0461          IP = (I-1)*INC
0462          CREGTH(IP+1) = ALPHA
0463          CREGTH(IP+2) = BETA
0464          CREGTH(IP+3) = RETOPT
0465          READ(LUI,1000) DUMMY
0466          READ(LUI,1003) AIRINK(I),SK(I),A,B
0467          IF (IPRINT .GT. 0)
0468      !      WRITE(LUW,4120) I,DUMMY,AIRINK(I),SK(I),A,B
0469          CREGKH(IP+1) = A
0470          CREGKH(IP+2) = B
0471      460 CONTINUE
0472      4100 FORMAT(/80(' ')/,
0473      ! '      KOPT = 2: Haverkamp functions for soil hydraulic',
0474      ! ' properties')
0475      4110 FORMAT(/' THETA vs H, MAT 'I1', 'A60,/I1,
0476      ! '      AIRINT = 'G12.5,T50'RETOPT = 'G12.5/,
0477      ! '      THET = 'G12.5,T50' THTR = 'G12.5/,
0478      ! '      ALPHA = 'G12.5,T50' BETA = 'G12.5/)
0479      4120 FORMAT('      K vs H, MAT 'I1', 'A60/I1,
0480      ! '      AIRINT = 'G12.5,T50' SK = 'G12.5/,
0481      ! '      A = 'G12.5,T50' B = 'G12.5)
0482      GO TO 440
0483      450 IF (KOPT .NE. 3) GO TO 470
0484      C
0485      C      KOPT = 3: Brooks-Corey functions
0486      C
0487      IF (IPRINT .GT. 0) WRITE(LUW,4200)
0488      DO 400 I=1,MATN
0489          READ(LUI,1000) DUMMY
0490          READ(LUI,1003) THET(I),THTR(I),AIRINT(I),B
0491          IF (IPRINT .GT. 0)
0492      !      WRITE(LUW,4210) I,DUMMY,AIRINT(I),B,THET(I),THTR(I)
0493          IP = (I-1)*INC
0494          CREGTH(IP+1) = B

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0495      READ(LUI,1000) DUMMY
0496      READ(LUI,1003) KMODEL,SK(I),AIRINK(I),B,EPIT
0497      IF (IPRINT .GT. 0)
0498      !      WRITE(LUW,4220) I,DUMMY,AIRINK(I),B,SK(I),EPIT,KMODEL
0499      CREGKH(IP+1) = KMODEL
0500      CREGKH(IP+2) = B
0501      CREGKH(IP+3) = EPIT
0502 480  CONTINUE
0503 4200 FORMAT(/80('-')/,
0504      !      ' KOPT = 3: Brooks-Corey functions for soil hydraulic',
0505      !      ' properties')
0506 4210 FORMAT(/' THETA vs H, MAT 'I1', 'A80/1P,
0507      !      ' AIRINT = 'Q12.5,T50' B = 'Q12.5/,
0508      !      ' THET = 'Q12.5,T50' THTR = 'Q12.5)
0509 4220 FORMAT( ' K vs H, MAT 'I1', 'A80/1P,
0510      !      ' AIRINK = 'Q12.5,T50' B = 'Q12.5/,
0511      !      ' SK = 'Q12.5,T50' EPIT = 'Q12.5/,
0512      !      ' KMODEL = 'Q12.5)
0513      GO TO 440
0514 470  IF (KOPT .NE. 4) GO TO 480
0515      C
0516      C      KOPT = 4: van Genuchten functions
0517      C
0518      IF (IPRINT .GT. 0) WRITE(LUW,4222)
0519      DO 485 I=1,MATN
0520      READ(LUI,1000) DUMMY
0521      READ(LUI,1003) THET(I),THTR(I),VGA,VGN
0522      AIRINT(I) = 0.D0
0523      VGM = 1.D0-1.D0/VGN
0524      IF (IPRINT .GT. 0)
0525      !      WRITE(LUW,4224)I,DUMMY,AIRINT(I),THET(I),THTR(I),VGA,VGN,VGM
0526      IP = (I-1)*INC
0527      CREGTH(IP+1) = VGA
0528      CREGTH(IP+2) = VGN
0529      CREGTH(IP+3) = VGM
0530      READ(LUI,1000) DUMMY
0531      READ(LUI,1003) KMODEL,SK(I),VGA,VGN,EPIT
0532      AIRINK(I) = 0.D0
0533      VGM = 1.D0-1.D0/VGN
0534      IF (IPRINT .GT. 0) WRITE(LUW,4226) I,DUMMY,
0535      !      AIRINK(I),SK(I),VGA,VGN,VGM,KMODEL,EPIT
0536      CREGKH(IP+1) = VGA
0537      CREGKH(IP+2) = VGN
0538      CREGKH(IP+3) = VGM
0539      CREGKH(IP+4) = KMODEL
0540      CREGKH(IP+5) = EPIT
0541 485  CONTINUE
0542 4222 FORMAT(/80('-')/,
0543      !      ' KOPT = 4: van Genuchten functions for soil hydraulic',
0544      !      ' properties')
0545 4224 FORMAT(/' THETA vs H, MAT 'I1', 'A80/1P,
0546      !      ' AIRINT = 'Q12.5,T50' THET = 'Q12.5/,
0547      !      ' THTR = 'Q12.5,T50' ALPHA = 'Q12.5/,
0548      !      ' N = 'Q12.5,T50' M = 'Q12.5)
0549 4226 FORMAT( ' K vs H, MAT 'I1', 'A80/1P,
0550      !      ' AIRINK = 'Q12.5,T50' SK = 'Q12.5/,
0551      !      ' A = 'Q12.5,T50' M = 'Q12.5/,
0552      !      ' M = 'Q12.5,T50' KMODEL = 'Q12.5/,
0553      !      ' EPIT = 'Q12.5)
0554      GO TO 440
0555 488  WRITE(LUS,4230) KOPT
0556      IF (LUSLUW) WRITE(LUW,4230) KOPT
0557 4230 FORMAT(' ERROR: Current KOPT options are 1, 2, 3, and 4.',/,
0558      !      ' The input value was ',I3)
0559 440  CONTINUE
0560      C

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0561 C Calculate moisture content, conductivity, and capacity at the
0562 C upper and lower head limits
0563 C
0564 H(1) = HIRRI
0565 H(2) = HDRI
0566 MAT2 = MAT(2)
0567 MAT(2) = MAT(1)
0568 CALL POLYTH(2,THETA,H)
0569 CALL POLYKH(2,KL,H)
0570 CALL POLYCH(2,C,H)
0571 SATTH = THETA(1)
0572 DRYTH = THETA(2)
0573 SATK = KL(1)
0574 DRYK = KL(2)
0575 SATC = C(1)
0576 DRYC = C(2)
0577 IF (IPRINT .GT. 0) THEN
0578 WRITE(LUW,4300) HIRRI,SATTH,SATK,SATC
0579 WRITE(LUW,4310) HDRI,DRYTH,DRYK,DRYC
0580 ENDIF
0581 4300 FORMAT(' Surface node hydraulic properties'//,
0582 ! ' HIRRI = ',1PG12.2,' , THETA = ',0PF8.4,' , K = ',1P,E12.4,
0583 ! ' , C = ',E12.4)
0584 4310 FORMAT(' HDRI = ',1PG12.2,' , THETA = ',0PF8.4,' , K = ',1P,E12.4,
0585 ! ' , C = ',E12.4)
0586 MAT(2) = MAT2
0587 IF (IHEAT .EQ. 1) THEN
0588 IF (IPRINT .GT. 0) WRITE(LUW,4349)
0589 DO 495 J=1,MATN
0590 READ(LUI,1000) DUMMY
0591 READ(LUI,1003) (TCON(I,J),I=1,5),CHS(J)
0592 IF (IPRINT .GT. 0) WRITE(LUW,4350) DUMMY,J,(TCON(I,J),I=1,5),
0593 ! CHS(J)
0594 C
0595 C The thermal conductivity and enhancement factor parameters are
0596 C reduced. The conductivity units are changed from W/m/K to J/cm/h/K
0597 C
0598 THETJ = THET(J)
0599 TCON(4,J) = 3.6D3*(TCON(1,J)-TCON(4,J))/1.D2
0600 TCON(1,J) = 3.6D3*TCON(1,J)/1.D2
0601 TCON(2,J) = 3.6D3*(TCON(2,J)/THETJ)/1.D2
0602 TCON(3,J) = TCON(3,J)/THETJ
0603 READ(LUI,1000) DUMMY
0604 READ(LUI,1003) (EF(I,J),I=1,5)
0605 IF (IPRINT .GT. 0) WRITE(LUW,4350) DUMMY,J,(EF(I,J),I=1,5)
0606 THETJ = THET(J)
0607 EF(2,J) = EF(2,J)/THETJ
0608 EF(4,J) = EF(1,J)-EF(4,J)
0609 EF(3,J) = EF(3,J)/THETJ
0610 495 CONTINUE
0611 IF (IPRINT .GT. 0) WRITE(LUW,1004)
0612 THICK(1) = 0.5*ZZ(1)
0613 THICK(NPT) = 0.5*(Z(NPT)-Z(NPT-1))
0614 DO 497 I=2,NPT-1
0615 THICK(I) = 0.5*(ZZ(I-1)+ZZ(I))
0616 497 CONTINUE
0617 DO 498 I=1,NPT
0618 MATI = MAT(I)
0619 CHSOIL(I) = CHS(MATI)*(1.-THET(MATI))
0620 498 CONTINUE
0621 ENDIF
0622 4349 FORMAT(' IHEAT = 1: Thermal conductivity and heat capacity',
0623 ! ' parameters'//,T64'Heat'//,
0624 ! ' Material'T15'A'T25'B'T35'C'T45'D'T55'E'T62'Capacity',
0625 ! /T82'(J/cm3/K)')
0626 4350 FDRMAT(1X,A80/' No. ',11,T11,1P7E10.3)

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0627 C-----
0628 C   INITIAL CONDITIONS
0629 C-----
0630 C
0631 C   Input initial conditions
0632 C   Output node, material, depth, and initial condition status
0633 C
0634 READ(LUI,5000) NDAY,(H(I),I=1,NPT)
0635 CALL POLYTH(NPT,THETA,H)
0636 CALL POLYCH(NPT,C,H)
0637 CALL POLYKH(NPT,KL,H)
0638 IF (IHEAT.EQ. 0) THEN
0639   DO 502 I=1,NPT
0640     T(I) = TSOIL
0641 502   CONTINUE
0642   ELSE
0643     READ(LUI,5001) (T(I),I=1,NPT)
0644   ENDIF
0645   IF (IPRINT.GT. 0) THEN
0646     WRITE(LUW,5010) NDAY
0647     WRITE(LUW,5020) (I,Z(I),MAT(I),H(I),KL(I),C(I),THETA(I),
0648   !       T(I),I=1,NPT)
0649   ENDIF
0650 5010 FORMAT(' NDAY = ',I3,'/',T2,'NODE',T11,'Z',T18,
0651   ! 'MAT',T24,'HEAD',T35,'CONDUCTIVITY',T52,'CAPACITY',T68,'THETA',
0652   ! 'T74',TEMP/T2,'-',T9,'-',T18,'-',T20,'-',T35,
0653   ! 'T50',T50,'-',T65,'-',T73,'-')
0654 5020 FORMAT(T2,I3,T7,F7.2,T17,I1,1P,T20,E12.4,T35,E12.4,T50,E12.4,T65,
0655   ! 'P,F8.4,F7.1)
0656   TWOIST = 0.5*(THETA(1)+ZZ(1)+THETA(NPT)+ZZ(NPT-1))
0657   DO 500 I=2,NPT-1
0658     TWOIST = TWOIST+THETA(I)*(ZZ(I)+ZZ(I-1))*0.5
0659 500   CONTINUE
0660   IF (IPRINT.GT. 0) WRITE(LUW,5030) TWOIST
0661   IF (IHEAT.EQ. 1.AND. IPRINT.GT. 2) THEN
0662     DO 505 I=1,NPT
0663       TTHETA(I) = THETA(I)
0664 505   CONTINUE
0665     CALL THERMK
0666     WRITE(LUW,5024) NDAY
0667     WRITE(LUW,5025) (I,Z(I),MAT(I),T(I),KH(I),CHSOIL(I),CH(I),
0668   !       I=1,NPT)
0669   ENDIF
0670 5024 FORMAT(' NDAY = ',I3,T55'SOIL',T70'TOTAL',T39'THERMAL',T55'HEAT',
0671   ! 'T70'HEAT',T2'NODE',T11'Z',T18'MAT',T25'TEMP',T38'CONDUCTIVITY',
0672   ! 'T53'CAPACITY',T68,'CAPACITY',T9'(cm)',T25'(K)',T37'(J/cm/hr/K)',
0673   ! 'T53'(J/cm3/K)',T87'(J/cm3/K)',T2'-----'T9'-----'T18'-----'T22,
0674   ! '-----'T38'-----'T52'-----'T87'-----')
0675 5025 FORMAT(T2,I3,T7,F7.2,T17,I1,1P,T20,E12.4,T35,E12.4,T50,E12.4,T65,
0676   ! 'E12.4)
0677   IF (NPRINT.EQ. 1.AND. DAYEND-NDAY.GT. 15) THEN
0678     WRITE(LUS,2015) DAYEND
0679     IF (LUSLUW) WRITE(LUW,2015) DAYEND
0680   ENDIF
0681 2015 FDMAT(/' WARNING: The choice of hourly output (NPRINT = 1)',/,
0682   ! 'and DAYEND = ',I3,' will result in a large *.RES file',/,
0683   ! 'when UNSAT-H is run. Check available disk space and',/,
0684   ! 'reset DAYEND accordingly.')
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0693      READ(LUI,1001) LEAF,NFROOT,NUPTAK,NFPET,NSOW,NHRVST
0694      IF (IPRINT.GT. 1) WRITE(LUW,6000) LEAF,NFROOT,NUPTAK,NFPET,
0695      ! NSOW,NHRVST
0696      6000 FORMAT(' IPLANT = 1'/' LEAF=',I3,', NFROOT=',I3,', NUPTAK=',
0697      ! I3,', NFPET=',I3,', NSOW=',I3,', NHRVST=',I3)
0698      C
0699      C LEAF = 1 Leaf area index NGROW,FLAI
0700      C = 2 User-supplied subroutine for leaf area index
0701      C
0702      IF (LEAF.EQ. 1) THEN
0703      READ(LUI,6010) NPOINT,BARE,(NGROW(I),FLAI(I),I=1,NPOINT)
0704      IF (NPOINT.GT. 30) THEN
0705      STOP ' NPOINT > 30, DIM OF NGROW, FLAI EXCEEDED'
0706      ENDIF
0707      IF (IPRINT.GT. 2) THEN
0708      WRITE(LUW,6020) NPOINT,(NGROW(I),FLAI(I),I=1,NPOINT)
0709      WRITE(LUW,6032) BARE
0710      WRITE(LUW,6025)
0711      ENDIF
0712      J = 1
0713      DO 600 I=1,NDAYS
0714      IF (I.LT. NGROW(1)) THEN
0715      DLAI(I) = 0.0
0716      ELSE IF (I.GT. NGROW(NPOINT)) THEN
0717      DLAI(I)=0.0
0718      ELSE IF (I.GE. NGROW(1).AND.
0719      ! I.LE. NGROW(NPOINT)) THEN
0720      IF (I.GE. NGROW(J).AND. J.LT. NPOINT) J = J+1
0721      JJ = J-1
0722      DIFF = (FLAI(J)-FLAI(JJ))/(NGROW(J)-NGROW(JJ))
0723      DLAI(I+NDAY) = FLAI(JJ)-DIFF*(I-NGROW(JJ))
0724      ENDIF
0725      600 CONTINUE
0726      IF (IPRINT.GT.2) WRITE(LUW,6030) (I,DLAI(I+NDAY),I=1,NDAYS)
0727      ELSE IF (LEAF.EQ. 2) THEN
0728      WRITE(LUS,*) ' Subroutine MYLAI was not provided'
0729      NSTOP = 1
0730      ELSE IF (LEAF.GT. 2) THEN
0731      WRITE(LUS,6040) LEAF
0732      IF (LUSLUW) WRITE(LUW,6040) LEAF
0733      NSTOP = 1
0734      ENDIF
0735      IF (NFROOT.NE. 1.AND. NFROOT.NE. 2) THEN
0736      WRITE(LUS,6050) NFROOT
0737      IF (LUSLUW) WRITE(LUW,6050) NFROOT
0738      NSTOP = 1
0739      GO TO 610
0740      ENDIF
0741      IF (NFROOT.EQ. 2) GO TO 620
0742      C
0743      C NFROOT = 1: Read AA,B1,B2,NTR00T
0744      C
0745      READ (LUI,1003) AA,B1,B2
0746      IF (IPRINT.GT. 1) WRITE(LUW,6060) AA,B1,B2
0747      READ (LUI,1001) (NTR00T(I),I=1,NPT)
0748      NGDAYS = NHRVST-NSOW-1
0749      IF (NSOW.GT. NHRVST) NGDAYS = LEAP+365-NSOW+1+NHRVST
0750      I = 1
0751      630 IF (NTR00T(I).LT. NGDAYS.AND. I.LE. NPT) THEN
0752      I = I+1
0753      GO TO 630
0754      ENDIF
0755      WDEPTH = I-1
0756      WXR00T = WDEPTH
0757      IF (IPRINT.LT. 2) GO TO 640
0758      WRITE(LUW,6070)

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0769 0070 FORMAT(/' Root depth, density, and weight/node versus depth'/)
0770 WRITE(LUW,0080)
0771 C
0772 C Estimate root density factor (RDF) at each node of root depth
0773 C
0774 ROOTS = 0.D0
0775 ZZ0 = 0.D0
0776 RDF(1) = 0.D0
0777 DO 050 I=2,MDEPTH
0778 RDF(I) = RLD(Z(I))
0779 ROOTS = ROOTS+RDF(I)*(ZZ(I)-ZZ0)*0.5
0780 ZZ0 = ZZ(I)
0781 050 CONTINUE
0782 ROOTS = ROOTS-RDF(MDEPTH)*ZZ0*0.5
0783 WRITE(LUW,0090) (NROOT(I),Z(I),RDF(I),RDF(I)/ROOTS,I=1,MDEPTH)
0784 040 IF (IPRINT .GT. 0) THEN
0785 WRITE(LUW,0100) MXROOT
0786 ENDIF
0787 0100 FORMAT(/' MXROOT (deepest node to which roots penetrate) = ',I2)
0788 GO TO 010
0789 C
0790 C NROOT = 2 User-defined root density
0791 C
0792 020 WRITE(LUS,*) ' Subroutine "MYROOT" was not provided'
0793 WRITE(LUW,*) ' Subroutine "MYROOT" was not provided'
0794 010 IF (NUPTAK .EQ. 1) THEN
0795 C
0796 C Read HW,HD,HN if NUPTAK = 1
0797 C
0798 IF (IPRINT .GT. 1) WRITE(LUW,0110)
0799 MATSAV = MAT(1)
0800 DO 070 I=1,MATN
0801 MAT(I) = 1
0802 READ (LUI,1003) HW,HD,HN
0803 CALL POLYTH(1,THETA(I),HW)
0804 CALL POLYTH(1,THETA(I),HD)
0805 CALL POLYTH(1,THETA(I),HN)
0806 IF (IPRINT .GT. 1) WRITE(LUW,0120)I,THETA(I),THETA(I),
0807 ! THETA(I)
0808 070 CONTINUE
0809 MAT(1) = MATSAV
0810 ELSE IF (NUPTAK .EQ. 2) THEN
0811 C
0812 C If NUPTAK = 2, call user-defined MYSINK
0813 C
0814 WRITE(LUS,*) ' User subroutine "MYSINK" was not provided'
0815 IF (LUSLW)
0816 ! WRITE(LUW,*) ' User subroutine "MYSINK" was not provided'
0817 NSTOP = 1
0818 ELSE
0819 WRITE(LUS,0130) NUPTAK
0820 IF (LUSLW) WRITE(LUW,0130) NUPTAK
0821 NSTOP = 1
0822 ENDIF
0823 IF (NFPET .EQ. 2) READ (LUI,1003) BIOMAS,BARE
0824 C-----
0825 C BOUNDARY CONDITIONS
0826 C-----
0827 090 IF (IPRINT .GT. 0 .AND. IPLANT .EQ. 1) WRITE(LUW,1004)
0828 IF (IPLANT .EQ. 0) THEN
0829 C
0830 C No plants
0831 C
0832 IF (IPRINT .GT. 1) THEN
0833 IF (NSURPE .EQ. 0) WRITE(LUW,7000) NSURPE
0834 IF (NSURPE .EQ. 1) WRITE(LUW,7010) NSURPE

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0825         ENDIF
0826         IF (NSURPE .EQ. 0) GO TO 700
0827     ENDIF
0828 7000 FORMAT(' NSURPE = ',I1,' : There will be no surface',
0829           ' evaporation')
0830 7010 FORMAT(' NSURPE = ',I1,' : There will be surface',
0831           ' evaporation')
0832 C
0833 C   Input FPET (NFHOUR = 1) or calculate FPET (NFHOUR = 2)
0834 C
0835     IF (IHEAT .EQ. 1) GO TO 721
0836     IF (NFHOUR .EQ. 1) THEN
0837         READ(LUI,1000) (FPET(I),I=1,24)
0838         IF (IPRINT .GT. 1) WRITE(LUW,7120)
0839     ELSE IF (NFHOUR .EQ. 2) THEN
0840         CALL MYHRLY(FPET)
0841         IF (IPRINT .GT. 1) WRITE(LUW,7130)
0842     ELSE
0843         WRITE(LUW,7140) NFHOUR
0844         STOP
0845     ENDIF
0846     SUM = 0.0
0847     DO 710 I=1,24
0848         SUM = SUM+FPET(I)
0849 710 CONTINUE
0850     IF (SUM .LT. 0.99900 .OR. SUM .GT. 1.00100) THEN
0851         WRITE(LUW,7150) SUM
0852         WRITE(LUW,7160) (FPET(I),I=1,24)
0853         STOP
0854     ELSE
0855         DO 720 I=1,24
0856             FPET(I) = FPET(I)/SUM
0857 720 CONTINUE
0858         IF (IPRINT .GT. 1) THEN
0859             WRITE(LUW,7160) (FPET(I),I=1,24)
0860         ENDIF
0861     ENDIF
0862 7150 FORMAT(' ERROR: Sum of diurnal PET distribution factors is ',
0863           'F8.4,'. It should be 1.0')
0864 721 IF (ET_OPT .EQ. 0) THEN
0865     READ(LUI,1000) (PET(I),I=1,NDAYS)
0866 ELSE
0867     IF (IHEAT .EQ. 0) THEN
0868         READ(LUI,1003) ALBEDO,ALT,ZU,PWB
0869         IF (IPRINT .GT. 1) WRITE(LUW,7160) ALBEDO,ALT,ZU,PWB
0870     ELSE
0871         IF (UPPERH .EQ. 0) THEN
0872             READ(LUI,1003) ZH,ZM,ZT,ZU,D,LAT
0873             IF (IPRINT .GT. 1) WRITE(LUW,7167) ZH,ZM,ZT,ZU,D,LAT
0874             DAYSEXT = SEXT+86400.00
0875             TPIY = 2.00*PI/365.00
0876             LAT = LAT+2.00*PI/360.00
0877             SINLAT = SIN(LAT)
0878             COSLAT = COS(LAT)
0879             TANLAT = TAN(LAT)
0880         ENDIF
0881     ENDIF
0882     READ(LUI,8095) ((METDAT(I,J),I=1,8),J=1,NDAYS)
0883     IF (IPRINT .GT. 2) WRITE(LUW,7168) ((METDAT(I,J),
0884       I=1,8),J=1,NDAYS)
0885     IF (IHEAT .EQ. 0) THEN
0886         CALL CALPET
0887 C
0888 C   CALPET utilizes data with same units as FAOPET
0889 C
0890 C   Once through CALPET, data are converted to UNSAT-H units

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0891 C METDAT(2) = TMAX (F) converted to K
0892 C METDAT(3) = TMIN (F) converted to K
0893 C METDAT(4) = TDEW (F) converted to K
0894 C METDAT(8) = precipitation (in.) converted to cm
0895 C
0896 DO 722 J=1,NDAYS
0897 METDAT(2,J) = 273.15D0+(METDAT(2,J)-32.D0)*5.D0/9.D0
0898 METDAT(3,J) = 273.15D0+(METDAT(3,J)-32.D0)*5.D0/9.D0
0899 METDAT(4,J) = 273.15D0+(METDAT(4,J)-32.D0)*5.D0/9.D0
0900 METDAT(8,J) = METDAT(8,J)*2.54D0
0901 722 CONTINUE
0902 ELSE
0903 C-----
0904 C METDAT(2) = TMAX (F) converted to K
0905 C METDAT(3) = TMIN (F) converted to K
0906 C METDAT(4) = TDEW (F) converted to K
0907 C METDAT(5) = SR MEAS (ly/d) converted to J/m2/d
0908 C METDAT(8) = WIND (mph) converted to m/s
0909 C METDAT(7) = CLOUD (tenths) converted to fraction
0910 C METDAT(8) = precipitation (in.) converted to cm
0911 C-----
0912 DO 723 J=1,NDAYS
0913 METDAT(2,J) = 273.15D0+(METDAT(2,J)-32.D0)*5.D0/9.D0
0914 METDAT(3,J) = 273.15D0+(METDAT(3,J)-32.D0)*5.D0/9.D0
0915 METDAT(4,J) = 273.15D0+(METDAT(4,J)-32.D0)*5.D0/9.D0
0916 METDAT(5,J) = METDAT(5,J)*41888.D0
0917 METDAT(8,J) = METDAT(8,J)*0.447D0
0918 METDAT(7,J) = METDAT(7,J)/10.D0
0919 METDAT(8,J) = METDAT(8,J)*2.54D0
0920 723 CONTINUE
0921 GO TO 700
0922 ENDIF
0923 ENDIF
0924 IF (IPLANT.EQ. 0) THEN
0925 IF (IHEAT.EQ. 1) GO TO 700
0926 C
0927 C No plants, read in PEVAP0
0928 C
0929 DO 7151 I=1,NDAYS
0930 PEVAP0(I) = PET(I)
0931 7151 CONTINUE
0932 IF (IPRINT.GT. 1) THEN
0933 WRITE(LUN,7170)
0934 WRITE(LUN,7180) (I,PEVAP0(I),I=1,NDAYS)
0935 ENDIF
0936 IF (IPRINT.GT. 0) THEN
0937 DO 725 I=1,NDAYS
0938 TOTPEV = TOTPEV+PEVAP0(I)
0939 725 CONTINUE
0940 WRITE(LUN,7190) TOTPEV
0941 ENDIF
0942 GO TO 700
0943 ENDIF
0944 7170 FORMAT(/(5(' DAY PEVAP0 ') / 5(' --- ----- ')))
0945 7180 FORMAT(5(I4,F8.4,3X))
0946 7190 FORMAT(/' Totals: PEVAP0 = ',F8.4)
0947 IF (NFPET.EQ. 1) THEN
0948 C
0949 C If NFPET = 1, Ritchie method of partitioning PET
0950 C
0951 IF (IPRINT.GT. 1) THEN
0952 WRITE(LUN,7200)
0953 WRITE(LUN,7210)
0954 ENDIF
0955 DO 730 I=1,NDAYS
0956 ALAI = DLAI(I)

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0957      PETT = PET(I)
0958      PTRANS(I) = PETT*(-.21D0+.7D0*SQRT(ALAI))
0959      IF (ALAI .LT. 0.1D0) PTRANS(I) = 0.D0
0960      IF (ALAI .GT. 2.7D0) PTRANS(I) = PETT
0961      PTRANS(I) = (1.D0-BARE)*PTRANS(I)
0962      PEVAP0(I) = PETT-PTRANS(I)
0963      TOTPET = TOTPET+PETT
0964      TOTPTR = TOTPTR+PTRANS(I)
0965      TOTPEV = TOTPEV-PEVAP0(I)
0966 730    CONTINUE
0967      IF (IPRINT .GT. 0) THEN
0968        IF (IPRINT .GT. 1) WRITE(LUW,7220) (I,PET(I),
0969          !      PTRANS(I),PEVAP0(I),I=1,NDAYS)
0970        WRITE(LUW,7230) TOTPET,TOTPTR,TOTPEV
0971      ENDIF
0972      ELSE IF (NFPET .EQ. 2) THEN
0973      C
0974      C      NFPET = 2 Daily PET and Hinds transpiration function to define
0975      C      PT and PE from PET (relation found by Ted Hinds).
0976      C      In addition, the user can scale the data according
0977      C      to biomass (BIOMAS). The base biomass is 220 g/m**2
0978      C
0979      IF (NSOW .GT. 90 .AND. NSOW .LT. 274) THEN
0980        IF (NSOW .LT. 152) THEN
0981          NSOW = 90
0982        ELSE
0983          NSOW = 274
0984        ENDIF
0985        WRITE(LUS,7235) NSOW
0986        IF (LUSLUW) WRITE(LUS,7235) NSOW
0987      ENDIF
0988      IF (NHRVST .LT. 151 .OR. NHRVST .GT. 243) THEN
0989        NHRVST = 151
0990        WRITE(LUS,7236) NHRVST
0991        IF (LUSLUW) WRITE(LUS,7236) NHRVST
0992      ENDIF
0993      IF (BIOMAS .EQ. 0) BIOMAS = 220.D0
0994      IF (IPRINT .GT. 1) THEN
0995        WRITE(LUW,7240) BIOMAS,BARE
0996        WRITE(LUW,7210)
0997      ENDIF
0998      IF (NSOW .LE. 90) THEN
0999        NGDAYS = NHRVST-NSOW+1
1000        PREDAY = 90-NSOW
1001      ELSE
1002        NGDAYS = LEAP+365-NSOW+1+NHRVST
1003        PREDAY = LEAP+365-NSOW+90+1
1004      ENDIF
1005      CRATIO = 0.300
1006      DO 740 IDAY=1,NDAYS
1007        IF (NSOW .LE. IDAY) THEN
1008          NGROWD = IDAY-NSOW+1
1009        ELSE
1010          NGROWD = LEAP+365+IDAY-NSOW+1
1011        ENDIF
1012        IF (NGROWD .GT. 0 .AND. NGROWD .LE. NGDAYS) THEN
1013          IF (IDAY .LT. 90) THEN
1014            RATIO = CRATIO*NGROWD/PREDAY
1015          ELSE IF (IDAY .GE. 90 .AND. IDAY .LE. 151) THEN
1016            RATIO = CRATIO
1017          ELSE IF (IDAY .GT. 151 .AND. IDAY .LE. NHRVST) THEN
1018            RATIO = CRATIO*(NHRVST-IDAY+1)/(NHRVST-151+1)
1019          ELSE IF (IDAY .GT. 273) THEN
1020            RATIO = CRATIO*NGROWD/PREDAY
1021          ENDIF
1022          RATIO = MIN(1.D0,RATIO*BIOMAS/220.D0)

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1023      PTRANS(IDAY) = (1.D0-BARE)*RATIO*PET(IDAY)
1024      PEVAP0(IDAY) = PET(IDAY)-PTRANS(IDAY)
1025      ELSE
1026      PEVAP0(IDAY) = PET(IDAY)
1027      ENDIF
1028      TOTPET = TOTPET+PET(IDAY)
1029      TOTPTR = TOTPTR+PTRANS(IDAY)
1030      TOTPEV = TOTPEV+PEVAP0(IDAY)
1031 740  CONTINUE
1032      IF (IPRINT .GT. 0) THEN
1033      IF (IPRINT .GT. 1) WRITE(LUW,7220) (I,PET(I+NDAY),
1034      ! PTRANS(I+NDAY),PEVAP0(I+NDAY),I=1,NDAYS)
1035      WRITE(LUW,7230) TOTPET,TOTPTR,TOTPEV
1036      ENDIF
1037      ELSE
1038      WRITE(LUS,7250) NFPET
1039      IF (LUSLUW) WRITE(LUW,7250) NFPET
1040      STOP
1041      ENDIF
1042 700  IF (LOWER .EQ. 3) THEN
1043      C
1044      C LOWER = 3: Water flux at lower boundary
1045      C
1046      READ (LUI,7300) NTLEAK,(NQLEAK(I),QLEAK(I),I=1,NTLEAK)
1047      IF (NTLEAK .GT. 368) STOP 'NQLEAK,QLEAK dimensions exceed 368'
1048      IF (IPRINT .GT. 2) THEN
1049      WRITE(LUW,7310) NTLEAK
1050      WRITE(LUW,7320) (NQLEAK(I),QLEAK(I),I=1,NTLEAK)
1051      ENDIF
1052      JJ = 1
1053      DO 750 I=1,NDAYS
1054      IF (I .GT. NQLEAK(JJ)) JJ = JJ+1
1055      J = JJ-1
1056      QWLEAK(I) = QLEAK(J)+(QLEAK(JJ)-QLEAK(J))*(I-NQLEAK(J))/
1057      ! (NQLEAK(JJ)-NQLEAK(J))
1058 750  CONTINUE
1059      IF (IPRINT .GT. 2) THEN
1060      WRITE(LUW,7330)
1061      WRITE(LUW,7320) (I,QWLEAK(I),I=1,NDAYS)
1062      ENDIF
1063      ELSE IF (LOWER .LT. 1 .OR. LOWER .GT. 4) THEN
1064      WRITE(LUS,7340) LOWER
1065      IF (LUSLUW) WRITE(LUW,7340) LOWER
1066      NSTOP = 1
1067      ENDIF
1068      C
1069      C If IRAIN = 0, read NWATER
1070      C
1071      IF (IRAIN .NE. 0) GO TO 7401
1072      READ (LUI,1001) NWATER
1073      IF (IPRINT .GT. 0 .AND. NWATER .EQ. 0) THEN
1074      WRITE(LUW,*)
1075      WRITE(LUW,*) 'NWATER = 0: There is no rain/irrigation'
1076      ENDIF
1077      IF (NSTOP .NE. 0) THEN
1078      WRITE(LUS,7400)
1079      IF (LUSLUW) WRITE(LUW,7400)
1080      STOP
1081      ENDIF
1082 7400 FORMAT('/' Program stopped due to input error ** See output')
1083      C
1084      C Write binary file (*.BIN) for input to UNSAT-H
1085      C
1086 7401 FILE(NCHR-3:NCHR+4) = 'BIN'
1087      OPEN(UNIT=LUB,FILE=FILE,STATUS='NEW',FORM='UNFORMATTED')
1088      WRITE(LUB) IPLANT,LOWER,NDAYS,NDAY,NPRINT,ITOPBC,HTOP,TGRAD,

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1089      !      KOPT,KEST,UP,DOWN,IVAPOR,DAYEND,NYEARS,ISWDIF,
1090      !      MATH,NPT,NGRAV,MAXSUB,MAXPOL,NSURPE,NSOW,NHRVST,
1091      !      INC,IXROOT,NWATER,DV,STOPHR,ET_OPT,SH_OPT,INMAX,
1092      !      INHMAX,IHEAT,UPPERH,LOWERH,GRAV,TSMEAN,TSAMP,IFILE
1093      WRITE(LUB) DMAXBA,DELMAX,DELMIN,RAINIF,RFACT,HIRRI,HDRY,SATK,
1094      !      DRYK,SATC,DRYC,SATTH,DRYTH,AA,B1,B2,TWOIST,LOG10E,
1095      !      DHMAX,DHFACT,ICONVH,QHTOP,OUTTIM
1096      WRITE(LUB) TITLE,(Z(I),H(I),NTROOT(I),THETA(I),KL(I),C(I),
1097      !      T(I),CHSOIL(I),I=1,NPT),THETAW,THETAD,THETAN,RDF,FPET,
1098      !      MGR,VC,TSOIL,PTRANS,PEVAPD,QWLEAK,QHLEAK
1099      WRITE(LUB) MAT,IHY,SINLAT,COSLAT,TANLAT,TPIY,PI,DAYSEXT,SB,CHW,
1100      !      ZU,ZH,ZM,ZT,D,VK,SEXT,CHA,ICLOUD,TCON,CHS,EF,WATDEN,
1101      !      LHV0,CHV,T0
1102      IF (NWATER.EQ. 0 .AND. IRAIN.EQ. 0) GO TO 760
1103      C
1104      C      Water input:  IRDAY,IRTP,NP,EFICEN,TIME,AMOUNT
1105      C
1106      NSTOP = 0
1107      IF (IPRINT.GT. 1) THEN
1108        WRITE(LUW,7409) IRAIN
1109        IF (IRAIN.EQ. 0) WRITE(LUW,7410) NWATER
1110        WRITE(LUW,7411)
1111      ENDIF
1112      PIRDAY = 0
1113      IRTYPE = 1
1114      EFICEN = 1.D0
1115      DO 770 I=1,NDAYS
1116        IF (IRAIN.EQ. 0) THEN
1117          IF (ET_OPT.EQ. 0) THEN
1118            IF (IRDAY.LT. 1)
1119              READ(LUI,7420,END=775) IRDAY,IRTYPE,NPP,EFICEN,
1120              (RTIME(J),AMOUNT(J),J=1,NPP)
1121          ELSE
1122            IF (IRDAY.LT. METDAT(1,I))
1123              READ(LUI,7420,END=775) IRDAY,IRTYPE,NPP,EFICEN,
1124              (RTIME(J),AMOUNT(J),J=1,NPP)
1125          ENDIF
1126          IF (ET_OPT.EQ. 0 .AND. IRDAY.LE. 1) GO TO 777
1127          IF (ET_OPT.EQ. 1 .AND. IRDAY.LE. METDAT(1,I)) GO TO 777
1128          NP = 0
1129          GO TO 769
1130          777 NP = NPP
1131          IF (EFICEN.EQ. 0.0) EFICEN = 1.D0
1132          IF (IRTYPE.EQ. 4 .AND. ET_OPT.GT. 0) THEN
1133            NSTOP = 1
1134            WRITE(LUS,7485)
1135            IF (LUSLUW) WRITE(LUW,7485)
1136          ENDIF
1137          DO 780 J=1,NP-1
1138            TOTALR = TOTALR+AMOUNT(J)
1139            IF (RTIME(J+1).LE. RTIME(J) .AND. IRTYPE.NE. 4) THEN
1140              WRITE(LUS,7430) IRDAY
1141              IF (LUSLUW) WRITE(LUW,7430) IRDAY
1142              NSTOP = 1
1143            ENDIF
1144          780 CONTINUE
1145          IF (IRDAY.LE. PIRDAY) THEN
1146            WRITE(LUS,7440) IRDAY
1147            IF (LUSLUW) WRITE(LUW,7440) IRDAY
1148            NSTOP = 1
1149          ENDIF
1150          PIRDAY = IRDAY
1151        ELSE
1152          NP = 0
1153          RAINTOT = METDAT(8,I)
1154          IF (RAINTOT.EQ. 0.D0) GO TO 769

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1155          NWATER = NWATER+1
1156          IRDAY = I
1157          IF (RAINTOT .LE. 1.D0) THEN
1158              FIRST = RAINTOT
1159              NP = 2
1160              RTIME(1) = 0.D0
1161              RTIME(2) = 1.D0
1162              AMOUNT(1) = FIRST
1163              AMOUNT(2) = 0.D0
1164              TOTALR = TOTALR+FIRST
1165          ELSE
1166              FIRST = INT(RAINTOT)
1167              SECOND = RAINTOT-FIRST
1168              NP = 3
1169              RTIME(1) = 0.D0
1170              RTIME(2) = FIRST
1171              RTIME(3) = FIRST + 1.D0
1172              AMOUNT(1) = FIRST
1173              AMOUNT(2) = SECOND
1174              AMOUNT(3) = 0.D0
1175              TOTALR = TOTALR+FIRST+SECOND
1176          ENDIF
1177      ENDIF
1178      IF (IPRINT .GT. 1) THEN
1179          WRITE(LUW,7450) IRDAY,RTIME(1),AMOUNT(1),IRTYPE,EFICEN,NP
1180          WRITE(LUW,7460) (RTIME(J),AMOUNT(J),J=2,NP)
1181      ENDIF
1182      760 IF (NSTOP .EQ. 0) THEN
1183          IF (ET_OPT .EQ. 0) THEN
1184              IF (I .NE. IRDAY) GO TO 770
1185              WRITE(LUB) IRDAY,IRTYPE,EFICEN,NP,
1186              ! (RTIME(J),AMOUNT(J),J=1,NP)
1187          ELSE
1188              METDAY = METDAT(1,I)
1189              WRITE(LUB) METDAY,(METDAT(J,I),J=2,7),IRTYPE,EFICEN,NP,
1190              ! (RTIME(J),AMOUNT(J),J=1,NP)
1191          ENDIF
1192      ELSE
1193          GO TO 776
1194      ENDIF
1195      770 CONTINUE
1196      IF (IPRINT .GT. 0) THEN
1197          IF (IRAIN .EQ. 1) WRITE(LUW,*)
1198          IF (IRAIN .EQ. 1) WRITE(LUW,7410) NWATER
1199          WRITE(LUW,7480) TOTALR
1200      ENDIF
1201      776 IF (NSTOP .EQ. 1) THEN
1202          WRITE(LUS,7490)
1203          IF (LUSLUW) WRITE(LUW,7490)
1204      ENDIF
1205      7430 FORMAT(' ERROR: Time of rain/irrigation not in ascending order',/
1206      !           ' on day',I4)
1207      7440 FORMAT(' ERROR: Day of rain/irrigation not in ascending order',
1208      !           ' on day',I4)
1209      7485 FORMAT(' ERROR: Currently,IRTYPE cannot equal 4 while ET_OPT',/
1210      !           ' is greater than zero')
1211      7490 FORMAT(' ERROR: Rain data not written to the binary file')
1212      760 CLOSE (UNIT=1)
1213      STOP
1214      900 WRITE(LUS,8005) FILE
1215      GO TO 20
1216      C-----
1217      C   Formats
1218      C-----
1219      1000 FORMAT(A80)
1220      1001 FORMAT(10I5)

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1221 1002 FORMAT(3I5,F5.0)
1222 1003 FORMAT(8F10.0)
1223 1004 FORMAT(/80(' ')/)
1224 1005 FORMAT(6I5,2F10.0)
1225 1006 FORMAT(8F7.0)
1226 2000 FORMAT(80(' ')/' Title: '/1X,A80,/,80(' ')/)
1227 5000 FORMAT(I5/(4F14.0))
1228 5001 FORMAT(4F14.0)
1229 5030 FORMAT(/' Total Initial Storage = ',F8.4,' cm')
1230 6005 FORMAT(/' No record of file ',A50/' Try again...'/)
1231 6010 FORMAT(I5,F5.0/(5(I5,F5.0)))
1232 6020 FORMAT(/
1233 ! ' Total number of Growth Day - Leaf Area Index (LAI) data'
1234 ! ' pairs = ',I5//,12X,'Growth Day',5X,'LAI'/12X,10(' '),4X,
1235 ! '-----',31(13X,I5,F13.3/))
1236 6025 FORMAT(8(' DAY LAI '),/,8(' --- -----'))
1237 6030 FORMAT(8(I0,F7.3))
1238 6032 FORMAT(/' BARE = ',F5.3)
1239 6040 FORMAT(/' ERROR: Current LEAF options are 0 and 1. Input value',
1240 ! ' was ',I2/)
1241 6050 FORMAT(/' ERROR: Current NFR00T options are 1. Input',
1242 ! ' value was ',I2)
1243 6060 FORMAT(80(' ')/' NFR00T = 1:',
1244 ! ' Negative exponential representation of root growth'//
1245 ! ' AA (intersection of the curve at z=0 with abscissa) = ',
1246 ! F10.3,/
1247 ! ' B1 (coefficient defining degree of curvature) = ',
1248 ! F10.5,/
1249 ! ' B2 (coefficient that determines the value of asymptote = ',
1250 ! F10.3)
1251 6080 FORMAT(T4,'DAY',T14,'MAX',T25,'ROOT',T33,'NORMALIZED',/
1252 ! T10,'ROOT DEPTH',T23,'DENSITY',T35,'DENSITY',/
1253 ! T23,'(cm/cm)',T35,'(1/cm)',/
1254 ! T4,'---',T10,'-----',T23,'-----',T33,'-----')
1255 6090 FORMAT(T4,I3,T12,F7.2,T20,F9.3,T34,F7.4)
1256 6095 FORMAT(8F5.0)
1257 6110 FORMAT(' NUPTAK = 1:',
1258 ! ' Feddes et al. 1975 moisture dependent sink term'/)
1259 6120 FORMAT(/' For Material No. ',I1,/,
1260 ! ' THETAW (wilting point moisture content) = ',F10.4/,
1261 ! ' THETAD (lower limit of optimum moisture content) = ',F10.4/,
1262 ! ' THETAN (upper limit of optimum moisture content) = ',F10.4)
1263 6130 FORMAT(/' ERROR: Current NUPTAK options are 1. Input',
1264 ! ' value was ',I2)
1265 7120 FORMAT(' NFHOUR = 1: Hourly PET distribution values',
1266 ! ' are entered by the user')
1267 7130 FORMAT(' NFHOUR = 2: User subroutine for hourly',
1268 ! ' PET distribution')
1269 7140 FORMAT(/' ERROR: Current NFHOUR options are 1 and 2. Input',
1270 ! ' value was ',I2)
1271 7160 FORMAT(3(/8(3X,F8.4)))
1272 7168 FORMAT(' ET_OPT = 1 and IHEAT = 1:',
1273 ! ' PET calculated from meteorological data',/,
1274 ! ' using subroutine CALPEN',//1P,
1275 ! ' ALBEDO = 'E10.3/,
1276 ! ' ALT = 'E10.3' (m)',/,
1277 ! ' ZU = 'E10.3' (m)',/,
1278 ! ' PWB = 'E10.3' (mm)/)
1279 7187 FORMAT(' IHEAT = 1: Evaporation calculated from met. data',/,
1280 ! ' and the results of the heat flow model',//1P,
1281 ! ' ZH = 'E10.3' (m)',/,
1282 ! ' ZM = 'E10.3' (m)',/,
1283 ! ' ZT = 'E10.3' (m)',/,
1284 ! ' ZU = 'E10.3' (m)',/,
1285 ! ' D = 'E10.3' (m)',/,
1286 ! ' LAT = 'E10.3' (deg)',/)

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1287 7168 FORMAT(/' ET_OPT = 1: Meteorological Data'//,
1288 ! ' Temperature Solar Wind Cloud',/,
1289 ! ' IDAY Max Min Dew Rad Speed Cover Prec.',/,
1290 ! ' F F F ly/d mph tenth in',/,
1291 ! ' -----'//,
1292 ! (F6.0,F5.0,F5.0,F6.1,F7.0,2F7.1,F7.2))
1293 7200 FORMAT(' NFPET = 1:',/,
1294 ! ' PET is partitioned into PT and PE according',/
1295 ! ' to the relationship developed by Ritchie',/
1296 ! ' (1972)',/)
1297 7210 FORMAT(2(6X,'DAY',4X,'PET',3X,'PTRANS',2X,'PEVAPD'),/,
1298 ! 2(6X,'---',2X,'-----',2X,'-----',2X,'-----'))
1299 7220 FORMAT(2(6X,I3,3F8.4))
1300 7235 FORMAT(' WARNING: NSDW was out-of-bounds (91 to 273), so it',/,
1301 ! ' was reset to ',I3/)
1302 7236 FORMAT(' WARNING: NHRVST was out-of-bounds (<151 or >243)',/,
1303 ! ' so it was reset to ',I3/)
1304 7238 FORMAT(/' Totals: PET = ',F8.4,/,
1305 ! ' PTRANS = ',F8.4,/,
1306 ! ' PEVAPD = ',F8.4)
1307 7240 FORMAT(' NFPET = 2: PET is partitioned into PT and PE according',/
1308 ! ' to the relationship developed by Ted Hinds',/
1309 ! ' Biomass, g/m**2 (BIOMAS) = ',F7.2,/,
1310 ! ' Bare soil fraction (BARE) = ',F7.2,/)
1311 7250 FORMAT(/' ERROR: Current NFPET options are 1 and 2. Input',
1312 ! ' value was ',I2/)
1313 7300 FORMAT(I5/,100(5(I5,F6.0)/))
1314 7310 FORMAT(/' LOWER = 3: Bottom boundary fluxes',/,
1315 ! ' NTLEAK = ',I2,' flux changes',/,
1316 ! ' Input Values (cm/day)')
1317 7320 FORMAT(5(' Day Flux'4X)/5(' ---' ),/, (5(I4,F8.4,3X)))
1318 7330 FORMAT(/' Output Values (cm/day) interpolated from input values')
1319 7340 FORMAT(/' ERROR: Current LOWER options are 1,2,3, and 4. ',
1320 ! ' Input value was ',I2)
1321 7400 FORMAT(/' IRAIN =',I2)
1322 7410 FORMAT(' MWATER (number of days of rain/irrigation) =',I3,/)
1323 7411 FORMAT(T17,'Rainfall/Irrigation Details',/,
1324 ! T2,'Day',T9,'Time',T16,'Amount',T25,'Application',
1325 ! T39,'Efficiency',T51,'Changes In',/,T9,'(hr)',T17,'(cm)',
1326 ! T29,'Type',T52,'Rate/Head',/,T2,'---',T9,'---',T16,'-----',
1327 ! T25,'-----',T39,'-----',T51,'-----')
1328 7420 FORMAT(3I5,F6.0/, (F7.0,F8.0))
1329 7450 FORMAT(T2,I3,T7,F6.3,T15,F7.4,T30,I1,T41,F5.3,T55,I2)
1330 7460 FORMAT(T7,F6.3,T15,F7.4)
1331 7480 FORMAT(/' Total Water Applied = ',F8.4,' cm')
1332 END

```

```

0001      SUBROUTINE CALPET
0002      C-----
0003      C      Version 2.0
0004      C
0005      C      Called by DATAINH
0006      C
0007      C      Calculates PET using Penman formula from FAOPET
0008      C      Note that negative PET values are reported as zero values.
0009      C-----
0010      INCLUDE 'BVAR.INC/NOLIST'
0011      INCLUDE 'BARRAY.INC/NOLIST'
0012      INCLUDE 'BMET.INC/NOLIST'
0013      REAL METDAT(8,366),NRATIO
0014      COMMON /MD/METDAT
0015      FUNED(TDEW) = EXP(64.878919D0-(6790.4985D0/TDEW)-5.02808D0*
0016      !      LOG(TDEW))
0017      C
0018      C      From Doorenbos and Pruitt (1977), the following equation is
0019      C      derived from long time mean PMB for a number of stations in Africa
0020      C      (Climate of Africa, Vol 10, World Survey of Climatology)
0021      C
0022      C      IF (PMB .LE. 0.0) PMB = 1013.D0-0.1152D0*ALT+5.44*10.D-8*ALT*ALT
0023      C      A = .17D0
0024      C      IF (ZU .LE. 2.D0) A = .22D0
0025      C      UHTCF = (2.D0/ZU)**A
0026      C      SIGMA = 2.8D-9
0027      C      FACTRS = 0.017D0
0028      C      FU24 = 38.6D0
0029      C      I = 0
0030      100 I = I+1
0031      C      TMAX = METDAT(2,I)
0032      C      TMIN = METDAT(3,I)
0033      C      TDEW = METDAT(4,I)
0034      C      SR_MEAS = METDAT(5,I)*FACTRS
0035      C      WIND = METDAT(6,I)*UHTCF*FU24
0036      C      CLOUD = METDAT(7,I)
0037      C      TMAX = (TMAX-32.D0)*5.D0/9.D0
0038      C      TMIN = (TMIN-32.D0)*5.D0/9.D0
0039      C      TMEAN = 273.16D0+(TMAX+TMIN)/2.D0
0040      C      TDEW = 273.16D0+(TDEW-32.D0)*5.D0/9.D0
0041      C      EA = FUNED(TMEAN)
0042      C      ED = FUNED(TDEW)
0043      C      NRATIO = 0.95D0-0.008D0*CLOUD-0.0023D0*CLOUD**2.D0
0044      C      GG = 0.000505D0*PMB
0045      C      D = (EA/TMEAN)*(6790.4985D0/TMEAN-5.02808D0)
0046      C      W = D/(D+GG)
0047      C      FT = SIGMA*TMEAN**4.D0
0048      C      FED = 0.34D0-0.044D0*SQRT(ED)
0049      C      FNN = 0.1D0+0.9D0*NRATIO
0050      C      RN = (1.0D0-ALBED0)*SR_MEAS-FT*FED*FNN
0051      C      FU = 0.27D0*(1.0D0+WIND/100.D0)
0052      C      PET(I) = MAX(0.D0,(W*RN+(1.D0-W)*FU*(EA-ED))/10.D0)
0053      C      IF (I .LE. NDAYS) GO TO 100
0054      C      RETURN
0055      C      END

```

```

0001      SUBROUTINE MYHRLY(FPT)
0002      C-----
0003      C   Version 2.0:
0004      C
0005      C   Called by DATAINH
0006      C
0007      C   Calculates hourly distribution of PET based on the sine wave
0008      C   approach of Hillel (SSSAJ 40:807-815, 1976)
0009      C-----
0010      INCLUDE 'BYAR.INC/WOLIST'
0011      DIMENSION FPT(24)
0012      DATA PI/3.141592653589793/
0013      TPI = 2.00*PI/24.00
0014      DO 100 IHOURL=1,24
0015      IF (IHOURL.LT. 7 .OR. IHOURL.GE. 18) THEN
0016      FPT(IHOURL) = 0.0100
0017      ELSE
0018      TEMP = -0.5000*COS(TPI*(IHOURL-8))+0.5000*COS(TPI*(IHOURL-7))
0019      FPT(IHOURL) = 0.8800*TEMP
0020      ENDIF
0021 100 CONTINUE
0022      RETURN
0023      END

```



```

0001      SUBROUTINE POLYCH(NPTS,C,H)
0002      C-----
0003      C      Version 2.0:
0004      C
0005      C      Called by DATAINH and UNSATH
0006      C
0007      C      Calculates the moisture capacity (C) of each node as a function
0008      C      of the head value (H) for that node
0009      C-----
0010      INCLUDE 'BVAR.INC/NOLIST'
0011      INCLUDE 'BSOIL.INC/NOLIST'
0012      DIMENSION C(NPTS),H(NPTS)
0013      C
0014      C      WCOMP is the compressibility of water, 1/cm
0015      C
0016      WCOMP = 4.68D-8
0017      DO 1000 I=1,NPTS
0018      M = MAT(I)
0019      X = H(I)
0020      IF (X .LE. AIRINT(M)) THEN
0021      C(I) = -WCOMP*THET(M)
0022      GO TO 1000
0023      ENDIF
0024      GO TO (100,200,300,400), KOPT
0025      C-----
0026      C      KOPT = 1: Polynomial description of capacity function
0027      C-----
0028      100      XX = X
0029      IPREV = (M-1)*MAXSUB
0030      IMAX = IPREV + NSUBTH(M)
0031      J = IPREV+1
0032      110      IF (X .GT. XDIVTH(J) .AND. J .LT. IMAX) THEN
0033      J = J+1
0034      GO TO 110
0035      ENDIF
0036      ID = J
0037      IP = (M-1)*INC+(J-IPREV-1)*MAXPOL
0038      X = LOG10(X)
0039      X0 = X
0040      SUM = CREGTH(IP+2)
0041      IF(NDEGTH(ID) .LE. 2) GO TO 130
0042      DO 120 K=3,NDEGTH(ID)
0043      SUM = SUM+(K-1)*CREGTH(IP+K)*X
0044      X = X*X0
0045      120      CONTINUE
0046      130      C(I) = LOG10E*SUM/XX
0047      GO TO 600
0048      C-----
0049      C      KOPT = 2: Haverkamp capacity function
0050      C-----
0051      200      IP = (M-1)*INC
0052      ALPHA = CREGTH(IP+1)
0053      BETA = CREGTH(IP+2)
0054      RETOPT = CREGTH(IP+3)
0055      IF (RETOPT .EQ. 1) THEN
0056      XBETA = X**BETA
0057      XBM1 = X** (BETA-1.D0)
0058      C(I) = -XBM1*ALPHA*BETA*(THET(M)-THTR(M))/((ALPHA+XBETA)
0059      * (ALPHA+XBETA))
0060      !
0061      ELSE
0062      XBETA = LOG(X)**BETA
0063      XBM1 = LOG(X)**(BETA-1)
0064      C(I) = -XBM1*ALPHA*BETA*(THET(M)-THTR(M))/(X*(ALPHA+XBETA)
0065      * (ALPHA+XBETA))
0066      !
0067      ENDIF
0068      GO TO 600

```

```

0140 C-----
0141 C      KOPT = 3: Brooks-Corey capacity function
0142 C-----
0143 300   IP = (M-1)*INC
0144       B = CREGTH(IP+1)
0145       TEM = (X/AIRINT(M))*(-1.D0-(1.D0/B))
0146       C(I) = -TEM*(THET(M)-THTR(M))/(B*AIRINT(M))
0147       GO TO 600
0148 C-----
0149 C      KOPT = 4: van Genuchten capacity function
0150 C-----
0151 400   IP = (M-1)*INC
0152       ALPHA = CREGTH(IP+1)
0153       VGN = CREGTH(IP+2)
0154       VGM = CREGTH(IP+3)
0155       TEMP = -ALPHA*VGM*VGN*(ABS(ALPHA*X))**(VGN-1.D0)*(THET(M)-
0156       !      THTR(M))
0157       C(I) = TEMP*(1.D0+(ABS(ALPHA*X))**VGN)**(-VGM-1.D0)
0158 C
0159 C      End of capacity functions
0160 C-----
0161 800   IF (C(I) .GT. 0.0) THEN
0162       IERROR = IERROR + 1
0163       WRITE(LUS,6000) M,-C(I),H(I),AIRINT(M)
0164       ENDIF
0165 1000  CONTINUE
0166       IF (IERROR .GT. 0) THEN
0167       WRITE(LUS,6010) IERROR
0168       STOP
0169       ENDIF
0170       RETURN
0171 C-----
0172 C      Format Statements
0173 C-----
0174 6000  FORMAT(' ERROR: Unsaturated capacity term negative, MAT No. ',
0175       !      'I' C = 'G12.5' H = 'G12.5' AIRINT = 'G12.5')
0176 6010  FORMAT(' Program execution stopped in subroutine POLYCH ',
0177       !      ' because of negative capacity term(s) for 'I3' nodes')
0178       END

```

```

0001      SUBROUTINE POLYKH(NPTS,KL,H)
0002      C-----
0003      C   Version 2.0:
0004      C
0005      C   Called by DATAINH and UNSATH
0006      C
0007      C   Calculates the conductivity (KL) of each node as a function of
0008      C   the head value (H) for that node
0009      C-----
0010      INCLUDE 'BVAR.INC/NOLIST'
0011      INCLUDE 'BSOIL.INC/NOLIST'
0012      REAL KL(NPTS),H(NPTS)
0013      DO 1000 I=1,NPTS
0014          M = MAT(I)
0015          X = H(I)
0016          IF (X .LE. AIRINK(M)) THEN
0017              KL(I) = SK(M)
0018              GO TO 1000
0019          ENDIF
0020          GO TO (100,200,300,400), KOPT
0021      C-----
0022      C   KOPT = 1: Polynomial description of conductivity function
0023      C-----
0024      100      IPREV = (M-1)*MAXSUB
0025              IMAX = IPREV + NSUBKH(M)
0026              J = IPREV+1
0027      110      IF (X .GT. XDIVKH(J) .AND. J .LT. IMAX) THEN
0028              J = J+1
0029              GO TO 110
0030      ENDIF
0031      ID = J
0032      IP = (M-1)*INC + (J-IPREV-1)*MAXPOL
0033      X = LOG10(X)
0034      X0 = X
0035      SUM = CREGKH(IP+1)
0036      DO 120 K = 2,NDEGKH(ID)
0037          SUM = SUM+CREGKH(IP+K)*X
0038          X = X*X0
0039      120      CONTINUE
0040      KL(I) = 10.D0**SUM
0041      GO TO 1000
0042      C-----
0043      C   KOPT = 2: Haverkamp conductivity function
0044      C-----
0045      200      IP = (M-1)*INC
0046              A = CREGKH(IP+1)
0047              B = CREGKH(IP+2)
0048              KL(I) = SK(M)*A/(A+X**B)
0049              GO TO 1000
0050      C-----
0051      C   KOPT = 3: Brooks-Corey w/Burdine or Mualem conductivity function
0052      C-----
0053      300      IP = (M-1)*INC
0054              KMODEL = CREGKH(IP+1)
0055              B = CREGKH(IP+2)
0056              EPIT = CREGKH(IP+3)
0057      IF (KMODEL .EQ. 1) THEN
0058          KL(I) = SK(M) * (AIRINK(M)/X)**(2.D0*(1.D0+EPIT)/B)
0059      ELSE
0060          KL(I) = SK(M) * (AIRINK(M)/X)**(2.D0*(2.D0+EPIT)/B)
0061      ENDIF
0062      GO TO 1000
0063      C-----
0064      C   KOPT = 4: van Genuchten w/Burdine or Mualem conductivity function
0065      C-----
0066      400      IP = (M-1)*INC

```

```

0140      ALPHA = CREGKH(IP+1)
0141      VGN    = CREGKH(IP+2)
0142      VGM    = CREGKH(IP+3)
0143      KMODEL = CREGKH(IP+4)
0144      EPIT   = CREGKH(IP+5)
0145      TEMP   = 1.D0*(ALPHA*X)**VGN
0146      IF (KMODEL .EQ. 1) THEN
0147          KL(I) = SK(M)*TEMP**(-VGM*EPIT)*(1D0-(1D0-1D0/TEMP)**VGM)
0148      ELSE
0149          KL(I) = SK(M)*TEMP**(-VGM*EPIT)*(1D0-(1D0-1D0/TEMP)**VGM)**2D0
0150      ENDIF
0151 1000 CONTINUE
0152      RETURN
0153      END

```

```

0001      SUBROUTINE POLYTH(NPTS,THETA,H)
0002      C-----
0003      C   Version 2.0:
0004      C
0005      C   Called by DATAINH and UNSATH
0006      C
0007      C   Calculates the water content (THETA) of each node as a
0008      C   function of the head (H) value for that node
0009      C-----
0010      INCLUDE 'BVAR.INC/NOLIST'
0011      INCLUDE 'BSOIL.INC/NOLIST'
0012      DIMENSION THETA(NPTS),H(NPTS)
0013      DO 1000 I=1,NPTS
0014          W = MAT(I)
0015          X = H(I)
0016          IF (X .LE. AIRINT(W)) THEN
0017              THETA(I) = THET(W)
0018              GO TO 1000
0019          ENDIF
0020          GO TO (100,200,300,400), KOPT
0021      C-----
0022      C   KOPT = 1: Polynomial description of retention function
0023      C-----
0024      100      IPREV = (M-1)*MAXSUB
0025              IMAX = IPREV + NSUBTH(M)
0026              J = IPREV+1
0027      110      IF (X .GT. XDIVTH(J) .AND. J .LT. IMAX) THEN
0028              J = J+1
0029              GO TO 110
0030      ENDIF
0031      ID = J
0032      IP = (M-1)*INC+(J-IPREV-1)*MAXPOL
0033      X = LOG10(X)
0034      X0 = X
0035      SUM = CREGTH(IP+1)
0036      DO 120 K = 2,NDEGTH(ID)
0037          SUM = SUM+CREGTH(IP+K)*X
0038          X = X*X0
0039      120      CONTINUE
0040      THETA(I) = SUM
0041      GO TO 1000
0042      C-----
0043      C   KOPT = 2: Haverkamp retention function
0044      C-----
0045      200      IP = (M-1)*INC
0046              ALPHA = CREGTH(IP+1)
0047              BETA = CREGTH(IP+2)
0048              RETOPT = CREGTH(IP+3)
0049              IF (RETOPT .EQ. 1) THEN
0050                  THETA(I) = ALPHA*(THET(W)-THTR(W))/(ALPHA*X+BETA)+THTR(W)
0051              ELSE
0052                  THETA(I) = ALPHA*(THET(W)-THTR(W))/(ALPHA*(LOG(X)+BETA))
0053                  +THTR(W)
0054              !
0055              ENDIF
0056      GO TO 1000
0057      C-----
0058      C   KOPT = 3: Brooks-Corey retention function
0059      C-----
0060      300      IP = (M-1)*INC
0061              B = CREGTH(IP+1)
0062              THETA(I) = THTR(W)+(THET(W)-THTR(W))*(X/AIRINT(W))**(-1.D0/B)
0063      GO TO 1000
0064      C-----
0065      C   KOPT = 4: van Genuchten retention function
0066      C-----
0067      400      IP = (M-1)*INC

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```

0140      ALPHA = CREGTH(IP+1)
0141      VGM    = CREGTH(IP+2)
0142      VGM    = CREGTH(IP+3)
0143      TEMP   = 1.D0*(ALPHA*X)**VGM
0144      THETA(I) = THTR(M)*(THET(M)-THTR(M))*(TEMP)**(-VGM)
0145 1000 CONTINUE
0146      RETURN
0147      END

```



```

0001      FUNCTION RLD(DEPTH)
0002      C-----
0003      C      Version 2.0:
0004      C
0005      C      Called by DATAINH and UNSATH
0006      C
0007      C      Calculates root density as a function of depth
0008      C      Note that roots are not allowed in node 1 (the surface node,
0009      C      where DEPTH = 0)
0010      C-----
0011      INCLUDE 'BVAR.INC/NOLIST'
0012      RLD = AA*EXP(-B1*DEPTH)+B2
0013      IF (DEPTH .EQ. 0.00) RLD = 0.00
0014      RETURN
0015      END

```

```

0001      SUBROUTINE THERMK
0002 C-----
0003 C      Version 2.0
0004 C
0005 C      Called by DATAINH and HEATFLOW
0006 C
0007 C      Calculates soil thermal conductivity and vol. heat capacity
0008 C-----
0009      INCLUDE 'BVAR.INC/NOLIST'
0010      INCLUDE 'BARRAY.INC/NOLIST'
0011      INCLUDE 'BSOIL.INC/NOLIST'
0012      INCLUDE 'BMET.INC/NOLIST'
0013      FUNVD(TD) = EXP(46.440973D0-(6790.4985D0/TD)-0.02800D0*LOG(TD))
0014      DO 100 I=1,NPT
0015          MATI = MAT(I)
0016          THETA(I) = THETA(I)
0017          TCONA = TCON(1,MATI)
0018          TCONB = TCON(2,MATI)
0019          TCONC = TCON(3,MATI)
0020          TCOND = TCON(4,MATI)
0021          TCONE = TCON(5,MATI)
0022          KH(I) = TCONA+TCONB*THETA(I)-TCOND*EXP(-1.D0*
0023      !      (TCONC+THETA(I))*TCONE)
0024          CH(I) = CHW*THETA(I)+CHSOIL(I)
0025          IF (IVAPOR.EQ. 1) THEN
0026              SVD = FUNVD(T(I))
0027              RHOV = SVD*EXP(-H(I)*MGR/T(I))
0028              THETA(I) = RHOV*(THET(MATI)-THETA(I))/WATDEN
0029              CH(I) = CH(I)+CHV*THETA(I)
0030          ENDIF
0031      100 CONTINUE
0032      RETURN
0033      END

```

```

0001      PROGRAM UNSATH
0002      C-----
0003      C   Version 2.0:
0004      C
0005      C   Calls B_L_R, DELCHK, HEATFLOW, HDRYCALC, POLYCH, POLYKH, POLYTH,
0006      C   RLD, THERME, and TRIDAG
0007      C
0008      C   Solves water and heat balance equations
0009      C-----
0010      INCLUDE 'BYAR.INC/NOLIST'
0050      DATA UV/2.0/
0059      CHARACTER*80 BIFILE,IFILE,OFIL,TFIL,TITLE,STIME*8,SDATE*9
0060      INTEGER SUBSTP,DAYSTP,TSTP,SUBUBC,DAYUBC,TUBC,UPPER,WINDEX
0061      INTEGER SUBAST,DAYAST,TAST,SUBSDH,DAYS DH,TS DH
0062      REAL KV(M1),KVMID(M1),KKVMID(M1),KVT(M1),KVTWID(M1),
0063      !     KLMID(M1),KKLMID(M1),KKVTWID(M1),KKLNPT
0064      DIMENSION A1(M1),A2(M1),A3(M1),ZY(M1),RATE(24),HSOL(M1),
0065      !     SUBQ(M1),DAYQ(M1),TQ(M1),SINK(M1),DAYSNK(M1),SUBSNK(M1)
0066      INCLUDE 'BARRAY.INC/NOLIST'
0070      INCLUDE 'BTIME.INC/NOLIST'
0085      INCLUDE 'BSOIL.INC/NOLIST'
0112      INCLUDE 'BMET.INC/NOLIST'
0127      FUNVD(TD) = EXP(46.440973D0-(6790.4985D0/TD)-6.02805D0*LOG(TD))
0128      WRITE(LUS,9000)
0129      9000 FORMAT('/ Results are based on the use of unverified software.',/
0130      !     ' No assurance is expressed or implied as to the accuracy',/
0131      !     ' completeness or usefulness of this information.'/)
0132      START = .TRUE.
0133      FINISH = .FALSE.
0134      CALL TIME(STIME)
0135      CALL DATE(SDATE)
0136      C
0137      C   BIFILE = Binary input filename
0138      C
0139      !     WRITE(LUS,8) UV
0140      8   FORMAT(/,80(' '),/T30' Program UNSAT-H',/T32,' Version 'F3.1,
0141      !     //,80(' '),/,' Enter binary input filename',
0142      !     ' (program appends ".BIN") ==> ',)
0143      READ(LUR,9,END=999) TFILE
0144      9   FORMAT(A80)
0145      NCHR = INDEX(TFILE,' ')
0146      TFILE(NCHR:NCHR+3) = '.BIN'
0147      OPEN(UNIT=LUI,FILE=TFILE,STATUS='OLD',FORM='UNFORMATTED')
0148      INQUIRE(UNIT=LUI,NAME=BIFILE)
0149      WRITE(LUS,10) SDATE,STIME,BIFILE
0150      10  FORMAT(/' Date: ',A9,' Time: ',A8,/
0151      !     ' Binary Input Filename: ',1X,A79/)
0152      C
0153      C   Read in the DATAINH input file
0154      C
0155      READ(LUI) IPLANT,LOWER,NDAYS,NDAY,NPRINT,ITOPBC,HTOP,TGRAD,
0156      !     KOPT,KEST,UP,DOWN,IVAPOR,DAYEND,NYEARS,ISWDIF,
0157      !     MATN,NPT,NGRAV,MAXSUB,MAXPOL,NSURPE,NSOW,NHRVST,
0158      !     INC,MXROOT,NWATER,DV,STOPHR,ET OPT,SH OPT,INMAX,
0159      !     INHMAX,IHEAT,UPPERH,LOWERH,GRAV,TSMEAN,TSAMP,IFILE
0160      IF (DV.NE.UV) THEN
0161          WRITE(8,20) DV,UV
0162          STOP
0163      ENDIF
0164      20  FORMAT(' ERROR: DATAINH Version No. ',F3.1,' does not match',/
0165      !     ' UNSAT-H Version No. ',F3.1,'. Program aborted.')
0166      READ(LUI) DMAXBA,DELMAX,DELMIN,RAINIF,RFACT,HIRRI,HDRI,SATK,
0167      !     DRYK,SATC,DRYC,SATTH,DRYTH,AA,B1,B2,TWOIST,LOG10E,
0168      !     DHMAX,DHFACT,ICONVH,QHTOP,OUTTIM
0169      READ(LUI) TITLE,(Z(I),H(I),NTRD(I),THETA(I),KL(I),C(I),
0170      !     T(I),CHSOIL(I),I=1,NPT),THETAW,THETAD,THETAN,RDF,FPET,

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0171      !      MGR,VC,TSOIL,PTRANS,PEVAPO,QWLEAK,QHLEAK
0172      READ(LUI) MAT,IHY,SINLAT,COSLAT,TANLAT,TPIY,PI,DAYSXT,SB,CHW,
0173      !      ZU,ZH,ZM,ZT,D,VK,SEXT,CHA,ICLOUD,TCON,CHS,EF,WATDEN,
0174      !      LHV0,CHV,T0
0175      NCHR = INDEX(BIFILE,')')
0176      IF (NCHR .EQ. 0) THEN
0177          OFILE = BIFILE
0178      ELSE
0179          OFILE = BIFILE(NCHR+1:80)
0180      ENDIF
0181      NCHR = INDEX(OFILE,')')
0182      OFILE(NCHR:NCHR+8) = '.RES'
0183      IRL = MAX(110,(2*IHEAT+IPLANT+3)*NPT+45)
0184      OPEN(UNIT=LUB,FILE=OFILE,STATUS='NEW',FORM='UNFORMATTED',
0185      #      ACCESS='DIRECT',RECL=IRL)
0186      DELT = DELMIN
0187      G = NGRAY
0188      NTOTAL = NINT(24.D0/DUTTIW)
0189      NSTOP = NINT(NTOTAL*STOPHR/24.D0)
0190      DELSUB = 24.D0/NTOTAL
0191      NGDAYS = NHRVST-NSOW+1
0192      IF (NSOW .GT. NHRVST) NGDAYS = 365-NSOW+1+NHRVST
0193      C
0194      C      Write initial conditions to binary output file
0195      C
0196      IDAY = NDAY
0197      HOUR = 0.D0
0198      STORE = TWOIST
0199      TPREV = TWOIST
0200      DAYBEG = NDAY+1
0201      IREC = 2
0202      IF (ITOPBC .EQ. 1) H(1) = HTOP
0203      C
0204      C      Storing initial values as previous values
0205      C      A double first letter implies 'previous value' (e.g., HH, TTHETA)
0206      C
0207      DO 182 I=1,NPT
0208          HH(I) = H(I)
0209          TTHETA(I) = THETA(I)
0210          CC(I) = C(I)
0211      182 CONTINUE
0212      ZZ(1) = Z(2)-Z(1)
0213      THICK(1) = 0.5*ZZ(1)
0214      THICK(NPT) = 0.5*(Z(NPT)-Z(NPT-1))
0215      DO 184 I=2,NPT-1
0216          ZZ(I) = Z(I+1)-Z(I)
0217          THICK(I) = 0.5*(ZZ(I-1)+ZZ(I))
0218      184 CONTINUE
0219      HSOL(1) = H(1)
0220      C
0221      C      Initialize the precipitation data
0222      C      If DAYBEG is greater than IRDAY, go through the data until
0223      C      the appropriate starting day is reached
0224      C
0225      IF (ET_OPT .EQ. 0) THEN
0226          IF (NWATER .GT. 0) THEN
0227              READ(LUI) IRDAY,IRTYPE,EFICEN,NP,
0228              !      (RTIME(J),AMOUNT(J),J=1,NP)
0229              WINDEX = 1
0230              IF (IRTYPE .EQ. 4) THEN
0231                  NEWPON = RTIME(2)
0232                  IF (NEWPON .EQ. 0) NEWPON = DAYEND
0233                  ITPOND = 2
0234              ENDIF
0235      188      IF (IRDAY .LT. DAYBEG) THEN
0236                  READ(LUI) IRDAY,IRTYPE,EFICEN,NP,(RTIME(J),

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0237      AMOUNT(J),J=1,NP)
0238      WINDEX = WINDEX+1
0239      GO TO 188
0240      ENDIF
0241      ENDIF
0242      ELSE
0243      READ(LUI) METDAY,TMAX,TMIN,TDEW,SR_MEAS,WIND,CLOUD,IRTYPE,
0244      ! EFICEN,NP,(RTIME(J),AMOUNT(J),J=1,NP)
0245      TMAXLAST = TMAX
0246      189 IF (METDAY .LT. DAYBEG) THEN
0247      TMAXLAST = TMAX
0248      READ(LUI) METDAY,TMAX,TMIN,TDEW,SR_MEAS,WIND,CLOUD,IRTYPE,
0249      ! EFICEN,NP,(RTIME(J),AMOUNT(J),J=1,NP)
0250      GO TO 189
0251      ENDIF
0252      IF (METDAY .LT. DAYEND) THEN
0253      READ(LUI) II,RR,TMINNEXT
0254      BACKSPACE 1
0255      ELSE
0256      TMINNEXT = TMIN
0257      ENDIF
0258      TMEAN = (TMAX+TMIN)*.5
0259      VD_A = FUNVD(TDEW)
0260      RHMEAN = VD_A/FUNVD(TMEAN)
0261      IF (NP .GT. 0) IRDAY = METDAY
0262      IF (SH_DPT .EQ. 1) CALL HDRYCALC(SVD_S)
0263      ENDIF
0264      IF (UPPERH .EQ. 0) THEN
0265      IF (HOUR .LT. 3.) THEN
0266      TMEANE = (TMAXLAST+TMIN)*0.5
0267      IF (TMIN .GT. TMAXLAST) THEN
0268      TA = TMEANE+(TMIN-TMEANE)*COS((3.D0-HOUR)*PI/12.D0)
0269      ELSE
0270      TA = TMEANE+(TMAXLAST-TMEANE)*COS((15.D0-HOUR)*PI/12.D0)
0271      ENDIF
0272      ELSE IF (HOUR .GE. 15) THEN
0273      TMEANL = (TMAX+TMINNEXT)*0.5
0274      IF (TMINNEXT .GT. TMAX) THEN
0275      TA = TMEANL+(TMINNEXT-TMEANL)*COS((3.D0-HOUR)*PI/12.D0)
0276      ELSE
0277      TA = TMEANL+(TMAX-TMEANL)*COS((15.D0-HOUR)*PI/12.D0)
0278      ENDIF
0279      ELSE
0280      TA = TMEAN+(TMAX-TMEAN)*COS((15.D0-HOUR)*PI/12.D0)
0281      ENDIF
0282      ELSE
0283      TA = TSMEAN
0284      ENDIF
0285      HOUR = NTOTAL*OUTTIM
0286      WRITE(LUB,REC=1) NPT,IPLANT,(Z(I),I=1,NPT),DAYEND,NPRINT,NSURPE,
0287      ! NTOTAL,IFILE,SDATE,STIME,UV,DAYBEG,STDPHR,TITLE,IHEAT,ICLOUD,
0288      ! ET_OPT,SH_OPT,UPPER,UPPERH,LOWER,LOWERH
0289      IF (IPLANT .EQ. 0) THEN
0290      IF (IHEAT .EQ. 0) THEN
0291      WRITE(LUB,REC=2) IDAY,HOUR,(H(J),THEA(J),DAYQ(J),
0292      ! J=1,NPT),DAYINF,DAYRAN,DAYE,DAYTRA,DAYRUN,
0293      ! TPREV,TWOIST,DAYSTP,PE,PT,DAYTIM,DAYAST,DAYUBC,RHMEAN,
0294      ! TMEAN,HDRY,DAYRN,DAYSHE,DAYSSEN,DAYHBE,
0295      ! TA,TMAX,TMIN,VD_A,WIND,CLOUD,SR_MEAS,DAYLE,DAYSDE
0296      ELSE
0297      WRITE(LUB,REC=2) IDAY,HOUR,(H(J),THETA(J),DAYQ(J),
0298      ! T(J),DAYQH(J),J=1,NPT),DAYINF,DAYRAN,DAYE,DAYTRA,DAYRUN,
0299      ! TPREV,TWOIST,DAYSTP,PE,PT,DAYTIM,DAYAST,DAYUBC,RHMEAN,
0300      ! TMEAN,HDRY,DAYRN,DAYSHE,DAYSSEN,DAYHBE,
0301      ! TA,TMAX,TMIN,VD_A,WIND,CLOUD,SR_MEAS,DAYLE,DAYSDE
0302      ENDIF

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0303      ELSE
0304      WRITE(LUB,REC=2) IDAY,HOUR,(H(J),THETA(J),DAYQ(J),
0305      DAYSIN(J),J=1,NPT),DAYINF,DAYRAN,DATE,DAYTRA,DAYRUM,
0306      ! TPREV,TWOIST,DAYSTP,PE,PT,DAYTIM,DAYAST,DAYUBC,RHMEAN,
0307      ! TMEAN,HDRY,DAYSDB
0308      ENDIF
0309      DO 190 I=NP+1,24
0310      RTIME(I) = 0.0
0311      190 CONTINUE
0312      IF (LOWER.EQ. 2) HSOL(NPT) = H(NPT)
0313      IF (LOWER.EQ. 4) QLAST = 0.00
0314      IF (IHEAT.EQ. 1) THEN
0315      CALL THERMK
0316      DO 192 I=1,NPT
0317      CCH(I) = CH(I)
0318      KKHWD(I) = (KH(I)+KH(I+1))*0.5
0319      TT(I) = T(I)
0320      TTHETA(I) = THETA(I)
0321      192 CONTINUE
0322      KKHNP = KH(NPT)
0323      HTIME = 0.5*DELMIN
0324      IF (UPPERH.EQ. 0) THEN
0325      IF (HTIME.LT. 3.) THEN
0326      TMEAN = (TMAXLAST+TMIN)*0.5
0327      IF (TMIN.GT. TMAXLAST) THEN
0328      TA = TMEAN+(TMIN-TMEAN)*COS((3.00-HTIME)*PI/12.00)
0329      ELSE
0330      TA = TMEAN+(TMAXLAST-TMEAN)*COS((15.00-HTIME)*PI/12.00)
0331      ENDIF
0332      ELSE IF (HTIME.GE. 16.) THEN
0333      TMEANL = (TMAX+TMINNEXT)*0.5
0334      IF (TMINNEXT.GT. TMAX) THEN
0335      TA = TMEANL+(TMINNEXT-TMEANL)*COS((3.00-HTIME)*PI/12.00)
0336      ELSE
0337      TA = TMEANL+(TMAX-TMEANL)*COS((15.00-HTIME)*PI/12.00)
0338      ENDIF
0339      ELSE
0340      TA = TMEAN+(TMAX-TMEAN)*COS((15.00-HTIME)*PI/12.00)
0341      ENDIF
0342      TSMEAN = TS
0343      CALL B_L_R(RH)
0344      ENDIF
0345      ENDIF
0346      C-----
0347      C Multiple Year Loop
0348      C
0349      C Head values are retained from end of previous year
0350      C Binary input data file is rewound and repeated each year
0351      C-----
0352      DO 32709 IYEAR=1,NYEARS
0353      IF (IYEAR.GT. 1) THEN
0354      REWIND LUI
0355      DO 200 I=1,4
0356      READ(LUI)
0357      200 CONTINUE
0358      IF (EY.OPT.EQ. 0) THEN
0359      IF (NWATER.GT. 0) THEN
0360      READ(LUI) IRDAY,IRTYPE,EFICEN,NP,
0361      ! (RTIME(J),AMOUNT(J),J=1,NP)
0362      WINDEX = 1
0363      ENDIF
0364      ELSE
0365      TMAXLAST = TMAX
0366      READ(LUI) METDAY,TMAX,TMIN,TDEW,SR,WEAS,WIND,CLOUD,IRTYPE,
0367      ! EFICEN,NP,(RTIME(J),AMOUNT(J),J=1,NP)
0368      IF (METDAY.LT. DAYEND) THEN

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0369          READ(LUI) II,RR,TMINNEXT
0370          BACKSPACE 1
0371      ELSE
0372          TMINNEXT = TMIN
0373      ENDIF
0374          TMEAN = (TMAX+TMIN)*.5
0375          VD_A = FUNVD(TDEM)
0376          RHMEAN = VD_A/FUNVD(TMEAN)
0377          IF (NP.GT. 0) IRDAY = METDAY
0378          IF (SH_OPT.EQ. 1) CALL HDRYCALC
0379      ENDOF
0380          DAYBEG = 1
0381          CLOSE(UNIT=LUB)
0382          STORE = TWOIST
0383          TPREV = TWOIST
0384          OPEN (UNIT=LUB,FILE=OFILE,STATUS='NEW',FORM='UNFORMATTED',
0385              ! ACCESS='DIRECT',RECL=IRL)
0386          WRITE(LUB,REC=1) NPT,IPLANT,(Z(I),I=1,NPT),DAYEND,NPRINT,NSURPE,
0387          ! NTOTAL,IFILE,SDATE,STIME,UV,DAYBEG,STOPHR,TITLE,IHEAT,ICLOUD,
0388          ! ET_OPT,SH_OPT,UPPER,UPPERH,LOWER,LJWERH
0389          IF (IPLANT.EQ. 0) THEN
0390              IF (IHEAT.EQ. 0) THEN
0391                  WRITE(LUB,REC=2) IDAY, HOUR, (H(J),THETA(J),DAYQ(J),
0392                  ! J=1,NPT),DAYINF,DAYRAN,DAYE,DAYTRA,DAYRUN,
0393                  ! TPREV,TWOIST,DAYSTP,PE,PT,DAYTIM,DAYAST,DAYUBC,RHMEAN,
0394                  ! TMEAN,HDRI,DAYRN,DAYSHE,DAYSIN,DAYHBE,
0395                  ! TA,TMAX,TMIN,VD_A,WIND,CLOUD,SR_MEAS,DAYLE,DAYSDE
0396              ELSE
0397                  WRITE(LUB,REC=2) IDAY, HOUR, (H(J),THETA(J),DAYQ(J),
0398                  ! T(J),DAYQH(J),J=1,NPT),DAYINF,DAYRAN,DAYE,DAYTRA,DAYRUN,
0399                  ! TPREV,TWOIST,DAYSTP,PE,PT,DAYTIM,DAYAST,DAYUBC,RHMEAN,
0400                  ! TMEAN,HDRI,DAYRN,DAYSHE,DAYSIN,DAYHBE,
0401                  ! TA,TMAX,TMIN,VD_A,WIND,CLOUD,SR_MEAS,DAYLE,DAYSDE
0402              ENDOF
0403          ELSE
0404              WRITE(LUB,REC=2) IDAY, HOUR, (H(J),THETA(J),DAYQ(J),
0405              ! DAYSIN(J),J=1,NPT),DAYINF,DAYRAN,DAYE,DAYTRA,DAYRUN,
0406              ! TPREV,TWOIST,DAYSTP,PE,PT,DAYTIM,DAYAST,DAYUBC,RHMEAN,
0407              ! TMEAN,HDRI,DAYSDE
0408          ENDOF
0409          IREC = 2
0410      ENDOF
0411      C
0412      C      Initialize yearly cumulatives
0413      C
0414          APLIED = 0.00
0415          OLDRAT = 0.00
0416          TAST = 0
0417          TE = 0.00
0418          TETRAN = 0.00
0419          TIMF = 0.00
0420          TPE = 0.00
0421          TPET = 0.00
0422          TPT = 0.00
0423          TRAIN = 0.00
0424          TRUNOF = 0.00
0425          TSDH = 0
0426          TSTP = 0
0427          TTIM = 0.00
0428          TTIRRI = 0.00
0429          TTRA = 0.00
0430          TUBC = 0
0431          DO 210 I=1,NPT
0432              TQ(I) = 0.00
0433              TQH(I) = 0.00
0434      210 CONTINUE

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0435      THBE = 0.00
0436      TLE = 0.00
0437      TRN = 0.00
0438      TSHF = 0.00
0439      TSEN = 0.00
0440  C-----
0441  C      Day Loop
0442  C
0443  C      IDAY = Day number
0444  C      DAYBEG = Beginning day
0445  C      DAYEND = Ending day
0446  C-----
0447      DO 32700 IDAY=DAYBEG, DAYEND
0448      TPREV = TMOIST
0449      IF (LOWER .EQ. 3) QLAST = QWLEAK(IDAY)/24.
0450      TOTALR = 0.
0451      IF (IRTYPE .NE. 4) THEN
0452          IRRI = 0
0453          IRAIN = 0
0454      ENDIF
0455      DO 310 I=1,24
0456          RATE(I) = 0.00
0457 310      CONTINUE
0458  C
0459  C      Check for rain on current day and set times
0460  C
0461      IF (ET OPT .EQ. 0) THEN
0462          IF (IRDAY .NE. IDAY) GO TO 330
0463      ELSE
0464          IF (NP .EQ. 0) GO TO 330
0465      ENDIF
0466      IF (IRTYPE .EQ. 1) THEN
0467          IRAIN = 1
0468      ELSE
0469          IRRI = 1
0470      ENDIF
0471      TSTART = RTIME(1)
0472      TSTOP = RTIME(NP)
0473  C
0474  C      Determines the water input rate (cm/h)
0475  C      If IRTYPE = 1, input is PPT, if IRTYPE = 2, input is IRRI
0476  C
0477      IF (IRTYPE .EQ. 1 .OR. IRTYPE .EQ. 2) THEN
0478          IF (NP .EQ. 0) GO TO 330
0479          DO 320 I=1,NP-1
0480              TOTALR = TOTALR+AMOUNT(I)
0481 320      CONTINUE
0482          IF (IRTYPE .EQ. 2) TOTALR = TOTALR*EFICEN
0483          APLIED = APLIED+TOTALR
0484          J = 1
0485          DO 322 I=1,24
0486              IF ((I-1) .LT. TSTART .OR. (I-1) .GE. TSTOP) GO TO 322
0487              IF ((I-1) .EQ. RTIME(J)) THEN
0488                  RATE(I) = AMOUNT(J)/(RTIME(J+1)-RTIME(J))
0489                  J = J+1
0490              ELSE
0491                  RATE(I) = RATE(I-1)
0492              ENDIF
0493 322      CONTINUE
0494      ELSE IF (IRTYPE .EQ. 3) THEN
0495          HPOND = AMOUNT(1)
0496      ELSE IF (IRTYPE .EQ. 4) THEN
0497          HPOND = AMOUNT(ITPOND)
0498          IHPOND = 1
0499      IF (IDAY .GT. NEWPON) THEN
0500          ITPOND = ITPOND+1

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0501         NEWPON = RTIME(ITPOND)
0502         IF (NEWPON .EQ. 0) NEWPON = DAYEND
0503     ENDIF
0504 ENDIF
0505 330 IF (IHEAT .EQ. 1) GO TO 435
0506 C
0507 C If IPLANT = 0, PTRANS = 0 and PET becomes PEVAPO
0508 C If IPLANT = 1, PET becomes PTRANS + PEVAPO
0509 C
0510 PE = PEVAPO(IDAY)
0511 PT = PTRANS(IDAY)
0512 IF (IPLANT .NE. 0) THEN
0513     IF (IDAY .GE. NSOW) THEN
0514         NGROW = IDAY-NSOW+1
0515     ELSE
0516         NGROW = 365-IDAY-NSOW+1
0517     ENDIF
0518     IF (NGROW .GT. NGDAYS) GO TO 435
0519 C
0520 C Determine to which depth roots have gone
0521 C
0522     I = 1
0523 400 IF (NGROW .GT. NROOT(I) .AND. I .LT. MXROOT) THEN
0524         I = I+1
0525         GO TO 400
0526     ENDIF
0527     WDEPTH = I
0528     IF (WDEPTH .EQ. 1) GO TO 435
0529 C
0530 C Estimate root density factor (RDF) at each node of root depth
0531 C Note that roots are not allowed to grow in node 1 (surface node)
0532 C
0533     ROOTS = 0.
0534     DO 410 I=2,WDEPTH
0535         RDF(I) = RLD(Z(I))
0536         ROOTS = ROOTS+RDF(I)*THICK(I)
0537 410 CONTINUE
0538     IF (WDEPTH .GT. 1 .AND. WDEPTH .LT. NPT) THEN
0539         ROOTS = ROOTS-RDF(WDEPTH)*THICK(WDEPTH)*0.5
0540         RDF(WDEPTH) = 0.5*RDF(WDEPTH)
0541     ENDIF
0542     DO 420 I=1,WDEPTH
0543         RDF(I) = RDF(I)/ROOTS
0544 420 CONTINUE
0545     ENDIF
0546 C
0547 C Initialize daily cumulative totals
0548 C
0549 435 DAYAST = 0
0550 DAYSTP = 0
0551 DAYTIW = 0.D0
0552 DAYE = 0.D0
0553 DAYPE = 0.D0
0554 DAYTRA = 0.D0
0555 DAYPT = 0.D0
0556 DAYINF = 0.D0
0557 DAYIRR = 0.D0
0558 DAYRUN = 0.D0
0559 DAYRAN = 0.D0
0560 DAYSDH = 0
0561 DAYUBC = 0
0562 HOUR = 0.D0
0563 TPREV = TMOIST
0564 DO 440 I=1,NPT
0565     DAYSNK(I) = 0.D0
0566     DAYQ(I) = 0.D0

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0567      DAYQH(I) = 0.D0
0568 440 CONTINUE
0569      PTSUB = 0.D0
0570      PESUB = 0.D0
0571      IF (IHEAT .EQ. 1) THEN
0572          DAYHBE = 0.D0
0573          DAYLE = 0.D0
0574          DAYRN = 0.D0
0575          DAYSHF = 0.D0
0576          DAYSEN = 0.D0
0577      ENDIF
0578 C-----
0579 C      NTOTAL Loop
0580 C
0581 C      Program will remain in this loop until 1 day has been simulated.
0582 C-----
0583      DO 32672 N=1,NTOTAL
0584          SPREV = TMOIST
0585          NHR = INT(1.0D0*(N-1)*24.D0/NTOTAL)
0586          IF (IPLANT .EQ. 1 .OR. NSURPE .EQ. 1) THEN
0587              PTSUB = PT+FPET(NHR)
0588              PESUB = PE+FPET(NHR)
0589          ENDIF
0590          IF (IRAIN .EQ. 1) PRRAIN = RATE(NHR)
0591          IF (IRRRI .EQ. 1) PIRRI = RATE(NHR)
0592          IF (RATE(NHR) .EQ. 0.) THEN
0593              ISATUK = 0
0594          ELSE
0595              ISATUK = 1
0596              IF (OLDRAT .GT. 0.) ISATUK = 2
0597          ENDIF
0598 C
0599 C      Initialize total values for each OUTTIM (output time)
0600 C
0601      SUBAST = 0
0602      SUBE = 0.D0
0603      SUBIRR = 0.D0
0604      SUBINF = 0.D0
0605      SUBRAN = 0.D0
0606      SUBRUN = 0.D0
0607      SUBSDH = 0
0608      SUBSTP = 0
0609      SUBTIM = 0.D0
0610      SUBTRA = 0.D0
0611      SUBUBC = 0
0612      DO 450 I=1,NPT
0613          SUBSNK(I) = 0.D0
0614          SUBQ(I) = 0.D0
0615          SUBQH(I) = 0.D0
0616 450 CONTINUE
0617      SUBHBE = 0.D0
0618      SUBLE = 0.D0
0619      SUBRN = 0.D0
0620      SUBSHF = 0.D0
0621      SUBSEN = 0.D0
0622 C-----
0623 C      Start of the DELSUB loop. The program remains here until DELSUB
0624 C      time has elapsed. (i.e. TSUB = DELSUB)
0625 C-----
0626      TSUB = 0.D0
0627 32649 IF (DELSUB-TSUB .LE. 0) GO TO 32648
0628      IF (DELSUB-TSUB .LT. DELMIN) DELT = DELSUB-TSUB
0629      DELSAV = DELT
0630      TSUB = TSUB+DELSAV
0631 C
0632 C      When UPPER = 0, Water flux surface bc

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0833 C      When UPPER = 1, constant head surface bc
0834 C
0835      UPPER = 0
0836      NSINK = 0
0837      IF (IPLANT .EQ. 1) NSINK = 1
0838 C
0839 C      Surface flux initially set to the evaporation rate
0840 C
0841      SFLUX = -PESUB
0842      IF (SH_OPT .EQ. 1) THEN
0843          IF (HH(1) .GT. HDRY) SFLUX = 0
0844      ENDIF
0845      IF (IHEAT .EQ. 1 .AND. UPPERH .EQ. 0) THEN
0846          SVD S = FUNVD(TS)
0847          CALL HDRYCALC(SVD_S)
0848      ENDIF
0849      IF (IRRI .EQ. 1 .AND. IRTYPE .GT. 2) THEN
0850          IF (HPOND .GT. 0) THEN
0851              H(1) = -HPOND
0852              UPPER = 1
0853          ELSE
0854              IHPOND = 0
0855              IRRI = 0
0856          ENDIF
0857          GO TO 32647
0858      ELSE
0859 C
0860 C      During watering, surface evaporation set to zero
0861 C
0862          IF (ISATUK .EQ. 0) GO TO 32647
0863          IF (ISATUK .EQ. 1) THEN
0864 C
0865 C      For the first time step of a rainfall event, C, K, and THETA are
0866 C      set to their values at saturation and DELT is reduced by RAINIF
0867 C
0868          C(1) = SATC
0869          KL(1) = SATK
0870          THETA(1) = SATTH
0871          TSUB = TSUB-DELT
0872          DELT = DELT*RAINIF
0873          IF (DELT .LT. DELMIN) DELT = DELMIN
0874          TSUB = TSUB+DELT
0875      ENDIF
0876      NSINK = 0
0877      SFLUX = RATE(NHR)
0878      ENDIF
0879 32647 IF (IPLANT .EQ. 0) GO TO 32639
0880      TRANSP = 0.00
0881      DO 500 I=1,MDEPTH
0882          SINK(I) = 0.00
0883 500 CONTINUE
0884 C
0885 C      Transpiration is assumed to be zero during irrigation or rainfall
0886 C
0887      IF (PYSUB .EQ. 0.0) NSINK = 0
0888 C
0889 C      Estimate sink term by a modified FEDDES method
0890 C
0891      IF (NSINK .NE. 1) GO TO 32639
0892      DO 520 I=1,MDEPTH
0893          MATI = MAT(I)
0894          TH = (THETA(I)+TTHETA(I))*0.5
0895          THW = THETAW(MATI)
0896          THD = THETAD(MATI)
0897          THN = THETAN(MATI)
0898          IF (TH .GT. THW .AND. TH .LE. THN) THEN

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0699          IF (TH .LT. THD) THEN
0700              ALPHAF = (TH-THW)/(THD-THW)
0701          ELSE
0702              ALPHAF = 1.D0
0703          ENDIF
0704          ELSE
0705              ALPHAF = 0.D0
0706          ENDIF
0707          SINK(I) = PTSUB+ALPHAF*RDF(I)
0708          TRANSP = TRANSP+SINK(I)*THICK(I)
0709 520  CONTINUE
0710  C-----
0711  C   Convergence loop for the current time step
0712  C-----
0713 32039 ISAVUP = UPPER
0714          IF (ITOPBC .EQ. 1) THEN
0715              UPPER = 1
0716              ISAVUP = UPPER
0717          ENDIF
0718  C
0719  C   "Decrease DELT" loop when solution unacceptable
0720  C
0721 150  DELSAV = DELT
0722      NPPT = NPT-1
0723  C-----
0724  C   Predictor-Corrector Loop (while "IN" < 2 )
0725  C
0726  C   This implicit scheme solves the partial differential equation
0727  C   for the change in head
0728  C-----
0729      IN = 0
0730      IF (IHEAT .EQ. 1) THEN
0731          HTIME = HOUR+TSUB-.5*DELT
0732          IF (UPPERH .EQ. 0) THEN
0733              IF (HTIME .LT. 3.) THEN
0734                  TMEANE = (TMAXLAST+TMIN)*0.5
0735                  IF (TMIN .GT. TMAXLAST) THEN
0736                      TA = TMEANE+(TMIN-TMEANE)*COS((3.D0-HTIME)*PI/12.D0)
0737                  ELSE
0738                      TA = TMEANE+(TMAXLAST-TMEANE)*COS((15.D0-HTIME)*PI/12.D0)
0739                  ENDIF
0740              ELSE IF (HTIME .GE. 15.) THEN
0741                  TMEANL = (TMAX+TMINNEXT)*0.5
0742                  IF (TMINNEXT .GT. TMAX) THEN
0743                      TA = TMEANL+(TMINNEXT-TMEANL)*COS((3.D0-HTIME)*PI/12.D0)
0744                  ELSE
0745                      TA = TMEANL+(TMAX-TMEANL)*COS((15.D0-HTIME)*PI/12.D0)
0746                  ENDIF
0747              ELSE
0748                  TA = TMEAN+(TMAX-TMEAN)*COS((15.D0-HTIME)*PI/12.D0)
0749              ENDIF
0750          ENDIF
0751      ENDIF
0752 32020 IF (IN .GE. INMAX) GO TO 32025
0753      IN = IN+1
0754      DEL = 1.D0/DELSAV
0755      IF (IQ0150 .EQ. 1 .AND. IN .EQ. 1) GO TO 550
0756  C
0757  C   Calculate internodal conductivities
0758  C   Loop 140 for repeating time step with held head at surface
0759  C
0760 140  IF (IVAPOR .EQ. 1) THEN
0761      IF (IHEAT .EQ. 0) THEN
0762  C
0763  C   VC was modified for isothermal vapor flow
0764  C

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0765      DO 554 I=1, NPPT+1
0766          AIRCON = (THET(MAT(I))-THETA(I))
0767          RELHUM = EXP(-H(I)*MGR/TSOIL)
0768          KV(I) = VC*AIRCON*RELHUM
0769      554 CONTINUE
0770      ELSE
0771          CALL THERME
0772          DO 555 I=1, NPPT+1
0773              TI = T(I)
0774              AIRCON = (THET(MAT(I))-THETA(I))
0775              RELHUM = EXP(-H(I)*MGR/TI)
0776              SVD = FUNVD(TI)
0777              DSVDDT = SVD*(-6.02808D0+6790.4905D0/TI)/TI
0778              KV(I) = VC*SVD*AIRCON*RELHUM*MGR/TI
0779              KVT(I) = VC*AIRCON*ENFACT(I)*RELHUM*DSVDDT
0780      555 CONTINUE
0781      ENDIF
0782  ENDIF
0783  DO 560 I=1, NPPT
0784      IF (KEST .EQ. 1) THEN
0785          IF (UP .EQ. 0.5) THEN
0786              KLMID(I) = (KL(I)+KL(I+1))*0.5
0787              IF (IVAPOR .EQ. 1) THEN
0788                  KVMID(I) = (KV(I)+KV(I+1))*0.5
0789                  IF (IHEAT .EQ. 1) KVTMID(I) = (KVT(I)+KVT(I+1))*0.5
0790              ENDIF
0791          ELSE
0792              IF (-(H(I)+Z(I)) .GT. -(H(I+1)+Z(I+1))) THEN
0793                  KLMID(I) = KL(I)*UP+KL(I+1)*DOWN
0794                  IF (IVAPOR .EQ. 1) THEN
0795                      KVMID(I) = KV(I)*UP+KV(I+1)*DOWN
0796                      IF (IHEAT .EQ. 1) KVTMID(I) = KVT(I)*UP+KVT(I+1)*DOWN
0797                  ENDIF
0798              ELSE
0799                  KLMID(I) = KL(I)*DOWN+KL(I+1)*UP
0800                  IF (IVAPOR .EQ. 1) THEN
0801                      KVMID(I) = KV(I)*DOWN+KV(I+1)*UP
0802                      IF (IHEAT .EQ. 1) KVTMID(I) = KVT(I)*DOWN+KVT(I+1)*UP
0803                  ENDIF
0804              ENDIF
0805          ENDIF
0806      ELSE IF (KEST .EQ. 2) THEN
0807          KLMID(I) = KL(I)*KL(I+1)/(KL(I)+KL(I+1))
0808          IF (IVAPOR .EQ. 1) THEN
0809              KVMID(I) = KV(I)*KV(I+1)/(KV(I)+KV(I+1))
0810              IF (IHEAT .EQ. 1) KVTMID(I) = KVT(I)*KVT(I+1)
0811              / (KVT(I)+KVT(I+1))
0812          ENDIF
0813      ELSE IF (KEST .EQ. 3) THEN
0814          KLMID(I) = (KL(I)*KL(I+1))*0.5
0815          IF (KLMID(I) .EQ. 0)
0816      !      KLMID(I) = EXP((LOG(KL(I))+LOG(KL(I+1)))/2)
0817          IF (IVAPOR .EQ. 1) THEN
0818              KVMID(I) = (KV(I)+KV(I+1))*0.5
0819              IF (IHEAT .EQ. 1) KVTMID(I) = (KVT(I)+KVT(I+1))*0.5
0820          ENDIF
0821      ENDIF
0822  560 CONTINUE
0823  IF (START) THEN
0824      KKLWPT = KL(NPT)
0825      DO 561 I=1, NPPT
0826          KKLWID(I) = KLMID(I)
0827          KKVWID(I) = KVMID(I)
0828          KKVWID(I) = KVTMID(I)
0829  561 CONTINUE
0830  ENDIF

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0831 IF (ITOPBC .EQ. 1) THEN
0832   UPPER = 1
0833   H(1) = HTOP
0834   ENDIF
0835 C
0836 C Calculate coefficients for simulation of change in head
0837 C
0838 568 DO 570 II=2,NPPT
0839   I = II-1
0840   III = II+1
0841   Z31 = Z(III)-Z(I)
0842   FZZ1 = 1./(Z31*ZZ(I))
0843   FZZ2 = 1./(Z31*ZZ(III))
0844   ZK1 = (KLMID(I)+KVMID(I))*FZZ1
0845   ZK2 = (KLMID(III)+KVMID(III))*FZZ2
0846   AVC = 0.6*(C(II)+CC(II))
0847   A2(II) = AVC*DEL-ZK1-ZK2
0848   A1(II) = ZK1
0849   A3(II) = ZK2
0850   PG1 = (HH(II)-HH(I))/ZZ(I)
0851   PG2 = (HH(III)-HH(II))/ZZ(III)
0852   ZY(II) = AVC*HH(II)*DEL-SINK(II)-(KLMID(II)*(PG2-G)+KVMID(II)
0853   ! *PG2-KLMID(I)*(PG1-G)+KVMID(I)*PG1+G*(KLMID(II)
0854   ! -KLMID(I)))/Z31
0855 570 CONTINUE
0856 IF (IHEAT .EQ. 1 .AND. IVAPOR .EQ. 1) THEN
0857   DO 571 II=2,NPPT
0858     I = II-1
0859     III = II+1
0860     Z31 = Z(III)-Z(I)
0861     ZY(II) = ZY(II)-((KVTMID(II)+KKVTMID(II))*(T(III)-T(II))
0862     ! /ZZ(II)+(KVTMID(I)+KKVTMID(I))*(T(II)-T(I))/Z31)
0863     ! /Z31
0864 571 CONTINUE
0865   ENDIF
0866 IF (IHEAT .EQ. 1) THEN
0867   SFLUXX = 0.0
0868   IF (SFLUX .LE. 0.0 .AND. UPPERH .EQ. 0) THEN
0869     IF (IN .EQ. 1) VVD_S = SVD_S*EXP(-HH(1)*MGR/TS)
0870     VD_S = SVD_S*EXP(-H(1)*MGR/TS)
0871 C
0872 C Because water and vapor density are in g/cm3 and RH is in s/m,
0873 C the calculated evaporation rate is multiplied by 3.8E5 cm s/m hr
0874 C to yield a SFLUX value with units of cm/hr. The SFLUXX term is
0875 C used to modify SFLUX in the matrix coefficient assembly loop
0876 C because exp(x) has been expanded to 1+x*x^2/2!...
0877 C
0878   SFLUX = 3.8D5*(VD_A-((VVD_S+VD_S)/2.D0))/(WATDEN+RH)
0879   SFLUXX = 3.8D5*SVD_S*MGR/(TS*2.D0*WATDEN+RH)
0880 C
0881 C Positive water fluxes (to the surface) caused by vapor density
0882 C gradients are not allowed to occur (i.e., no dew additions)
0883 C
0884   IF (SFLUX .GE. 0) THEN
0885     SFLUX = 0.D0
0886     SFLUXX = 0.D0
0887   ENDIF
0888 ENDIF
0889 ENDIF
0890 IF (UPPER .EQ. 1) THEN
0891 C
0892 C Surface node equation for constant head b.c.
0893 C
0894   ISTART = 2
0895   ZY(2) = ZY(2)-A1(2)*H(1)
0896   A1(2) = 0.D0

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0897 ELSE
0898 C
0899 C Surface node equation for flux b.c.
0900 C
0901 Z1 = ZZ(1)
0902 Z11 = (KLMID(1)+KVMID(1))/(Z1*Z1)
0903 AVC = (C(1)+CC(1))*0.5
0904 A1(1) = 0.D0
0905 A2(1) = AVC*DEL-Z11-2*SFLUX/Z1
0906 A3(1) = Z11
0907 PG2 = (HH(2)-HH(1))/Z1
0908 ZY(1) = AVC*DEL*HH(1)-SINK(1)-(KLMID(1)*(PG2+G)+KVMID(1)*PG2
0909 ! +G*KLMID(1)-2.D0*(SFLUX-SFLUX*H(1)))/Z1
0910 IF (IHEAT.EQ. 1 .AND. IVAPOR.EQ. 1) ZY(1) = ZY(1)
0911 ! -((KVTMID(1)+KKVTMID(1))*(T(2)-T(1))/Z1)/Z1
0912 ISTART = 1
0913 ENDIF
0914 IF (IG0140.EQ. 1) THEN
0915 NPPT = NPT-1
0916 IF (LOWER.NE. 2) NPPT = NPT
0917 IG0140 = 0
0918 GO TO 575
0919 ENDIF
0920 C
0921 C LOWER: 1=unit grad.; 2=cons. head; 3=specified flux; 4=imperv.
0922 C
0923 IF (LOWER.NE. 2) THEN
0924 ZN = ZZ(NPPT)
0925 ZK1 = (KLMID(NPPT)+KVMID(NPPT))/(ZN*ZN)
0926 AVC = 0.5*(C(NPT)+CC(NPT))
0927 A3(NPT) = 0.D0
0928 IF (LOWER.EQ. 1) QLAST = 0.5*(KL(NPT)+KKLNPT)
0929 A1(NPT) = ZK1
0930 A2(NPT) = AVC*DEL-ZK1
0931 PG1 = (HH(NPT)-HH(NPPT))/ZN
0932 ZY(NPT) = AVC*HH(NPT)*DEL-(2.D0*QLAST-KLMID(NPPT)*(PG1+G)
0933 ! -KVMID(NPPT)*PG1-G*KLMID(NPPT))/ZN
0934 IF (IHEAT.EQ. 1 .AND. IVAPOR.EQ. 1) ZY(NPT) = ZY(NPT)
0935 ! -((KVTMID(NPPT)+KKVTMID(NPPT))*(T(NPT)-T(NPPT))/ZN)/ZN
0936 NPPT = NPT
0937 ELSE
0938 ZY(NPPT) = ZY(NPPT)-A3(NPPT)*H(NPT)
0939 A3(NPPT) = 0.D0
0940 ENDIF
0941 C
0942 C Solution of tridiagonal matrix
0943 C
0944 575 CALL TRIDAG(ISTART,NPPT,A1,A2,A3,ZY,HSOL)
0945 C-----
0946 C Solution estimate complete for this iteration
0947 C-----
0948 NPPT = NPT-1
0949 C
0950 C Check whether surface b.c. changed due to solution with given
0951 C flux. If so, repeat as constant surface head b.c.
0952 C
0953 IG0140 = 0
0954 IF (UPPER.EQ. 0) THEN
0955 IF (HSOL(1).LT. HIRRI) THEN
0956 H(1) = HIRRI
0957 HSOL(1) = HIRRI
0958 UPPER = 1
0959 KL(1) = SATK
0960 C(1) = SATC
0961 THETA(1) = SATTH
0962 IG0140 = 1

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0963      ENDIF
0964      IF (HSOL(1) .GT. HDRY) THEN
0965          IF (HH(1) .GT. HDRY) GO TO 783
0966              H(1) = HDRY
0967              HSOL(1) = HDRY
0968              KL(1) = DRYK
0969              C(1) = DRYC
0970              THETA(1) = DRYTH
0971              UPPER = 1
0972              IG0140 = 1
0973      ENDIF
0974  ENDIF
0975  IF (IG0140 .EQ. 1) THEN
0976      SUBUBC = SUBUBC+1
0977      NPPT = 2
0978      GO TO 140
0979  ENDIF
0980  C
0981  C Check whether delta head of lowest node with HH=HDRY is less than
0982  C DHMAX
0983  C
0984      IF (DHMAX .GT. 0) THEN
0985          IG0150 = 0
0986          IF (DELT .GT. DELMIN .AND. ISATUK .NE. 1) THEN
0987              DO 580 I=1,NPT
0988                  IF (ABS(HH(I)-HSOL(I)) .GE. DHMAX) THEN
0989                      TSUB = TSUB-DELT
0990                      DELT = DELT*DHFACT
0991                      IF (DELT .LT. DELMIN) DELT = DELMIN
0992                      TSUB = TSUB+DELT
0993                      SUBSDH = SUBSDH+1
0994                      IG0150 = 1
0995                      GO TO 796
0996                  ENDIF
0997  580      CONTINUE
0998      ENDIF
0999  ENDIF
1000  C
1001  C Passed check on upper boundary condition
1002  C
1003  783  DO 784 I=1,NPT
1004      H(I) = HSOL(I)
1005  784  CONTINUE
1006      IF (IN .LT. INMAX) THEN
1007          CALL POLYKH(NPT,KL,H)
1008          CALL POLYCH(NPT,C,H)
1009      ENDIF
1010      CALL POLYTH(NPT,THETA,H)
1011      GO TO 32626
1012  C-----
1013  C End of the Predictor-Corrector Loop
1014  C-----
1015  32625 SUBAST = SUBAST+1
1016      IG0150 = 0
1017  C
1018  C Check for convergence on THETA
1019  C
1020      IF (ISWDIF .EQ. 0) THEN
1021          DIFMAX = 0.D0
1022          DO 788 I=1,NPT
1023              THDIF = ABS((THETA(I)-TTHETA(I))/TTHETA(I))
1024              DIFMAX = MAX(DIFMAX,THDIF)
1025  788      CONTINUE
1026  C
1027  C If time step reaches DELMIN, accept the % THETA change error,
1028  C even if it is greater than DMAXBA, and continue

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1029 C
1030 IF (DELT .GT. DELMIN .OR. DIFMAX .LT. DMAXBA) CALL DELCHK
1031 IF (IG0150 .EQ. 1) GO TO 795
1032 ENDF
1033 C
1034 C Fluxes are calculated at all column segments
1035 C
1036 DO 792 II=2,NPT
1037 I = II-1
1038 ZI = ZZ(I)
1039 PG = (H(II)-H(I))/ZI
1040 PPG = (HH(II)-HH(I))/ZI
1041 QL(I) = DELSAV*0.5*(KLMID(I)*(PG+G)+KKLMID(I)*(PPG+G))
1042 IF (IVAPOR .EQ. 1) THEN
1043 QVH = DELSAV*0.5*(KVMID(I)*PG+KKVMID(I)*PPG)
1044 IF (IHEAT .EQ. 1)
1045 ! QVT = -DELSAV*0.5*(KVTMID(I)+KKVTMID(I))*(T(II)-T(I))/ZI
1046 QV(I) = QVH+QVT
1047 ENDF
1048 QT(I) = QL(I)+QV(I)
1049 792 CONTINUE
1050 C
1051 C SSFLUX is surface infiltration (cm) for the time step
1052 C Estimate from THETA and geometry if saturated.
1053 C If the infiltration was from rainfall, however, do not let it
1054 C exceed the actual rainfall (i.e. ISAVUP .NE. 1)
1055 C
1056 IF (UPPER .EQ. 1) THEN
1057 SSFLUX = QT(1)+(THETA(1)-TTHETA(1))*THICK(1)
1058 IF (ISAVUP .NE. 1) THEN
1059 IF (H(1) .EQ. HIRRI) SSFLUX = MIN(SSFLUX,SFLUX*DELSAV)
1060 IF (IHEAT .EQ. 0 .AND. H(1) .EQ. HDRI)
1061 # SSFLUX = MAX(SSFLUX,SFLUX*DELSAV)
1062 ENDF
1063 ELSE
1064 SSFLUX = SFLUX*DELSAV
1065 ENDF
1066 C
1067 C Deep drainage flux
1068 C
1069 IF (LOWER .EQ. 2) THEN
1070 QL(NPT) = QT(NPPT)
1071 QT(NPT) = QL(NPT)
1072 ELSE
1073 QL(NPT) = QLAST*DELSAV
1074 QT(NPT) = QL(NPT)
1075 ENDF
1076 C
1077 C Estimate total water storage in the profile (SMOIST) and the
1078 C mass balance error (DIFMAX)
1079 C
1080 SMOIST = 0.0
1081 DO 794 I=1,NPT
1082 SMOIST = SMOIST+THETA(I)*THICK(I)
1083 794 CONTINUE
1084 DIFMAX = ABS((TWOIST-SSFLUX-TRANSP*DELSAV-QT(NPT)-SMOIST))
1085 C
1086 C Reduce the time step if the mass balance error is not within
1087 C limits (when ISWDIF .EQ. 1)
1088 C
1089 IF (ISWDIF .EQ. 0) GO TO 798
1090 IF (DELT .GT. DELMIN .OR. DIFMAX .LT. DMAXBA) CALL DELCHK
1091 795 IF (IG0150 .NE. 1) GO TO 798
1092 DO 796 I=1,NPT
1093 THETA(I) = TTHETA(I)
1094 C(I) = CC(I)

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1095      H(I)      = HH(I)
1096      KLMID(I) = KKLWID(I)
1097 798  CONTINUE
1098      KL(NPT) = KKLNPT
1099      IF (IVAPOR .EQ. 1) THEN
1100        DO 797 I=1,NPT
1101          KVMID(I) = KKVWID(I)
1102          KVTWID(I) = KKVWID(I)
1103 797  CONTINUE
1104      ENDIF
1105      IF (ISATUK .EQ. 1) THEN
1106        KL(1) = SATK
1107        C(1) = SATC
1108        THETA(1) = SATTH
1109      ENDIF
1110      UPPER = ISAVUP
1111      GO TO 150
1112  C-----
1113  C   End of convergence loop for water flow
1114  C   Time step successful, all conditions satisfied.
1115  C
1116  C   If IHEAT = 1, the HEATFLOW subroutine is called
1117  C-----
1118 798  IF (IHEAT .EQ. 1) CALL HEATFLOW(RH)
1119  C
1120  C   Old water flow parameters are reset to new values
1121  C   Hourly water and heat totals are updated
1122  C
1123      IF (ISATUK .EQ. 1) ISATUK = 2
1124      SUBSTP = SUBSTP+1
1125      SUBTIM = SUBTIM+DELSAV
1126      DO 800 I=1,NPT
1127        SUBQ(I) = SUBQ(I)+QT(I)
1128 800  CONTINUE
1129      SUBTRA = SUBTRA+TRANSP*DELSAV
1130      DO 805 I=1,MDEPTH
1131        SUBSNK(I) = SUBSNK(I)+SINK(I)*DELSAV
1132 805  CONTINUE
1133      IF (SSFLUX .GT. 0.D0) SUBINF = SUBINF+SSFLUX
1134      IF (SSFLUX .LT. 0.D0) SUBE = SUBE-SSFLUX
1135      IF (SSFLUX .LT. 0.D0) PSFLUX = SSFLUX/DELSAV
1136      IF (RATE(NHR) .GT. 0.D0 .OR. HPOND .GT. 0.D0) THEN
1137        SUBRAN = SUBRAN+DELSAV*PRAIN
1138        SUBIRR = SUBIRR+DELSAV*PIRRI
1139        RUNOFF = 0.D0
1140        IF (PIRRI*DELSAV .GT. SSFLUX) RUNOFF = PIRRI*DELSAV-SSFLUX
1141        IF (PRAIN*DELSAV .GT. SSFLUX) RUNOFF = PRAIN*DELSAV-SSFLUX
1142        IF (RUNOFF .GT. 0.D0) SUBRUN = SUBRUN+RUNOFF
1143      ENDIF
1144      CALL POLYCH(NPT,C,H)
1145      CALL POLYKH(NPT,KL,H)
1146      DO 810 I=1,NPT
1147        TTHETA(I) = THETA(I)
1148        CC(I) = C(I)
1149        HH(I) = H(I)
1150        KKLWID(I) = KLMID(I)
1151 810  CONTINUE
1152      KKLNPT = KL(NPT)
1153      TMOIST = SMOIST
1154      START = .FALSE.
1155      IF (IVAPOR .EQ. 1) THEN
1156        DO 582 I=1,NPPT
1157          KKVWID(I) = KVMID(I)
1158 582  CONTINUE
1159      IF (IHEAT .EQ. 1) THEN
1160        DO 583 I=1,NPPT

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1161             KKVTMID(I) = KVTMID(I)
1162 563         CONTINUE
1163         ENDIF
1164     ENDIF
1165     GO TO 32649
1166 C-----
1167 C     End of the DELSUB Loop. (TSUB = DELSUB)
1168 C     Daily totals are updated
1169 C-----
1170 32648 DAYAST = DAYAST+SUBAST
1171     DAYE = DAYE+SUBE
1172     DAYINF = DAYINF+SUBINF
1173     DAYIRR = DAYIRR+SUBIRR
1174     DAYPE = DAYPE+PESUB
1175     DAYPT = DAYPT+PTSUB
1176     DAYRAN = DAYRAN+SUBRAN
1177     DAYRUN = DAYRUN+SUBRUN
1178     DAYSDH = DAYSDH+SUBSDH
1179     DAYSTP = DAYSTP+SUBSTP
1180     DAYTIM = DAYTIM+SUBTIM
1181     DAYTRA = DAYTRA+SUBTRA
1182     DAYUBC = DAYUBC+SUBUBC
1183     HOUR = HOUR+DELSUB
1184     OLDRAT = RATE(NHR)
1185     DO 825 I=1,NPT
1186         DAYSNN(I) = DAYSNN(I)+SUBSNN(I)
1187         DAYQ(I) = DAYQ(I)+SUBQ(I)
1188 825     CONTINUE
1189     IF (IHEAT .EQ. 1) THEN
1190         DAYHBE = DAYHBE+SUBHBE
1191         DAYLE = DAYLE+SUBLE
1192         DAYRN = DAYRN+SUBRN
1193         DAYSHF = DAYSHF+SUBSHF
1194         DAYSEN = DAYSEN+SUBSEN
1195         DO 826 I=1,NPT
1196             DAYQH(I) = DAYQH(I)+SUBQH(I)
1197 826     CONTINUE
1198     IF (UPPERH .EQ. 0) THEN
1199         IF (HOUR .LT. 3.) THEN
1200             TMEANE = (TMAXLAST+TMIN)*0.5
1201             IF (TMIN .GT. TMAXLAST) THEN
1202                 TA = TMEANE+(TMIN-TMEANE)*COS((3.D0-HOUR)*PI/12.D0)
1203             ELSE
1204                 TA = TMEANE+(TMAXLAST-TMEANE)*COS((15.D0-HOUR)*PI/12.D0)
1205             ENDIF
1206         ELSE IF (HOUR .GE. 15.) THEN
1207             TMEANL = (TMAX+TMINNEXT)*0.5
1208             IF (TMINNEXT .GT. TMAX) THEN
1209                 TA = TMEANL+(TMINNEXT-TMEANL)*COS((3.D0-HOUR)*PI/12.D0)
1210             ELSE
1211                 TA = TMEANL+(TMAX-TMEANL)*COS((15.D0-HOUR)*PI/12.D0)
1212             ENDIF
1213         ELSE
1214             TA = TMEAN+(TMAX-TMEAN)*COS((15.D0-HOUR)*PI/12.D0)
1215         ENDIF
1216     ENDIF
1217 ENDIF
1218 C
1219 C     Write DELSUB summary to binary output file
1220 C
1221     IF (NPRINT .EQ. 1) THEN
1222         IREC = IREC+1
1223         IF (IPLANT .EQ. 0) THEN
1224             IF (IHEAT .EQ. 0) THEN
1225                 WRITE(LUB,REC=IREC) IDAY,HOUR,(H(J),THETA(J),SUBQ(J),
1226                     J=1,NPT),SUBINF,SUBRAN,SUBE,SUBTRA,SUBRUN,

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1227      !      SPREV,TWOIST,SUBSTP,PESUB,PTSUB,SUBTIM,SUBAST,SUBUBC,RHMEAN,
1228      !      TMEAN,HDRY,SUBRN,SUBSHF,SUBSEN,SUBHBE,
1229      !      TA,TMAX,TMIN,VD_A,WIND,CLOUD,SR_MEAS,SUBLE,SUBSDH
1230      ELSE
1231      WRITE(LUB,REC=IREC) IDAY,HOUR,(H(J),THETA(J),SUBQ(J),
1232      !      T(J),SUBQH(J),J=1,NPT),SUBINF,SUBRAN,SUBE,SUBTRA,SUBRUN,
1233      !      SPREV,TWOIST,SUBSTP,PESUB,PTSUB,SUBTIM,SUBAST,SUBUBC,RHMEAN,
1234      !      TMEAN,HDRY,SUBRN,SUBSHF,SUBSEN,SUBHBE,
1235      !      TA,TMAX,TMIN,VD_A,WIND,CLOUD,SR_MEAS,SUBLE,SUBSDH
1236      !
1237      ENDIF
1238      ELSE
1239      WRITE(LUB,REC=IREC) IDAY,HOUR,(H(J),THETA(J),SUBQ(J),
1240      !      SUBSNK(J),J=1,NPT),SUBINF,SUBRAN,SUBE,SUBTRA,SUBRUN,
1241      !      SPREV,TWOIST,SUBSTP,PESUB,PTSUB,SUBTIM,SUBAST,SUBUBC,RHMEAN,
1242      !      TMEAN,HDRY,SUBSDH
1243      ENDIF
1244      IF (IDAY.EQ.DAYEND.AND.N.EQ.NSTOP) THEN
1245      FINISH = .TRUE.
1246      GO TO 32673
1247      ENDIF
1248      C
1249      C      Estimate new DELT to start the next DELSUB period
1250      C
1251      DELT = MIN(1.D0*DELMAX,(2.D0*DELSUB)/SUBSTP)
1252      32672 CONTINUE
1253      C-----
1254      C      End of the NTOTAL Loop for this day
1255      C
1256      C      Add daily total to simulation total
1257      C-----
1258      32673 TAST = TAST+DAYAST
1259      TSTP = TSTP+DAYSTP
1260      TTIM = TTIM+DAYTIM
1261      TPE = TPE+DAYPE
1262      TE = TE+DAYE
1263      IF (NGROW.GT.0.AND.NGROW.LE.NGDAYS) TETRAN = TETRAN+DAYE
1264      TTIRRI = TTIRRI+DAYIRR
1265      TINF = TINF+DAYINF
1266      TRUNOF = TRUNOF+DAYRUN
1267      TTRA = TTRA+DAYTRA
1268      TPT = TPT+DAYPT
1269      TRAIN = TRAIN+DAYRAN
1270      TPET = TPET+PE+PT
1271      TSDH = TSDH+DAYSDH
1272      TUBC = TUBC+DAYUBC
1273      DO 860 I=1,NPT
1274      TQ(I) = TQ(I)+DAYQ(I)
1275      860 CONTINUE
1276      IF (IHEAT.EQ.1) THEN
1277      THBE = THBE+DAYHBE
1278      TLE = TLE+DAYLE
1279      TRN = TRN+DAYRN
1280      TSHF = TSHF+DAYSHF
1281      TSEN = TSEN+DAYSEN
1282      DO 861 I=1,NPT
1283      TQH(I) = TQH(I)+DAYQH(I)
1284      861 CONTINUE
1285      ENDIF
1286      C
1287      C      Write daily summary to binary output file
1288      C
1289      IREC = IREC+1
1290      IF (IPLANT.EQ.0) THEN:
1291      IF (IHEAT.EQ.0) THEN
1292      WRITE(LUB,REC=IREC) IDAY,HOUR,(H(J),THETA(J),DAYQ(J),

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1293      ! J=1,NPT), DAYINF, DAYRAN, DAYE, DAYTRA, DAYRUN,
1294      ! TPREV, TWOIST, DAYSTP, PE, PT, DAYTIM, DAYAST, DAYUBC, RHMEAN,
1295      ! TMEAN, HDRY, DAYRN, DAYSHF, DAYSEN, DAYHBE,
1296      ! TA, TMAX, TWIN, VD_A, WIND, CLOUD, SR_MEAS, DAYLE, DAYSDH
1297      ELSE
1298      WRITE(LUB,REC=IREC) IDAY, HOUR, (H(J), THETA(J), DAYQ(J), T(J),
1299      ! DAYQH(J), J=1, NPT), DAYINF, DAYRAN, DAYE, DAYTRA, DAYRUN,
1300      ! TPREV, TWOIST, DAYSTP, PE, PT, DAYTIM, DAYAST, DAYUBC, RHMEAN,
1301      ! TMEAN, HDRY, DAYRN, DAYSHF, DAYSEN, DAYHBE,
1302      ! TA, TMAX, TWIN, VD_A, WIND, CLOUD, SR_MEAS, DAYLE, DAYSDH
1303      ENDIF
1304      ELSE
1305      WRITE(LUB,REC=IREC) IDAY, HOUR, (H(J), THETA(J), DAYQ(J),
1306      ! DAYSNK(J), J=1, NPT), DAYINF, DAYRAN, DAYE, DAYTRA, DAYRUN,
1307      ! TPREV, TWOIST, DAYSTP, PE, PT, DAYTIM, DAYAST, DAYUBC, RHMEAN,
1308      ! TMEAN, HDRY, DAYSDH
1309      ENDIF
1310      IF (FINISH) GO TO 32708
1311      IF (ET_OPT .EQ. 0) THEN
1312      IF (NWATER .GT. WINDEX .AND. IDAY .EQ. IRDAY) THEN
1313      READ(LUI) IRDAY, IRTYPE, EFICEN, NP, (RTIME(J),
1314      ! AMOUNT(J), J=1, NP)
1315      WINDEX = WINDEX+1
1316      ENDIF
1317      ELSE
1318      IF (IDAY .EQ. DAYEND) GO TO 32708
1319      TMAXLAST = TMAX
1320      READ(LUI) METDAY, TMAX, TWIN, TDEW, SR_MEAS, WIND, CLOUD, IRTYPE,
1321      ! EFICEN, NP, (RTIME(J), AMOUNT(J), J=1, NP)
1322      IF (METDAY .LT. DAYEND) THEN
1323      READ(LUI) II, RR, TWINNEXT
1324      BACKSPACE 1
1325      ELSE
1326      TWINNEXT = TWIN
1327      ENDIF
1328      TMEAN = (TMAX+TWIN)*.5
1329      VD_A = FUNVD(TDEW)
1330      RHMEAN = VD_A/FUNVD(TMEAN)
1331      IF (NP .GT. 0) IRDAY = METDAY
1332      IF (SH_OPT .EQ. 1) CALL HDRYCALC
1333      ENDIF
1334      32708 CONTINUE
1335      C-----
1336      C      End of the Day Loop for this simulation
1337      C
1338      C      Write final simulation summary to binary output file
1339      C-----
1340      TERR = STORE+TINF-TE-TTRA-TQ(NPT)-TWOIST
1341      IREC = IREC+1
1342      TTIM = TTIM/24.D0
1343      WRITE(LUB,REC=IREC) IDAY, G, IPLANT, TPET, TPT, TTRA, TPE, TE, TETRAN,
1344      ! TRUNOF, TINF, TTIM, TRAIN, APLIED, TTIRRI, TWOIST, TERR, TSTP,
1345      ! (TQ(I), TQH(I), I=1, NPT), TAST, TUBC, TRN, TSHF, TSEN, TLE, THBE, TSDH
1346      32709 CONTINUE
1347      CLOSE(UNIT=LUB)
1348      999 STOP
1349      END

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0001      SUBROUTINE B_L_R(RH)
0002      C-----
0003      C      Version 2.0
0004      C
0005      C      Called by HEATFLOW and UNSATH
0006      C
0007      C      Calculates boundary layer resistance (RH [s/m]) to heat and vapor
0008      C      as a function of wind speed and measurement height, air
0009      C      temperature and measurement height, zero plane displacement,
0010      C      roughness lengths for heat and momentum, and surface temperature.
0011      C-----
0012      INCLUDE 'BVAR.INC/NOLIST'
0013      INCLUDE 'BARRAY.INC/NOLIST'
0014      INCLUDE 'BMET.INC/NOLIST'
0015      INCLUDE 'BTIME.INC/NOLIST'
0016      PSIM = 0.
0017      PSIH = 0.
0018      DO 10 I=1,3
0019          RRR = RH
0020          USTAR = VK*WIND/(LOG((ZU-D+ZM)/ZM)+PSIM)
0021          RH = (LOG((ZT-D+ZH)/ZH)+PSIH)/(VK*USTAR)
0022          IF (I .EQ. 3) GO TO 10
0023          ZETA = -(VK*ZT+GRAV/(CHA*TA+USTAR+USTAR+USTAR))*
0024                (CHA*(TSMEAN-TA)/RH)
0025          IF (TSMEAN .LT. TA) THEN
0026              PSIH = 4.7D0*ZETA
0027              PSIM = PSIH
0028          ELSE
0029              PSIH = -LOG((1.D0+SQRT(1.D0-16.D0*ZETA)))/2.D0
0030              PSIM = 0.6D0*PSIH
0031          ENDIF
0032      10 CONTINUE
0033      IF (ABS((RH-RRR)/RRR) .GE. 0.1)
0034          ! WRITE(LUS,6000) RH,RRR,HOUR+TSUB-DELSAV,IDAY
0035      RETURN
0036      6000 FORMAT(/' B_L_R: RH change ('1PE9.3' and 'E9.3') was not <10%/',
0037          ! ' of the second value at '1PE11.4' hr on day 'I3)
0038      END

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0001      SUBROUTINE DELCHK
0002 C-----
0003 C      Version 2.0:
0004 C
0005 C      Called by UNSAT-H
0006 C
0007 C      Adjusts the time step according to the mass balance error.
0008 C      Specifically, it will increase or decrease the time step
0009 C      according to the ratio DMAXBA/DIFMAX |
0010 C-----
0011      INCLUDE 'BVAR.INC/NOLIST'
0012      INCLUDE 'BTIME.INC/NOLIST'
0013      R = 20.00
0014      IF (DIFMAX .GT. 1.E-7) R = DMAXBA/DIFMAX
0015      IF (R .LE. 1.00) THEN
0016 C-----
0017 C      Decrease the time step
0018 C-----
0019      RPRIM = R*R
0020      IF (RPRIM .LT. 0.500) RPRIM = 0.500
0021      TSUB = TSUB - DELT
0022      DELT = DELT * RPRIM
0023      IF (DELT .LT. DELMIN) THEN
0024      IF (IDAY .NE. IDAYLS) THEN
0025      IDAYLS=IDAY
0026      WRITE(LUS,6000) IDAY,HOUR+TSUB,DELT,ISWDIF,DIFMAX,R
0027      ENDIF
0028      DELT = DELMIN
0029      ENDIF
0030      IG0150 = 1
0031      TSUB = TSUB+DELT
0032      GO TO 1000
0033      ELSE
0034 C-----
0035 C      Increase the time step
0036 C-----
0037      RPRIM = 0.500*(1+R)
0038      IF (RPRIM .GT. RFACT) RPRIM = RFACT
0039      DELT = DELT*RPRIM
0040      IF (DELT .GT. DELMAX) DELT = DELMAX
0041      TLEFT = DELSUB-TSUB
0042      IF (TLEFT .EQ. 0. .OR. TLEFT .GT. 2.00*DELT) GO TO 900
0043      IF (TLEFT .LE. DELT) THEN
0044      DELT = MAX(DELMIN,TLEFT)
0045      ELSE
0046      DELT = TLEFT/2.000
0047      ENDIF
0048      ENDIF
0049      900 RSAVE = R
0050      1000 RETURN
0051 C-----
0052 C      Format statements
0053 C-----
0054      6000 FORMAT(' IDAY = ',I3,T18'TDONE = 'G12.5,T42'DELT = 'G12.5/,
0055      #          ' ISWDIF = ',I3,T18'DIFMAX = 'G12.5,T42'R = 'G12.5/,
0056      #          ' Simulation continued with DELMIN')
0057      END

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0001      SUBROUTINE HEATFLOW(RH)
0002      C-----
0003      C   Version 2.0:
0004      C
0005      C   Called by UNSATH
0006      C   Calls B_L_R, NETRAD, THERMK, and TRIDAG
0007      C
0008      C   Solves heat balance equations
0009      C-----
0010      INCLUDE 'BVAR.INC/NOLIST'
0011      INCLUDE 'BARRAY.INC/NOLIST'
0012      INCLUDE 'BTIME.INC/NOLIST'
0013      INCLUDE 'BSOIL.INC/NOLIST'
0014      REAL KH1,KH2,KHMID(M1)
0015      DIMENSION A1(M1),A2(M1),A3(M1),ZY(M1),QQHL(M1),QQHV(M1)
0016      INCLUDE 'BMET.INC/NOLIST'
0017      FUMVD(TD) = EXP(46.440973D0-(6790.4985D0/TD)-8.02808D0*LOG(TD))
0018      IF (TSUB.EQ. DELSAV) THEN
0019          SUBRN = 0.
0020          SUBSHF = 0.
0021          SUBSEN = 0.
0022      ENDIF
0023      NPPT = NPT-1
0024      CALL THERMK
0025      C
0026      C   Calculate the heat flux attributable to vapor flow
0027      C
0028      IF (IVAPOR.EQ. 1) THEN
0029          QQHV0 = 0.
0030          IF (SSFLUX.LT. 0) QQHV0 = CHW*(TS-T0)*SSFLUX/DELSAV
0031          DO 564 I=1,NPPT
0032              QQHV(I) = (LHV0+CHV*(0.5*(TT(I+1)+TT(I))-T0))*QV(I)/DELSAV
0033          564 CONTINUE
0034      ENDIF
0035      C
0036      C   Calculate the heat flux attributable to liquid flow
0037      C
0038      IF (ICONVH.EQ. 1) THEN
0039          QQHL0 = 0.
0040          IF (SSFLUX.GT. 0) QQHL0 = CHW*(TA-T0)*SSFLUX/DELSAV
0041          DO 566 I=1,NPPT
0042              QQHL(I) = CHW*(0.5*(TT(I+1)+TT(I))-T0)*QL(I)/DELSAV
0043          566 CONTINUE
0044          QQHL(NPT) = 0.
0045          IF (LOWERH.NE. 2) QQHL(NPT) = CHW*((TT(NPT)+0.5*TGRAD
0046              *ZZ(NPPT))-T0)*QL(NPT)/DELSAV
0047      ENDIF
0048      C
0049      C   Calculate internodal conductivities [J/cm/hr/K] and QQHL
0050      C
0051      DO 568 I=1,NPPT
0052          KHMID(I) = (KH(I)+KH(I+1))*0.5
0053      568 CONTINUE
0054      C-----
0055      C   Predictor-Corrector Loop (while "IN" < INHMAX )
0056      C
0057      C   This implicit scheme solves the partial differential equation
0058      C   for the change in temperature
0059      C-----
0060      INH = 0
0061      32626 IF (INH.GE. INHMAX) GO TO 32625
0062      INH = INH+1
0063      DEL = 1./DELSAV
0064      C
0065      C   Calculate coefficients for simulation of change in temperature
0066      C

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0171      DO 670 II=2,NPPT
0172      I      = II-1
0173      III     = II+1
0174      Z31    = Z(III)-Z(I)
0175      KH1     = -KHMID(I)/(Z31+ZZ(I))
0176      KH2     = -KHMID(II)/(Z31+ZZ(II))
0177      AVCH    = 0.5*(CCH(II)+CH(II))
0178      A2(II)  = AVCH*DEL-KH1-KH2
0179      A1(II)  = KH1
0180      A3(II)  = KH2
0181      TG1     = (TT(II)-TT(I))/ZZ(I)
0182      TG2     = (TT(III)-TT(II))/ZZ(II)
0183      ZY(II)  = AVCH*TT(II)*DEL
0184      !      -((-KKHMID(II)*TG2+KKHMID(I)*TG1)/Z31
0185      DELZ31 = DELSAV*Z31*2
0186      C
0187      C      Add in the heat flux attributable to latent heat transfer
0188      C
0189      IF (IVAPOR .EQ. 1) THEN
0190      DELTHV = THETA(II)-TTHETA(II)
0191      A1(II) = A1(II)-CHV*QV(I)/DELZ31
0192      A2(II) = A2(II)+CHV*DEL*0.5*DELTHV+CHV*(QV(II)-QV(I))/DELZ31
0193      A3(II) = A3(II)+CHV*QV(II)/DELZ31
0194      ZY(II) = ZY(II)+DEL*(LHV0-CHV*(0.5*TT(II)-T0))*DELTHV
0195      !      -((LHV0-CHV*T0)*(QV(II)-QV(I))/DELSAV)+QQHV(II)-QQHV(I))/Z31
0196      !
0197      ENDOF
0198      C
0199      C      Add in the heat flux attributable to water flow
0200      C
0201      IF (ICONVH .EQ. 1) THEN
0202      DELTHE = THETA(II)-TTHETA(II)
0203      A1(II) = A1(II)-CHW*QL(I)/DELZ31
0204      A2(II) = A2(II)+CHW*DEL*0.5*DELTHE
0205      !      +CHW*(QL(II)-QL(I))/DELZ31
0206      A3(II) = A3(II)+CHW*QL(II)/DELZ31
0207      ZY(II) = ZY(II)-CHW*DEL*0.5*(-T0*(TT(II)-T0))*DELTHE
0208      !      -((QQL(II)-QQL(I)-CHW*T0*(QL(II)-QL(I))/DELSAV)/Z31
0209      !
0210      ENDOF
0210      670 CONTINUE
0211      IF (UPPERH .EQ. 0 .OR. UPPERH .EQ. 3) THEN
0212      C
0213      C      Surface node equation for heat flux b.c.
0214      C
0215      IF (UPPERH .EQ. 0) THEN
0216      TSMEAN = .5*(TT(1)+TS)
0217      CALL NETRAD(INH)
0218      SENFLX = CHA*(TSMEAN-TA)/RH
0219      LE      = 0.0
0220      C
0221      C      When evaporation occurs, SSFLUX (cm) is converted into LE (W/m2)
0222      C
0223      IF (SSFLUX .LT. 0) THEN
0224      LHV = LHV0-(CHW-CHV)*(TSMEAN-T0)
0225      LE = -(LHV/0.36)*(SSFLUX/DELSAV)
0226      SHFLUX = RN-SENFLX-LE
0227      ELSE
0228      SHFLUX = RN-SENFLX
0229      ENDOF
0230      ELSE
0231      SHFLUX = QHTOP
0232      ENDOF
0233      Z1      = ZZ(1)
0234      KH2     = -KHMID(1)/(Z1+Z1)
0235      AVCH    = 0.5*(CH(1)+CCH(1))
0236      A1(1)   = 0.0

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0237      A2(1) = AVCH*DEL-KH2
0238      A3(1) = KH2
0239      TG2 = (TT(2)-TT(1))/Z1
0240      ZY(1) = AVCH*TT(1)*DEL
0241      !      -(-KKHMID(1)*TG2-2.*SHFLUX*.38)/Z1
0242      C
0243      C      Add in the heat flux attributable to vapor flow
0244      C
0245      IF (IVAPOR .EQ. 1) THEN
0246          DELTHV = THETA(1)-TTHETA(1)
0247          A2(1) = A2(1)+CHV*DEL*.5*DELTHV*CHV*QV(1)/(DELSAV*Z1*2)
0248          A3(1) = A3(1)+CHV*QV(1)/(DELSAV*Z1*2)
0249          ZY(1) = ZY(1)+DEL*(LHV0+CHV*(0.5*TT(1)-T0))*DELTHV
0250      !      -(((LHV0-CHV*T0)+QV(1)/DELSAV)*QQHV(1))/Z1
0251      IF (SSFLUX .LT. 0) THEN
0252          A2(1) = A2(1)-CHW*SSFLUX/(DELSAV*Z1)
0253          ZY(1) = ZY(1)-((CHW*T0+SSFLUX/DELSAV)-QQHV0)/Z1
0254      ENDIF
0255      ENDIF
0256      C
0257      C      Add in the heat flux attributable to water flow
0258      C
0259      IF (ICONVH .EQ. 1) THEN
0260          DELTHE = THETA(1)-TTHETA(1)
0261          A2(1) = A2(1)+CHW*DEL*.5*DELTHE*CHW*QL(1)/(DELSAV*Z1*2)
0262          A3(1) = A3(1)+CHW*QL(1)/(DELSAV*Z1*2)
0263          ZY(1) = ZY(1)-CHW*DEL*.5*(-T0*(TT(1)-T0))*DELTHE
0264      !      -(QQHL(1)-CHW*T0*QL(1)/DELSAV)/Z1
0265      IF (SSFLUX .GT. 0) THEN
0266          ZY(1) = ZY(1)+(QQHL0+CHW*(TA-T0)*SSFLUX/DELSAV)/Z1
0267      ENDIF
0268      ENDIF
0269      ISTART = 1
0270      ELSE
0271      C
0272      C      Surface node equation for constant or specified temperature b.c.
0273      C
0274      IF (UPPERH .EQ. 2) TS = TSMEAN+TSAMP*SIN(PI*(HOUR-TSUB-8.)/12.)
0275      ISTART = 2
0276      ZY(2) = ZY(2)-A1(2)*TS
0277      A1(2) = 0.
0278      ENDIF
0279      C
0280      C      LOWERH: 1) specified temperature gradient, 2) constant temp, and
0281      C      3) specified flux
0282      C
0283      IF (LOWERH .NE. 2) THEN
0284          ZN = ZZ(NPPT)
0285          KH1 = -KH MID(NPPT)/(ZN*ZN)
0286          A3(NPT) = 0.0
0287          IF (LOWERH .EQ. 1) THEN
0288              QHLAST = -0.5*(KH(NPT)+KKHNPT)*TGRAD
0289          ELSE
0290              QHLAST = QHLEAK
0291          ENDIF
0292          AVCH = 0.5*(CH(NPT)+CCH(NPT))
0293          A1(NPT) = KH1
0294          A2(NPT) = AVCH*DEL-KH1
0295          TQ1 = (TT(NPT)-TT(NPPT))/ZN
0296          ZY(NPT) = AVCH*TT(NPT)*DEL
0297      !      -(2*QHLAST+KKHMID(NPPT)*TQ1)/ZN
0298      C
0299      C      Add in the heat flux attributable to vapor flow
0300      C
0301      IF (IVAPOR .EQ. 1) THEN
0302          DELTHV = THETA(NPT)-THETA(NPT)

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0303      A1(NPT) = A1(NPT)+CHV*DEL*0.5*DELTHV-CHV*QV(NPPT)
0304      ! / (DELSAV*ZN+2)
0305      A2(NPT) = A2(NPT)-CHV*QV(NPPT) / (DELSAV*ZN+2)
0306      ZY(NPT) = ZY(NPT)+DEL*(LHV0-CHV*(0.5*TT(NPT)-T0))*DELTHV
0307      ! -((LHV0-CHV*T0)*QV(NPPT)/DELSAV-QQHV(NPPT))/ZN
0308      ENDIF
0309      C
0310      C Add in the heat flux attributable to water flow
0311      C
0312      IF (ICONVH .EQ. 1) THEN
0313          DELTHE = THETA(NPT)-TTHETA(NPT)
0314          A1(NPT) = A1(NPT)-CHW*QL(NPPT) / (DELSAV*ZN+2)
0315          A2(NPT) = A2(NPT)+CHW*DEL*0.5*DELTHE-CHW*(2*QL(NPT)
0316      ! -QL(NPPT)) / (DELSAV*ZN+2)
0317          ZY(NPT) = ZY(NPT)-CHW*DEL*0.5*(-T0+(TT(NPT)-T0))*DELTHE
0318      ! -((CHW*(0.5*(0.5*TRAD+ZZ(NPPT))-T0)
0319      ! *QL(NPT)+T0*QL(NPPT))/DELSAV+QQHL(NPT)-QQHL(NPPT))/ZN
0320      ENDIF
0321      NPPT = NPT
0322      ELSE
0323          ZY(NPPT) = ZY(NPPT)-A3(NPPT)*T(NPT)
0324          A3(NPPT) = 0.0
0325      ENDIF
0326      C
0327      C Solution of tridiagonal matrix
0328      C
0329      CALL TRIDAG(ISTART,NPPT,A1,A2,A3,ZY,T)
0330      C-----
0331      C Solution estimate complete for this iteration
0332      C-----
0333      IF (INH .LT. INHMAX .AND. IVAPOR .EQ. 1) CALL THERMK
0334      NPPT = NPT-1
0335      GO TO 32626
0336      C-----
0337      C End of the Predictor-Corrector Loop
0338      C-----
0339      32625 CONTINUE
0340      C
0341      C Heat flux across the surface (SHFLUX [W/m2]) and heat flow within
0342      C the soil (QH [J/cm2]) are calculated.
0343      C
0344      DO 800 II=2,NPT
0345          I = II-1
0346          ZI = ZZ(I)
0347          TG = (T(II)-T(I))/ZI
0348          TTG = (TT(II)-TT(I))/ZI
0349          QH(I) = -0.5*DELSAV*(KHMID(I)*TG+KXHMID(I)*TTG)
0350      800 CONTINUE
0351      C
0352      C Calculate the heat flux attributable to vapor flow
0353      C
0354      IF (IVAPOR .EQ. 1) THEN
0355          DO 805 I=1,NPT
0356              SVD = FUNVD(T(I))
0357              RH0V = SVD*EXP(-H(I)*MGR/T(I))
0358              THETAV(I) = RH0V*(THET(MAT(I))-THETA(I))/WATDEN
0359      805 CONTINUE
0360          QHV0 = 0
0361          IF (SSFLUX .LT. 0) QHV0 = 0.5*(QQHV0*DELSAV+CHW*(TS-T0)*SSFLUX)
0362          QHV1 = 0.5*((LHV0-CHV*(0.5*(TS-T(2))-T0))*QV(1)+QQHV(1)*DELSAV)
0363          QHVNPT = 0.5*((LHV0-CHV*(0.5*(T(NPPT)-T(NPT))-T0))*QV(NPPT)
0364      ! +QQHV(NPPT)*DELSAV)
0365          ENDIF
0366      C
0367      C Calculate the heat flux attributable to water flow
0368      C

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0369      IF (ICONVH .EQ. 1) THEN
0370          QHL0 = 0
0371          IF (SSFLUX .GT. 0) QHL0 = CHW*(TA-T0)*SSFLUX
0372          QHL1 = 0.5*(QQHL(1)*DELSAV+CHW*(0.5*(T(2)+T(1))-T0)*QL(1))
0373          QHLNPPT = 0.5*(QQHL(NPPT)*DELSAV+CHW*QL(NPPT)*(0.5
0374      |      *(T(NPT)+T(NPPT))-T0))
0375          QHLNPT = 0.5*(QQHL(NPT)*DELSAV+CHW*
0376      |      (T(NPT)+0.5*TGRAD*ZZ(NPPT)-T0)*QL(NPT))
0377      ENDIF
0378      IF (UPPERH .EQ. 1 .OR. UPPERH .EQ. 2) THEN
0379          SHFLUX = (0.5*(CH(1)+CCH(1))*(T(1)-TT(1))+THICK(1)*QH(1)+QHV1
0380      |      +QHL1-QHV0-QHL0)/(DELSAV*.38)
0381      ENDIF
0382      IF (LOWERH .EQ. 2) THEN
0383          QH(NPT) = QH(NPPT)+QHVNPPT-QHLNPPT-0.5*(CH(NPT)+CCH(NPT))
0384      |      *(T(NPT)-TT(NPT))*THICK(NPT)-QHLNPT
0385      ELSE
0386          QH(NPT) = QHLAST*DELSAV
0387      ENDIF
0388      C
0389      C      Estimate change in heat storage in the profile (DHSTORE [J/cm2])
0390      C      and the heat balance error (HEATBAL [J/cm2])
0391      C
0392          DHSTORE = 0.0
0393          DO 794 I=1,NPT
0394              DHSTORE = DHSTORE+0.5*(CH(I)+CCH(I))*(T(I)-TT(I))*THICK(I)
0395              IF (IVAPOR .EQ. 1)
0396      |      DHSTORE = DHSTORE+(LHV0+0.5*CHV*(T(I)+TT(I)-2*T0))
0397      |      *(THETAV(I)-TTHETAV(I))*THICK(I)
0398              IF (ICONVH .EQ. 1) DHSTORE = DHSTORE+CHW*0.5*(T(I)+TT(I)-2*T0)
0399      |      *(THETA(I)-TTHETA(I))*THICK(I)
0400      794      CONTINUE
0401          HEATBAL = SHFLUX*0.38*DELSAV+QHL0+QHV0-QHLNPT-QH(NPT)-DHSTORE
0402      C-----
0403      C      End of convergence loop for HEATFLOW.
0404      C      DELSUB totals are updated: The surface heat fluxes are converted
0405      C      from [W/m2] to [J/m2].
0406      C      Old heat flow parameters are reset to new values.
0407      C-----
0408          SUBHBE = SUBHBE+HEATBAL
0409          SUBLE = SUBLE+LE*3800*DELSAV
0410          SUBRN = SUBRN+RN*3800*DELSAV
0411          SUBSHF = SUBSHF+SHFLUX*3800*DELSAV
0412          SUBSEN = SUBSEN+SENFLX*3800*DELSAV
0413          IF (UPPERH .EQ. 0) THEN
0414              TSMEAN = .5*(TT(1)+TS)
0415              CALL B_L_R(RH)
0416          ENDIF
0417          IF (TVAPOR .EQ. 1) CALL THERMK
0418          DO 810 I=1,NPT
0419              SUBQH(I) = SUBQH(I)+QH(I)
0420              CCH(I) = CH(I)
0421              KKHWD(I) = KHWID(I)
0422              TT(I) = T(I)
0423              IF (IVAPOR .EQ. 1) TTHETAV(I) = THETAV(I)
0424      810      CONTINUE
0425          KKHNPPT = KH(NPT)
0426          RETURN
0427      END

```

```

0001      SUBROUTINE HDRYCALC(SVD_S)
0002      C-----
0003      C   Version 2.0:
0004      C
0005      C   Called by UNSATH
0006      C
0007      C   Calculates a value for HDRY based on the temperature of the soil
0008      C   surface and the vapor density of the atmosphere
0009      C-----
0010      INCLUDE 'BVAR.INC/NOLIST'
0011      INCLUDE 'BARRAY.INC/NOLIST'
0012      INCLUDE 'BSOIL.INC/NOLIST'
0013      INCLUDE 'BMET.INC/NOLIST'
0014      IF (IHEAT.EQ. 0) THEN
0015         HDRY = -TS*LOG(RHMEAN)/WGR
0016      ELSE
0017         HDRY = -TS*LOG(VD_A/SVD_S)/WGR
0018      ENDIF
0019      H1 = H(1)
0020      H(1) = HDRY
0021      C1 = C(1)
0022      KL1 = KL(1)
0023      THETA1 = THETA(1)
0024      CALL POLYCH(1,C,H)
0025      CALL POLYKH(1,KL,H)
0026      CALL POLYTH(1,THETA,H)
0027      DRYC = C(1)
0028      DRYK = KL(1)
0029      DRYTH = THETA(1)
0030      H(1) = H1
0031      C(1) = C1
0032      KL(1) = KL1
0033      THETA(1) = THETA1
0034      RETURN
0035      END

```

```

0001      SUBROUTINE METRAD(INH)
0002      C-----
0003      C   Version 2.0
0004      C
0005      C   Called by HEATFLOW
0006      C
0007      C   Calculates net radiation (RN [W/m2])
0008      C   as a function of latitude, time of year, time of day,
0009      C   air and surface temperature, atmospheric vapor density, albedo,
0010      C   cloud cover, surface and air emissivities, and extraterrestrial
0011      C   solar flux) in W/m2.
0012      C-----
0013      INCLUDE 'BVAR.INC/NOLIST'
0061      INCLUDE 'BARRAY.INC/NOLIST'
0072      INCLUDE 'BTIME.INC/NOLIST'
0079      INCLUDE 'BMET.INC/NOLIST'
0094      IF ((HTIME-0.5*DELSAV) .EQ. 0 .AND. INH .EQ. 1) THEN
0095          SINDEC = .3985D0*SIN(4.869D0*TPIY*METDAY+0.83345D0
0096      !          *SIN(6.224D0*TPIY*METDAY))
0097          DEC = ASIN(SINDEC)
0098          COSDEC = COS(DEC)
0099          TANDEC = TAN(DEC)
0100          HS = ACOS(-TANLAT*TANDEC)
0101          SR_POT = DAYSEXT*(HS*SINLAT*SINDEC+COSLAT*COSDEC+SIN(HS))/PI
0102          SR_FRAC = SR_MEAS/SR_POT
0103      C
0104      C   Atmospheric emissivity calculated using equation from Campbell
0105      C   (1985) modified to accept vapor density units of g/cm3
0106      C
0107          EMISS_A = 4.174D0*VD_A**(.1D0/7.D0)
0108          IF (ICLOUD .EQ. 0) THEN
0109              CLOUD = 2.33D0-0.93D0*SR_FRAC
0110              IF (CLOUD .GT. 1.0) CLOUD = 1.0D0
0111              IF (CLOUD .LT. 0.0) CLOUD = 0.0D0
0112          ENDIF
0113          IF (CLOUD .GT. 0) EMISS_A = (1.D0-0.84D0*CLOUD)*EMISS_A+0.84D0*
0114      !      CLOUD
0115          ENDIF
0116          SR = SEXT*SR_FRAC*(SINLAT*SINDEC+COSLAT*COSDEC+
0117      !      COS(PI*(HTIME-12.D0)/12.D0))
0118          IF (SR .LT. 0) SR = 0.D0
0119      C
0120      C   ALBEDO and EMISS S calculations are taken from van Bavel
0121      C   and Hillel (1978)
0122      C
0123          AVETHE = (THETA(1)+TTHETA(1))/2.D0
0124          IF (AVETHE .LT. 0.10D0) THEN
0125              ALBEDO = 0.25D0
0126          ELSE IF (AVETHE .GT. 0.25D0) THEN
0127              ALBEDO = 0.10D0
0128          ELSE
0129              ALBEDO = 0.10D0+0.25D0-AVETHE
0130          ENDIF
0131          EMISS_S = MIN(0.9D0+0.18D0*AVETHE,1.D0)
0132          IF (INH .EQ. 1) TAQ = TA*TA*TA*TA
0133          TSQ = TSMEAN*TSMEAN*TSMEAN*TSMEAN
0134          RN = (1.D0-ALBEDO)*SR+SB*(EMISS_A*TAQ-EMISS_S*TSQ)
0135          RETURN
0136      END

```

```

0001      SUBROUTINE THERME
0002      C-----
0003      C      Version 2.0
0004      C
0005      C      Called by UNSATH
0006      C
0007      C      Calculates enhancement factor for soil vapor flow caused by
0008      C      thermal gradients
0009      C-----
0010      INCLUDE 'BYAR.INC/NOLIST'
0058      INCLUDE 'BARRAY.INC/NOLIST'
0069      INCLUDE 'BSOIL.INC/NOLIST'
0096      DO 100 I=1,NPT
0097          MATI = MAT(I)
0098          THETAI = THETA(I)
0099          EFA = EF(1,MATI)
0100          EFB = EF(2,MATI)
0101          EFC = EF(3,MATI)
0102          EFD = EF(4,MATI)
0103          EFE = EF(5,MATI)
0104          ENFACT(I) = EFA+EFB*THETAI-EFD*EXP(-1.00*
0105      !              (EFC*THETAI)**EFE)
0106      100 CONTINUE
0107      RETURN
0108      END

```



```

0001      SUBROUTINE TRIDAG(IF,L,A,B,C,D,V)
0002      C-----
0003      C   Version 2.0:
0004      C
0005      C   Called by UNSAT-H
0006      C
0007      C   Solves the tridiagonal solution matrix
0008      C-----
0009      INCLUDE 'BVAR.INC/NOLIST'
0057      DIMENSION A(L),B(L),C(L),D(L),V(L),BETA(M1),GAMMA(M1)
0058      BETA(IF) = B(IF)
0059      GAMMA(IF) = D(IF)/BETA(IF)
0060      IFP1 = IF+1
0061      DO 100 I=IFP1,L
0062          II = I - 1
0063          BETA(I) = B(I) - A(I)*C(II)/BETA(II)
0064          GAMMA(I) = (D(I)-A(I)*GAMMA(II))/BETA(I)
0065      100 CONTINUE
0066      V(L) = GAMMA(L)
0067      LAST = L - IF
0068      DO 200 K = 1,LAST
0069          I = L - K
0070          V(I) = GAMMA(I) - C(I)*V(I+1)/BETA(I)
0071      200 CONTINUE
0072      RETURN
0073      END

```

```

0001      PROGRAM DATAOUT
0002      C-----
0003      C   Version 2.0:
0004      C
0005      C   Calls HARDCOPY, LISTDATA, PROFILER, REINIT, and SCAN
0006      C
0007      C   Processes the binary output file (*.RES) generated by UNSAT-H.
0008      C-----
0009      INCLUDE 'BOUT.INC/MOLIST'
0010      DATA DOV/2.0/
0011      WRITE(LUS,0000)
0012      9000 FORMAT(/' Results are based on the use of unverified software.',/,
0013      !      ' No assurance is expressed or implied as to the accuracy,',/,
0014      !      ' completeness or usefulness of this information.'/)
0015      WRITE(LUS,0000) DOV
0016      20  WRITE(LUS,0010)
0017      READ(LUR,5000) TMFILE
0018      OPEN(UNIT=LUI,FILE=TMFILE,STATUS='OLD',FORM='UNFORMATTED',
0019      !      ACCESS='DIRECT',ERR=9000)
0020      INQUIRE(UNIT=LUI,NAME=RFILE)
0021      NCHR = INDEX(RFILE,')')
0022      IF (NCHR .EQ. 0) THEN
0023          RFILE = RFILE
0024      ELSE
0025          RFILE = RFILE(NCHR+1:00)
0026      ENDIF
0027      NCHR = INDEX(RFILE,')')
0028      READ(LUI,REC=1) NPT,IPLANT,(Z(I),I=1,NPT),DAYEND,NPRINT,NSURPE,
0029      !      NTOTAL,IFILE,SDATE,STIME,UV,DAYBEG,STOPHR,TITLE,IHEAT,ICLOUD,
0030      !      ET OPT,SH OPT,UPPER,UPPERH,LOWER,LOWERH
0031      IF (DOV .NE. UV) THEN
0032          WRITE(0,45) DOV,UV
0033          STOP
0034      ENDIF
0035      45  FORMAT(' ERROR: DATAOUT Version No. ',F3.1,' does not match',/,
0036      !      ' UNSAT-H Version No. ',F3.1,'. Program stopped.')
0037      MAXREC = 3*(DAYEND-DAYBEG+1)*(1+NTOTAL*NPRINT)-
0038      !      NPRINT*NTOTAL*(1-STOPHR/24.)
0039      DO 47 I=1,MAXREC+1
0040          READ(LUI,REC=I,ERR=48)
0041      47  CONTINUE
0042      48  IF (I-1 .NE. MAXREC) WRITE(LUS,0111) I-1,MAXREC-I+1
0043      IREC = 2
0044      WRITE(LUS,*)
0045      50  WRITE(LUS,0020)
0046      READ(LUR,*) IOPT
0047      IF (IOPT .LT. 1 .OR. IOPT .GT. 6) IOPT = 0
0048      C
0049      C   Call the chosen option
0050      C
0051      GO TO (999,100,200,300,400,500,600), IOPT+1
0052      100  CALL REINIT
0053      GO TO 50
0054      200  CALL SCAN
0055      GO TO 50
0056      300  CALL HARDCOPY
0057      GO TO 50
0058      400  CALL LISTDATA
0059      GO TO 50
0060      500  CALL PROFILER
0061      GO TO 50
0062      600  CLOSE (LUI)
0063      GO TO 20
0064      900  WRITE(LUS,0040) TMFILE
0065      GO TO 20
0066      999  STOP ' '

```

```

0090 C-----
0091 C   FORMAT Statements
0092 C-----
0093 5000 FORMAT(A00)
0094 6000 FORMAT(10(/),
0095      !      '      Program DATAOUT ',/,
0096      !      '      Version ',F3.1,/,
0097      !      '      Contact: MJ Fayer 378-8326',/,
0098      !      '      Program DATAOUT provides several options for',/,
0099      !      '      processing the UNSAT-H output file (*.RES)')
0100 6010 FORMAT(/' Enter data filename ==> ',S)
0101 6020 FORMAT(' COMMAND LEVEL: The processing options are...',/,
0102      !      '      0) Exit the program',/,
0103      !      '      1) Reinitialize',/,
0104      !      '      2) Scan the data',/,
0105      !      '      3) Create hardcopy output',/,
0106      !      '      4) Create data vs time data files',/,
0107      !      '      5) Create data vs depth data files',/,
0108      !      '      6) Change the current *.RES file',/,
0109      !      '      Enter the number of your choice ==> ',S)
0110 6040 FORMAT(/' No record of file ',A50,/,
0111      !      ' Try again...')
0112 6111 FORMAT(/' CAUTION: Be advised that this results file contains ',
0113      !      ' only',I5,'/T12' records, which is',I5' less than it should ',
0114      !      ' have.'/)
0115      END

```

```

0001      SUBROUTINE DOSUM(JH)
0002      C-----
0003      C   Version 2.0:
0004      C
0005      C   Called by HARDCOPY and SCAN
0006      C
0007      C   Calls READREC
0008      C
0009      C   Reads and outputs end-of-DELSUB and end-of-day
0010      C   summaries for any day of a simulation
0011      C-----
0012      INCLUDE 'BOUT.INC/NOLIST'
0036      CALL READREC
0037      IF (IERROR .EQ. 1) RETURN
0038      C
0039      C   Output DELSUB/daily summaries
0040      C
0041      WRITE(LOUT,6000)
0042      IF (NPRINT .EQ. 0 .OR. JH .EQ. 1+NTOTAL .OR.
0043      !   IREC .EQ. MAXREC-1) THEN
0044      WRITE(LOUT,6090) IDAY, DAYTIM
0045      ELSE
0046      WRITE(LOUT,6100) IDAY, HOUR, DAYTIM
0047      ENDIF
0048      SSFLUX = DAYINF-DAYE
0049      TNEW = TPREV-DAYINF-DAYE-DAYTRA-DAYQ(NPT)
0050      DAYERR = TNEW-TWOIST
0051      WRITE(LOUT,6105) (NODE(I), I=1, NDEPTH)
0052      WRITE(LOUT,6110) (Z(NODE(I)), I=1, NDEPTH)
0053      WRITE(LOUT,6120) (THETA(NODE(I)), I=1, NDEPTH)
0054      WRITE(LOUT,6130) (H(NODE(I)), I=1, NDEPTH)
0055      WRITE(LOUT,6140) (DAYQ(NODE(I)), I=1, NDEPTH)
0056      IF (IHEAT .EQ. 1) THEN
0057      WRITE(LOUT,6142) (T(NODE(I)), I=1, NDEPTH)
0058      WRITE(LOUT,6144) (DAYQH(NODE(I)), I=1, NDEPTH)
0059      ENDIF
0060      IF (IPLANT .GT. 0) WRITE(LOUT,6150) (DAYSX(NODE(I)), I=1, NDEPTH)
0061      WRITE(LOUT,6160)
0062      WRITE(LOUT,6170) TPREV, DAYINF, DAYRUN, DAYE,
0063      !   DAYTRA, DAYQ(NPT), TNEW, TWOIST
0064      WRITE(LOUT,6180) DAYERR, DAYAST, DAYSTP
0065      IF (NSURPE .EQ. 1 .AND. IHEAT .EQ. 0) WRITE(LOUT,6190) PE, DAYE
0066      IF (IPLANT .EQ. 1) WRITE(LOUT,6200) PT, DAYTRA
0067      IF (IHEAT .EQ. 0) THEN
0068      C
0069      C   RHMEAN converted to percent
0070      C
0071      IF (ET OPT .EQ. 1) WRITE(LOUT,6181) 100+RHMEAN, TMEAN, HDRY,
0072      !   DAYUBC
0073      ELSE
0074      IF (UPPERH .EQ. 0) WRITE(LOUT,6230) TMAX, TMIN, VD_A, WIND,
0075      !   CLOUD, SR MEAS
0076      WRITE(LOUT,6235) DAYRN, DAYSHF, DAYSEN, DAY_E, DAYQH(NPT), DAYHBE
0077      ENDIF
0078      RETURN
0079      C-----
0080      C   FORMAT Statements
0081      C-----
0082      6000 FORMAT(/80('-'))
0083      6090 FORMAT(/' DAILY SUMMARY: Day =', I4, ', Simulated Time = ',
0084      !   F7.4, ' hr', /, 1X, 13('-'))
0085      6100 FORMAT(/' DELSUB SUMMARY: Day =', I4, ', Hour = ',
0086      !   F7.4, ', Simulated DELSUB Time = ', F7.4, ' hr', /, 1X, 14('-'))
0087      6105 FORMAT(' Node Number      =', 5(I8,4X))
0088      6110 FORMAT(' Depth (cm)        =', 5F12.5)
0089      6120 FORMAT(' Water (cm3/cm3)    =', 5F12.5)

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0090 0130 FORMAT(' Head (cm)          =',5(1PE12.5))
0091 0140 FORMAT(' Water Flow (cm)     =',5(1PE12.5))
0092 0142 FORMAT(' Temperature (K)     =',5(1PE12.5))
0093 0144 FORMAT(' Heat Flow (J/cm2)    =',5(1PE12.5))
0094 0150 FORMAT(' Plant Sink (cm)      =',5(1PE12.5))
0095 0160 FORMAT(/' PRESTOR',X,' INFIL',X,' RUNOFF ',X,' EVAPO ',
0096 ! X,' TRANS',2X,' DRAIN',X,' NEWSTOR',10X,'STORAGE')
0097 0170 FORMAT(F9.4,'+',F7.4,'+',F7.4,1X,'-',
0098 ! F7.4,'-',F7.4,'-',F8.4,'=',F8.4,' Versus',F9.4/)
0099 0180 FORMAT(' Mass Balance = ',1PE11.4,0P,' cm; Time step attempts',
0100 ! ' = ',I5,' and successes = ',I5)
0101 0181 FORMAT(' RHMEAN = ',F4.1,' %; TMEAN = ',F5.1,' K; HDRY = ',
0102 ! 1PE11.4,' cm',0P,'; DAYUBC = ',I6)
0103 0190 FORMAT(' Evaporation: Potential = ',F7.4,' cm, Actual = ',
0104 ! F7.4,' cm')
0105 0200 FORMAT(' Transpiration: Potential = ',F7.4,' cm, Actual = ',
0106 ! F7.4,' cm')
0107 0230 FORMAT(' Daily meteorological parameters',/
0108 ! T4'TMAX (K)'T12' = '1PE11.4,T31'TMIN (K)'T39' = 'E11.4,
0109 ! T55'VD A (g/cm3)'T87' = 'E11.4/,
0110 ! T2'WIND (m/s)'T12' = 'E11.4,T27'CLOUD (frac)'T39' = 'E11.4,
0111 ! T53'SR MEAS (J/m2)'T87' = 'E11.4)
0112 0235 FORMAT(' Heat flow parameters (units = J/cm2 unless noted)',/
0113 ! T3'RN (J/m2)'T12' = '1PE11.4,T29'SHF (J/m2)'T39' = 'E11.4,
0114 ! T57'SEN (J/m2)'T87' = 'E11.4/,T3'LE (J/m2)',T12' = 'E11.4,
0115 ! T32,'QH(NPT)'T39' = 'E11.4,T64,'HBE'T87' = 'E11.4)
0116
0118 END

```

```

0001      SUBROUTINE HARDCOPY
0002      C-----
0003      C   Version 2.0:
0004      C
0005      C   Called by DATAOUT
0006      C
0007      C   Calls DDSUM, INITSUM, NODEZ, and SUMMARY
0008      C
0009      C   Creates a hard copy of the results of an UNSAT-H simulation,
0010      C   including the initial conditions and the simulation-end summary.
0011      C   The user can choose to have the copy saved as a file on disk or
0012      C   have the copy printed directly without saving it on disk.
0013      C-----
0014      INCLUDE 'BOUT.INC/NOLIST'
0038      JH = NTOTAL+1
0039      LOUT = LUN
0040      WRITE(LUS,6000)
0041      WRITE(LUS,6010)
0042      TMFILE = RFILEN
0043      TMFILE(NCHR:NCHR+8) = '.OUT'
0044      OPEN(UNIT=LOUT,FILE=TMFILE,STATUS='NEW')
0045      INQUIRE(UNIT=LOUT,NAME=OFILE)
0046      WRITE(LUS,6020)
0047      READ(LUR,*) OPTION
0048      CALL NODEZ(5)
0049      WRITE(LUS,*)
0050      IREC = 2
0051      JDAY = DAYBEG-1
0052      100 IF (OPTION .EQ. 1 .AND. IREC .GT. (NPRINT*NTOTAL+3))
0053          # IREC = MAXREC-1
0054          IF (OPTION .EQ. 2 .AND. JDAY .EQ. DAYEND .AND. STOPHR .LT. 24.)
0055              # IREC = MAXREC-1
0056          IF (IREC .EQ. 2) THEN
0057              C
0058              C   Initial Condition summary
0059              C
0060              CALL INITSUM
0061              IF (IERROR .EQ. 1) THEN
0062                  WRITE(LUS,6040)
0063                  GO TO 300
0064              ENDIF
0065          ELSE
0066              C
0067              C   Daily summary
0068              C
0069              CALL DDSUM(JH)
0070              IF (IERROR .EQ. 1) THEN
0071                  WRITE(LUS,6041)
0072                  GO TO 300
0073              ENDIF
0074          ENDIF
0075          IF (IREC .EQ. MAXREC-1) GO TO 200
0076          JDAY = JDAY+1
0077          IF (JDAY .EQ. DAYEND) JH = 1+NTOTAL*STOPHR/24.00
0078          KDAY = JDAY-DAYBEG+1
0079          IREC = 2+KDAY*(JH+(KDAY-1)*NTOTAL-1)*NPRINT
0080          GO TO 100
0081      C
0082      C   Simulation-end Summary
0083      C
0084      200 WRITE(LOUT,6200)
0085          IREC = MAXREC
0086          CALL SUMMARY
0087      300 CLOSE (LOUT,STATUS='KEEP')
0088          WRITE(LUS,6220) OFILE
0089          WRITE(LUS,6000)

```

```

0090      RETURN
0091  C-----
0092  C   FORMAT Statements
0093  C-----
0094  6000 FORMAT(/80('-'))
0095  6010 FORMAT(' HARDCOPY (Option No. 3)')
0096  6020 FORMAT(' This HARDCOPY implementation does not support output',/,
0097      !      ' for time periods less than one day.',/,
0098      !      ' The HARDCOPY options are:',/,
0099      !      '      1) Initial conditions, summaries of ',/,
0100      !      '      the first and last days, and the ',/,
0101      !      '      year-end summary',/,
0102      !      '      2) Same as option (1) but includes a ',/,
0103      !      '      summary of each and every day',/,
0104      !      ' Enter the desired option ==> ',)
0105  6040 FORMAT(/' HARDCOPY stopped: Error reading initial conditions')
0106  6041 FORMAT(/' HARDCOPY stopped: Error reading DELSUB/daily ',
0107      !      ' summaries')
0108  6200 FORMAT(1H1)
0109  6220 FORMAT(/' HARDCOPY output can be found in'/
0110      !      ' file ',A80)
0111      END

```



```

0001      SUBROUTINE INITSUM
0002      C-----
0003      C   Version 2.0:
0004      C
0005      C   Called by HARDCOPY and SCAN
0006      C
0007      C   Calls READREC
0008      C
0009      C   Reads and outputs the the initial conditions of a simulation
0010      C-----
0011      INCLUDE 'BOUT.INC/NOLIST'
0035      C
0036      C   Read and output the initial conditions
0037      C
0038      CALL READREC
0039      IF (IERROR .EQ. 1) RETURN
0040      WRITE(LOUT,6040) DOV,IFILE,RFILE,SDATE,STIME,TITLE
0041      WRITE(LOUT,6060)
0042      WRITE(LOUT,6070) (I,Z(I),H(I),THETA(I),T(I),I=1,NPT)
0043      WRITE(LOUT,6080) TWOIST
0044      IF (IPLANT .EQ. 1) WRITE(LOUT,6090)
0045      RETURN
0046      C-----
0047      C   FORMAT Statements
0048      C-----
0049      6040  FORMAT(80(' ')/T20' UNSAT-H Version 'F3.1/,
0050      !      T27'INITIAL CONDITIONS'//,
0051      !      ' Input Filename: ',A81/,
0052      !      ' Results Filename: ',A81/,
0053      !      ' Date of Run: ',A9/,
0054      !      ' Time of Run: ',A8/,
0055      !      ' Title: '/1X,A79/80(' '))
0056      6060  FORMAT(2('          Initial Conditions  ')/,
0057      !      2('          -----'//,
0058      !      2('  NODE   DEPTH   HEAD   THETA  TEMP ')/,
0059      !      2('          (cm)   (cm)  (vol.)  (K) ')/,
0060      !      2('          -----'//))
0061      6070  FORMAT(2(I8,1P,2E10.3,0PF7.4,F7.2))
0062      6080  FORMAT(/' Initial Water Storage = ',F8.4,' cm')
0063      6090  FORMAT(/' NOTE: There are no temperature data when plants are ',
0064      !      'modelled.'/)
0065      END

```

```

0001      SUBROUTINE LISTDATA
0002  C-----
0003  C      Version 2.0:
0004  C
0005  C      Called by DATAOUT
0006  C
0007  C      Calls NODEZ and READREC
0008  C
0009  C      Creates data lists, such as head values at the end of each day,
0010  C      for review on the screen or for output to a separate file to be
0011  C      used for plotting purposes.
0012  C-----
0013      INCLUDE 'BOUT.INC/NOLIST'
0037      DIMENSION FZ(M1)
0038      DO 50 I=1,NPT-1
0039          FZ(I) = (Z(I+1)+Z(I))/2
0040 50    CONTINUE
0041      FZ(NPT) = Z(NPT)
0042      WRITE(LUS,6000)
0043      WRITE(LUS,6010)
0044  C
0045  C      Choose UNSAT-H variable for output
0046  C
0047 100    NOUT = 1
0048      LOUT = LUS
0049      WRITE(LUS,6020)
0050      IF (IHEAT .EQ. 1) WRITE(LUS,6022)
0051      WRITE(LUS,6024)
0052      READ(LUR,*) CHOICE
0053      IF (CHOICE .LE. -1) GO TO 200
0054      IF (NPRINT .EQ. 1 .AND. CHOICE .EQ. 2) THEN
0055          WRITE(LUS,6030) NTOTAL
0056          READ(LUR,*) NOUT
0057          IF (NOUT .LT. 1) NOUT = 1
0058          IF (NOUT .GT. NTOTAL) NOUT = NTOTAL
0059          ICOUNT = 1
0060      ENDIF
0061  C
0062  C      Choose output device option, either screen or file
0063  C
0064      WRITE(LUS,6040)
0065      READ(LUR,*) IOUT
0066      IF (IOUT .EQ. 1) THEN
0067          OFILE = RFILE
0068          OFILE(NCHR:NCHR+8) = '.LST'
0069          LOUT = LUR
0070          OPEN(UNIT=LOUT,FILE=OFILE,STATUS='NEW')
0071          INQUIRE(UNIT=LOUT,NAME=TMFILE)
0072          OFILE = TMFILE
0073      ENDIF
0074      IF (LOUT .EQ. LUR) WRITE(LOUT,6060) DOV,IFILE,RFILE,SDATE,STIME
0075      IF (CHOICE .EQ. 0) THEN
0076          CALL NODEZ(0)
0077          WRITE(LOUT,6061)
0078          WRITE(LOUT,6069)
0079          WRITE(LOUT,6070) (NODE(I),I=1,NDEPTH), (Z(NODE(I)),I=1,NDEPTH)
0080      ELSE IF (CHOICE .EQ. 1) THEN
0081          CALL NODEZ(0)
0082          WRITE(LOUT,6082)
0083          WRITE(LOUT,6089)
0084          WRITE(LOUT,6070) (NODE(I),I=1,NDEPTH), (Z(NODE(I)),I=1,NDEPTH)
0085      ELSE IF (CHOICE .EQ. 2) THEN
0086          WRITE(LOUT,6080)
0087          CUMINF = 0.0
0088          RATINF = 0.0
0089          PDAY = DAYBEG-1

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```

0090 ELSE IF (CHOICE .EQ. 3) THEN
0091 WRITE(LOUT,8082)
0092 ELSE IF (CHOICE .EQ. 4) THEN
0093 CALL NODEZ(8)
0094 WRITE(LOUT,8083)
0095 WRITE(LOUT,8089)
0096 WRITE(LOUT,8071) (NODE(I),I=1,NDEPTH),(FZ(NODE(I)),I=1,NDEPTH)
0097 ELSE IF (CHOICE .EQ. 5) THEN
0098 WRITE(LOUT,8085)
0099 ELSE IF (CHOICE .EQ. 6) THEN
0100 WRITE(LOUT,8130)
0101 ELSE IF (CHOICE .EQ. 7) THEN
0102 IF (UPPERM .EQ. 0) THEN
0103 CALL NODEZ(5)
0104 WRITE(LOUT,8072)
0105 WRITE(LOUT,8074)
0106 WRITE(LOUT,8076) (NODE(I),I=1,NDEPTH),(Z(NODE(I)),I=1,NDEPTH)
0107 ELSE
0108 CALL NODEZ(6)
0109 WRITE(LOUT,8084)
0110 WRITE(LOUT,8089)
0111 WRITE(LOUT,8070) (NODE(I),I=1,NDEPTH),(Z(NODE(I)),I=1,NDEPTH)
0112 ENDIF
0113 ELSE IF (CHOICE .EQ. 8) THEN
0114 CALL NODEZ(8)
0115 WRITE(LOUT,8085)
0116 WRITE(LOUT,8089)
0117 WRITE(LOUT,8071) (NODE(I),I=1,NDEPTH),(FZ(NODE(I)),I=1,NDEPTH)
0118 ELSE IF (CHOICE .EQ. 9) THEN
0119 WRITE(LOUT,8140)
0120 ENDIF
0121 IDAY = 0
0122 HOUR = 0.0
0123 C
0124 C Read variables and write to screen or file
0125 C
0126 DO 130 IREC=2,MAXREC-1
0127 IF (IREC .GT. 2 .AND. WPRINT .EQ. 1) THEN
0128 IF (IREC .EQ. (2+(IDAY-DAYBEG+1)*(NTOTAL+1))) GO TO 130
0129 IF (IDAY .EQ. DAYEND .AND. IREC .EQ. MAXREC-1) GO TO 130
0130 ENDIF
0131 CALL READREC
0132 IF (IERROR .EQ. 1) GO TO 135
0133 DAY = IDAY-1.0+HOUR/24.00
0134 IF (IDAY .EQ. 0) DAY = 0.00
0135 IF (CHOICE .EQ. 0) THEN
0136 WRITE(LOUT,8090) DAY,(H(NODE(I)),I=1,NDEPTH)
0137 ELSE IF (CHOICE .EQ. 1) THEN
0138 WRITE(LOUT,8100) DAY,(THETA(NODE(I)),I=1,NDEPTH)
0139 ELSE IF (CHOICE .EQ. 2) THEN
0140 IF (DAYTIM .GT. 0) RATINF = DAYINF/DAYTIM
0141 CUMINF = CUMINF+DAYINF
0142 RATTIM = (DAY+PDAY)/2.00
0143 PDAY = DAY
0144 IF (ICOUNT .EQ. NOUT) THEN
0145 WRITE(LOUT,8090) RATTIM,RATINF,DAY,CUMINF
0146 ICOUNT = 0
0147 ENDIF
0148 ICOUNT = ICOUNT+1
0149 ELSE IF (CHOICE .EQ. 3) THEN
0150 WRITE(LOUT,8112) DAY,DAYTIM,DAYSTP,DAYAST,DAYSDH,DAYUBC
0151 ELSE IF (CHOICE .EQ. 4) THEN
0152 WRITE(LOUT,8090) DAY,(DAYQ(NODE(I)),I=1,NDEPTH)
0153 ELSE IF (CHOICE .EQ. 5) THEN
0154 WRITE(LOUT,8090) DAY,TWOIST
0155 ELSE IF (CHOICE .EQ. 6) THEN

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0156      WRITE(LOUT,6000) DAY, DAYRN, DAYINF, DAYE, DAYTRA, DAYQ(NPT),
0157      ! TPREV-TWOIST+DAYINF-DAYE-DAYTRA-DAYQ(NPT)
0158      ELSE IF (CHOICE .EQ. 7) THEN
0159      IF (UPPERH .EQ. 0) THEN
0160      WRITE(LOUT,6000) DAY, TA, (T(NODE(I)), I=1, NDEPTH)
0161      ELSE
0162      WRITE(LOUT,6000) DAY, (T(NODE(I)), I=1, NDEPTH)
0163      ENDIF
0164      ELSE IF (CHOICE .EQ. 8) THEN
0165      WRITE(LOUT,6000) DAY, (DAYQH(NODE(I)), I=1, NDEPTH)
0166      ELSE IF (CHOICE .EQ. 9) THEN
0167      C
0168      C DAYQH(NPT) and DAYHBE converted from J/cm2 to J/m2 for output
0169      C
0170      WRITE(LOUT,6000) DAY, DAYRN, DAYSEN, DAYLE, DAYSHF,
0171      ! DAYQH(NPT)*1.D4, DAYHBE*1.D4
0172      ENDIF
0173      130 CONTINUE
0174      135 IF (IOUT .EQ. 1) THEN
0175      WRITE(LUS,8120) OFILE
0176      CLOSE (LOUT, STATUS='KEEP')
0177      ENDIF
0178      WRITE(LUS,6000)
0179      GO TO 100
0180      200 WRITE(LUS,6000)
0181      RETURN
0182      C-----
0183      C FORMAT Statements
0184      C-----
0185      6000 FORMAT(/80('-'))
0186      6010 FORMAT(' LISTDATA (Option No. 4)')
0187      6020 FORMAT(' The LISTDATA options are:/',
0188      ! T13'-1) Return to DATAOUT command level',
0189      ! T13' 0) Look at H (head) values',
0190      ! T13' 1) Look at THETA (water content) values',
0191      ! T13' 2) Look at infiltration (rate and cum)',
0192      ! T13' 3) Look at DAYTIM, DAYSTP, DAYAST, DAYSDH, DAYUBC',
0193      ! T13' (simulated time and time step information)',
0194      ! T13' 4) Look at QT (water flow) values',
0195      ! T13' 5) Look at TWOIST (water storage)',
0196      ! T13' 6) Look at Water Balance values')
0197      6022 FORMAT(X,
0198      ! T13' 7) Look at T (temperature) values',
0199      ! T13' 8) Look at QH (heat flow) values',
0200      ! T13' 9) Look at Heat Balance values')
0201      6024 FORMAT('/ Enter the desired option ==> ', $)
0202      6030 FORMAT('/ Options for reducing the amount of infil. output',
0203      ! ' 1) output every DELSUB period',
0204      ! ' 2 to 15) output reduced by a factor equal to ',
0205      ! ' the selected choice',
0206      ! ' Choose output reduction option ==> ', $)
0207      6040 FORMAT('/ Options for output device: ', $,
0208      ! ' 0) screen',
0209      ! ' 1) file',
0210      ! ' Choose output device option ==> ', $)
0211      6060 FORMAT(' UNSAT-H Version 'F3.1/,
0212      ! ' Input Filename: ', A50,/,
0213      ! ' Results Filename: ', A50,/,
0214      ! ' Date of Run: ', A9,/,
0215      ! ' Time of Run: ', A9,/)
0216      6061 FORMAT(' Time (day) 'T15'H (cm)')
0217      6062 FORMAT(' Time (day) 'T15'THETA (cm3/cm3)')
0218      6063 FORMAT(' Time (day) 'T15'QT (cm)')
0219      6064 FORMAT(' Time (day) 'T15'T (K)')
0220      6065 FORMAT(' Time (day) 'T15'QH (J/cm2)')
0221      6069 FORMAT(1X, 11('-')T15, (NDEPTH)(11('-')))

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0222 0070 FORMAT(T7,'MODE =' ,T15,<NDEPTH>(I7,4X)/,
0223 !      T2,'DEPTH (cm)=' ,2X,1P<NDEPTH>(E11.4)/)
0224 0071 FORMAT(T2,'MODE OVER Z =' ,T15,<NDEPTH>(I7,4X)/,
0225 !      T2,'DEPTH (cm)=' ,2X,1P<NDEPTH>(E11.4)/)
0226 0072 FORMAT(' Time (day) ' ,T15,'TA (K)' ,T26,'T (K)')
0227 0074 FORMAT(1X,11('-')T15,(10('-')) ,T26,<NDEPTH>(11('-'))))
0228 0076 FORMAT(T7,'MODE =' ,T26,<NDEPTH>(I7,4X)/,
0229 !      T2,'DEPTH (cm)=' ,T26,1P,6(E11.4)/)
0230 0080 FORMAT(' Infil Rate ' ,T18,'Infil Rate' ,T27,'Cumulative',
0231 !      T38,'Cumulative'/' Time (d)' ,T15' (cm/hr) ' ,T27' Time (d)',
0232 !      T37' Infil (cm)' /X,11('-')T15,3(1X,10('-'))))
0233 0082 FORMAT(' Time (day) ',
0234 !      T15,' Simulated Time' ,T38' Attempted Time Step Upper BC'/
0235 !      T15' Time (h) Steps' ,T38' Time Steps Reductions Changed'/
0236 !      1X,11('-')T15,5(1X,10('-')))/)
0237 0085 FORMAT(' Time (day) ' ,T15' TMOIST(cm)' /,
0238 !      1X,11('-')T15,1(1X,10('-')))/)
0239 0130 FORMAT(' Water Balance Parameters Per Output Cycle (units = cm)' /,
0240 !      ' Time (day)' ,T18'DAYRAN' ,T29'DAYINF' ,T41'DAYE' ,T51'DAYTRA',
0241 !      T61'DAYQ(NPT)' ,T71'MassBalance' /1X,11('-')T15,6(1X,10('-'))))
0242 0140 FORMAT(' Heat Balance Parameters Per Output Cycle (units = J/m2)',
0243 !      ' Time (day)' ,T19'DAYRN' ,T29'DAYSEN' ,T40'DAYLE' ,T51'DAYSHF',
0244 !      T60'DAYQH(NPT)' ,T73'DAYHBE' /1X,11('-')T15,6(1X,10('-'))))
0245 0090 FORMAT(1P,E12.5,2X,1P,6E11.4)
0246 0100 FORMAT(1P,E12.5,2X,6E11.4)
0247 0112 FORMAT(1P,E12.5,2X,1PE11.4,0P,4I11)
0248 0120 FORMAT('/' The data have been written to'
0249 !      ' file ',A60)
0250      END

```

```

0001      SUBROUTINE NODEZ(NL)
0002      C-----
0003      C   Version 2.0:
0004      C
0005      C   Called by HARDCOPY, LISTDATA, and SCAN
0006      C
0007      C   Allows user to enter node numbers for desired output
0008      C-----
0009      INCLUDE 'BOUT.INC/NOLIST'
0033      WRITE(LUS,6050) NL,NL,NPT
0034      READ(LUR,*) NDEPTH, (NODE(I), I=1, NDEPTH)
0035      WRITE(LUS,*)
0036      IF (NDEPTH .LE. 0) THEN
0037          NDEPTH = 1
0038          NODE(1) = 1
0039      ENDIF
0040      IF (NDEPTH .GT. NL) NDEPTH = NL
0041      RETURN
0042      6050 FORMAT(/' Data for up to 'I1' individual nodes can be viewed.',/,
0043      !          ' Enter the number of nodes desired (1 to 'I1') followed',/,
0044      !          ' by the node numbers (1 to ',I3,') ==> ', $)
0045      END

```

```

0001      SUBROUTINE PROFILER
0002      C-----
0003      C      Version 2.0:
0004      C
0005      C      Called by DATAOUT
0006      C
0007      C      Calls READREC
0008      C
0009      C      Creates data (e.g., water content, head) vs depth data lists
0010      C      which can be output to a screen or a separate file (with a
0011      C      *.PRD extension) to be used for plotting purposes.
0012      C-----
0013      INCLUDE 'BOUT.INC/MOLIST'
0037      REAL HEAD(8,M1),WATCONT(8,M1),TIME(8),WFLOW(8,M1),
0038      !      TEMP(8,M1),HFLOW(8,M1),FZ(M1)
0039      INTEGER JDAY(8),ND(8)
0040      DO 30 I=1,NPT-1
0041          FZ(I) = (Z(I-1)-Z(I))/2
0042      30  CONTINUE
0043      FZ(NPT) = Z(NPT)
0044      WRITE(LUS,8000)
0045      WRITE(LUS,8010)
0046      120 WRITE(LUS,8020)
0047      IF (IHEAT .EQ. 1) WRITE(LUS,8022)
0048      WRITE(LUS,8024)
0049      READ(LUR,*) VOUT
0050      IF (VOUT .LE. 0) GO TO 200
0051      WRITE(LUS,8030) DAYBEG-1,DAYEND
0052      IF (NPRINT .EQ. 0) THEN
0053          OPT = 1
0054      ELSE
0055          WRITE(LUS,8040)
0056          READ(LUR,*) OPT
0057      ENDIF
0058      ND(1) = NTOTAL
0059      NDELSUB = NTOTAL*STOPHR/24.00
0060      IF (OPT .EQ. 1) THEN
0061      C
0062      C      Choose the days for scanning
0063      C
0064          WRITE(LUS,8070)
0065          READ(LUR,*) NUMDAY,(JDAY(I),I=1,NUMDAY)
0066      ELSE
0067      C
0068      C      Choose the DELSUB periods for scanning
0069      C
0070          NUMDAY = 1
0071          WRITE(LUS,8080) NTOTAL,24.00/NTOTAL
0072          IF (STOPHR .LT. 24) WRITE(LUS,8090) DAYEND,NDELSUB,STOPHR
0073          WRITE(LUS,8100)
0074          READ(LUR,*) JDAY(1),NUMDEL,(ND(I),I=1,NUMDEL)
0075      ENDIF
0076      C
0077      C      Choose the output device (screen or file)
0078      C
0079          WRITE(LUS,8110)
0080          READ(LUR,*) IOUT
0081          LOUT = LUS
0082          IF (IOUT .EQ. 1) THEN
0083              LOUT = LUN
0084              TMFILE = RFILEN
0085              TMFILE(NCHR:NCHR+8) = '.PRD'
0086              OPEN(UNIT=LOUT,FILE=TMFILE,STATUS='NEW')
0087              INQUIRE(UNIT=LOUT,NAME=OFILE)
0088          ENDIF
0089      C

```



```

0090 C      Fill the arrays
0091 C
0092 IF (OPT .EQ. 1) THEN
0093     NUMBER = NUMDAY
0094 ELSE
0095     NUMBER = NUMDEL
0096 ENDIF
0097 DO 60 I=1,NUMBER
0098     IF (OPT .EQ. 1) THEN
0099         ND(I) = NTOTAL+1
0100         IF (JDAY(I) .EQ. DAYEND) ND(I) = NDELSUB+1
0101     ELSE
0102         JDAY(I) = JDAY(1)
0103     ENDIF
0104     KDAY = JDAY(I)-DAYBEG+1
0105     IREC = 2+KDAY+(ND(I)+(KDAY-1)*NTOTAL-1)*NPRINT
0106     CALL READREC
0107     TIME(I) = IDAY-1+HOUR/24.D0
0108     DO 40 J=1,NPT
0109         IF (VOUT .EQ. 1) WATCONT(I,J) = THETA(J)
0110         IF (VOUT .EQ. 2) HEAD(I,J) = H(J)
0111         IF (VOUT .EQ. 3) WFLOW(I,J) = DAYQ(J)
0112         IF (VOUT .EQ. 4) TEMP(I,J) = T(J)
0113         IF (VOUT .EQ. 5) HFLOW(I,J) = DAYQH(J)
0114     40 CONTINUE
0115 60 CONTINUE
0116 C
0117 C      Output the node number, depth, and array contents
0118 C
0119 IF (IOUT .EQ. 0) WRITE(LUS,*)
0120 IF (LOUT .EQ. LOW) WRITE(LOUT,0115) DOV,IFILE,RFILE,SDATE,STIME
0121 IF (VOUT .EQ. 1) THEN
0122     WRITE(LOUT,0120)
0123 ELSE IF (VOUT .EQ. 2) THEN
0124     WRITE(LOUT,0130)
0125 ELSE IF (VOUT .EQ. 3) THEN
0126     WRITE(LOUT,0131)
0127 ELSE IF (VOUT .EQ. 4) THEN
0128     WRITE(LOUT,0132)
0129 ELSE IF (VOUT .EQ. 5) THEN
0130     WRITE(LOUT,0134)
0131 ENDIF
0132 WRITE(LOUT,0130) (TIME(I),I=1,NUMBER)
0133 DO 100 J=1,NPT
0134     IF (VOUT .EQ. 1) THEN
0135         WRITE(LOUT,0140) J,Z(J),(WATCONT(I,J),I=1,NUMBER)
0136     ELSE IF (VOUT .EQ. 2) THEN
0137         WRITE(LOUT,0150) J,Z(J),(HEAD(I,J),I=1,NUMBER)
0138     ELSE IF (VOUT .EQ. 3) THEN
0139         WRITE(LOUT,0150) J,FZ(J),(WFLOW(I,J),I=1,NUMBER)
0140     ELSE IF (VOUT .EQ. 4) THEN
0141         WRITE(LOUT,0150) J,Z(J),(TEMP(I,J),I=1,NUMBER)
0142     ELSE IF (VOUT .EQ. 5) THEN
0143         WRITE(LOUT,0150) J,FZ(J),(HFLOW(I,J),I=1,NUMBER)
0144     ENDIF
0145 100 CONTINUE
0146 IF (IOUT .EQ. 1) WRITE(LUS,0160) OFILE
0147 CLOSE (LOUT)
0148 WRITE(LUS,0000)
0149 GO TO 120
0150 200 WRITE(LUS,0000)
0151 RETURN
0152 C-----
0153 C      FORMAT Statements
0154 C-----
0155 0000 FORMAT(/00(' ')/)

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```

0156 0010 FORMAT(' PROFILER (Option No. 5)')
0157 0020 FORMAT(' The PROFILER output options are: '//,
0158 !      T13' 0) return to DATAOUT command level'//,
0159 !      T13' 1) output water content vs depth'//,
0160 !      T13' 2) output head vs depth'//,
0161 !      T13' 3) output water flow amounts between nodes')
0162 0022 FORMAT(T13' 4) output soil temperature vs depth or'//,
0163 !      T13' 5) output heat flow amount between nodes')
0164 0024 FORMAT('/' Enter PROFILER option ==> ', $)
0165 0030 FORMAT('/' The days of the year available for viewing are'//,
0166 !      ' days ', I3, ' through ', I3)
0167 0040 FORMAT('/' The temporal options are: '//,
0168 !      ' 1) end-of-day data for up to 8 days'//,
0169 !      ' 2) end-of-DELSUB data for 1 day for up'//,
0170 !      ' to 8 DELSUB periods'//,
0171 !      ' Enter temporal option ==> ', $)
0172 0070 FORMAT('/' Enter the number of days for viewing (up to 8)'//,
0173 !      ' followed by a list of the desired days ==> ', $)
0174 0080 FORMAT('/' There are ', I5, ' DELSUB periods ('F8.5' hours each)',
0175 !      ' per day.')
0176 0090 FORMAT(' NOTE: On the last day (day 'I3') of this run, there',
0177 !      ' are only', I9, ' DELSUB periods (total simulated',
0178 !      ' time = 'F8.5' hours)')
0179 0100 FORMAT('/' Enter the simulation day, the number of DELSUB '//,
0180 !      ' periods for that day, followed by a list'//,
0181 !      ' of the periods (up to 8) ==> ', $)
0182 0110 FORMAT('/' The output options are: '//,
0183 !      ' 0) screen or'//,
0184 !      ' 1) file'//,
0185 !      ' Enter output option ==> ', $)
0186 0115 FORMAT(' UNSAT-H Version 'F3.1',
0187 !      ' Input Filename: ', A50, '//,
0188 !      ' Results Filename: ', A50, '//,
0189 !      ' Date of Run: ', A9, '//,
0190 !      ' Time of Run: ', A8, '//)
0191 0120 FORMAT(T32' WATER CONTENTS (cm3/cm3)')
0192 0130 FORMAT(T32' HEAD (cm)')
0193 0131 FORMAT(T32' WATER FLOW AMOUNT (cm)')
0194 0132 FORMAT(T32' SOIL TEMPERATURE (K)')
0195 0134 FORMAT(T32' SOIL HEAT FLOW (J/cm2)')
0196 0138 FORMAT(T15, 88(' - ')/,
0197 !      ' Node Depth', T35, ' Simulation Day'//,
0198 !      ' No. (cm)', 1X, (NUMBER)(F11.5)/,
0199 !      ' -----', 1X, (NUMBER)(' -----'))
0200 0140 FORMAT(I5, F8.2, 1X, 8F11.6)
0201 0150 FORMAT(I5, F8.2, 1X, 1P, 8E11.4)
0202 0160 FORMAT('/' PROFILER output can be found in'
0203 !      ' file 'A60)
0204      END

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```

0001      SUBROUTINE READREC
0002  C-----
0003  C      Version 2.0:
0004  C
0005  C      Called by DDSUM, INITSUM, LISTDATA, PROFILER, and REINIT
0006  C
0007  C      Reads the *.RES file (from UNSATH), either DELSUB or daily
0008  C      summary records
0009  C-----
0010      INCLUDE 'BOUT.INC/NOLIST'
0011      IERROR = 0
0012      IF (IPLANT.EQ. 0) THEN
0013      IF (IHEAT.EQ. 0) THEN
0014      READ(LUI,REC=IREC,ERR=200) IDAY,HOUR,(H(J),THETA(J),DAYQ(J),
0015      !      J=1,NPT),DAYINF,DAYRAN,DAYE,DAYTRA,DAYRUN,
0016      !      TPREV,TWOIST,DAYSTP,PE,PT,DAYTIM,DAYAST,DAYUBC,RHMEAN,
0017      !      TMEAN,HDRY,DAYRN,DAYSHE,DAYSEN,DAYHBE,
0018      !      TA,TMAX,TMIN,VD_A,WIND,CLOUD,SR_MEAS,DAYLE,DAYSDE
0019      ELSE
0020      READ(LUI,REC=IREC,ERR=200) IDAY,HOUR,(H(J),THETA(J),DAYQ(J),
0021      !      T(J),DAYQH(J),J=1,NPT),DAYINF,DAYRAN,DAYE,DAYTRA,DAYRUN,
0022      !      TPREV,TWOIST,DAYSTP,PE,PT,DAYTIM,DAYAST,DAYUBC,RHMEAN,
0023      !      TMEAN,HDRY,DAYRN,DAYSHE,DAYSEN,DAYHBE,
0024      !      TA,TMAX,TMIN,VD_A,WIND,CLOUD,SR_MEAS,DAYLE,DAYSDE
0025      ENDIF
0026      ELSE
0027      READ(LUI,REC=IREC,ERR=200) IDAY,HOUR,(H(J),THETA(J),DAYQ(J),
0028      !      DAYSNE(J),J=1,NPT),DAYINF,DAYRAN,DAYE,DAYTRA,
0029      !      DAYRUN,TPREV,TWOIST,DAYSTP,PE,PT,DAYTIM,DAYAST,DAYUBC,
0030      !      RHMEAN,TMEAN,HDRY,DAYSDE
0031      ENDIF
0032      100 RETURN
0033      200 WRITE(LUS,0000) IREC
0034      IERROR = 1
0035      GO TO 100
0036  C-----
0037  C      FORMAT Statements
0038  C-----
0039      0000 FORMAT(' Record No. ',I5,' could not be read'/)
0040      END

```

```

0001      SUBROUTINE REINIT
0002  C-----
0003  C      Version 2.0:
0004  C
0005  C      Called by DATAOUT
0006  C
0007  C      Calls READREC
0008  C
0009  C      Reads the *.RES output file from UNSAT-H and outputs a file
0010  C      (TOSS.OUT) with the head values for the end of the chosen time
0011  C      period. If IHEAT = 1, then the temperature values for the end
0012  C      of the chosen time period are also output.
0013  C      The TOSS.OUT file can serve as the initial conditions
0014  C      for a new simulation.
0015  C-----
0016      INCLUDE 'BOUT.INC/NOLIST'
0017      LOUT = LUW
0018      ID = 1
0019      IF (DAYEND .GT. 9) ID = 2
0020      IF (DAYEND .GT. 99) ID = 3
0021      WRITE(LUS,0000)
0022      WRITE(LUS,0010)
0023 120  WRITE(LUS,0020) DAYBEG, DAYEND
0024      READ(LUR,*) JDAY
0025      IF (JDAY .LE. -1) THEN
0026          WRITE(LUS,0000)
0027          GO TO 100
0028      ELSE IF (JDAY .EQ. 0) THEN
0029          IREC = 2
0030          GO TO 140
0031      ELSE
0032          IF (JDAY .LT. DAYBEG .OR. JDAY .GT. DAYEND) THEN
0033              WRITE(LUS,0030) JDAY
0034              GO TO 120
0035          ENDIF
0036      ENDIF
0037  C
0038  C      Choose a DELSUB period for scanning
0039  C
0040      IF (NPRINT .EQ. 1) THEN
0041          LESS = 0
0042          IF (JDAY .EQ. DAYEND) LESS = NTOTAL-NTOTAL*STOPHR/24.D0
0043 130  WRITE(LUS,0040) 24.D0/NTOTAL, NTOTAL-LESS, 1+NTOTAL-LESS
0044      READ(LUR,*) JH
0045      IF (JH .LT. 1 .OR. JH .GT. 1+NTOTAL-LESS) THEN
0046          WRITE(LUS,0050) JH
0047          GO TO 130
0048      ENDIF
0049      ENDIF
0050  C
0051  C      Read the results file
0052  C
0053      KDAY = JDAY-DAYBEG+1
0054      IREC = 2+KDAY*(JH+(KDAY-1)*NTOTAL-1)*NPRINT
0055 140  CALL READREC
0056      IF (IERROR .EQ. 1) THEN
0057          WRITE(LUS,0060)
0058          GO TO 120
0059      ENDIF
0060      TIME = JDAY-1+HOUR/24.D0
0061      NDAY = JDAY
0062      IF (NDAY .EQ. DAYEND) NDAY = 0
0063  C
0064  C      Output the head values to the TOSS.OUT file
0065  C
0066      OPEN (UNIT=LOUT, FILE='TOSS.OUT', STATUS='NEW')

```

```

0090      WRITE(LUN,6070) NDAY,TIME,DOY,(H(I),I=1,NPT)
0091      IF (IHEAT.EQ.1) WRITE(LUN,6075) (T(I),I=1,NPT)
0092      WRITE(LUS,6080) TIME,NDAY
0093      WRITE(LUS,6080)
0094      CLOSE (LOUT)
0095 100    RETURN
0096 C-----
0097 C      FORMAT Statements
0098 C-----
0099 6080 FORMAT(/80(' ')/)
0100 6010 FORMAT(' REINIT (Option No. 1)')
0101 6020 FORMAT(' The REINIT options are:',/,
0102      !      ' -1) return to DATAOUT command level',/,
0103      !      ' 0) reinitialize initial conditions',/,
0104      !      '(10-2*ID)*X,I(ID)' to 'I(ID)' reinitialize on the',
0105      !      ' chosen day',/,
0106      !      ' Enter the desired option ==> ',8)
0107 6030 FORMAT(/' The chosen day ('I3,') is not an option.',
0108      !      ' Try again...')
0109 6040 FORMAT(/' This file contains data for each DELSUB period',
0110      !      ' ('F7.5' hours per period).', ' The options are:',/,
0111      !      ' T0,'1 to',I5,T15') solution at the end of the',
0112      !      ' chosen DELSUB (time) period',/,
0113      !      ' T0,I5,T15') solution at the end of the chosen day',/,
0114      !      ' Enter the desired choice ==> ',8)
0115 6050 FORMAT(/' Option ',I5,' does not exist. Try again...')
0116 6060 FORMAT(/' The chosen day ('I3,') is not available. ',/,
0117      !      ' Try again...')
0118 6070 FORMAT(I5,T10,'(TOSS.OUT file for day '1PE12.5,')',T60,'NDAY',
0119      !      '(UNSAT-H V'0PF3.1')'/1P,4E14.5,T60,'Head Values',
0120      !      /(4E14.5))
0121 6075 FORMAT(1P,4E14.5,T60,'Temperature Values',/(4E14.5))
0122 6080 FORMAT(/' The initialized values are for the end of day',1PE12.5,
0123      !      '.'/ ' File TOSS.OUT was created with NDAY set to ',I3,')
0124      END

```

```

0001      SUBROUTINE SCAN
0002      C-----
0003      C      Version 2.0:
0004      C
0005      C      Called by DATAOUT
0006      C
0007      C      Calls INITSUM, DDSUM, NODEZ, and SUMMARY
0008      C
0009      C      Displays on the screen the end-of-DELSUB and end-of-day
0010      C      summaries for any day of a simulation, including the initial
0011      C      conditions and the simulation-end summary
0012      C-----
0013      INCLUDE 'BOUT.INC/NOLIST'
0037      LOUT = LUS
0038      WRITE(LUS,8000)
0039      WRITE(LUS,8010)
0040      CALL NODEZ(6)
0041      ID = 1
0042      IF (DAYEND .GT. 0) ID = 2
0043      IF (DAYEND .GT. 99) ID = 3
0044      C
0045      C      Choose a day for scanning
0046      C
0047      120 WRITE(LUS,8020) DAYBEG,DAYEND,DAYEND+1
0048      READ(LUR,*) JDAY
0049      IF (JDAY .LE. -1) GO TO 200
0050      IF (JDAY .GT. DAYEND+1) THEN
0051          WRITE(LUS,8030) JDAY,DAYEND+1
0052          GO TO 120
0053      ENDIF
0054      C
0055      C      Output simulation-end summary
0056      C
0057      IF (JDAY .EQ. DAYEND+1) THEN
0058          IREC = MAXREC
0059          CALL SUMMARY
0060          WRITE(LUS,8000)
0061          GO TO 120
0062      ENDIF
0063      C
0064      C      Choose a DELSUB period for scanning
0065      C
0066      IF (NPRINT .EQ. 1 .AND. JDAY .NE. 0) THEN
0067          LESS = 0
0068          IF (JDAY .EQ. DAYEND) LESS = NTOTAL-NTOTAL*STOPHR/24.
0069      130 WRITE(LUS,8040) NTOTAL-LESS,1-NTOTAL-LESS
0070      READ(LUR,*) JH
0071      IF (JH .LT. 1 .OR. JH .GT. 1-NTOTAL-LESS) THEN
0072          WRITE(LUS,8050) JH
0073          GO TO 130
0074      ENDIF
0075      ENDIF
0076      KDAY = JDAY-DAYBEG+1
0077      IREC = 2+KDAY*(JH+(KDAY-1)*NTOTAL-1)*NPRINT
0078      IF (JDAY .EQ. 0) IREC = 2
0079      C
0080      C      Output the initial conditions
0081      C
0082      IF (IREC .EQ. 2) THEN
0083          CALL INITSUM
0084          IF (IERROR .EQ. 1) GO TO 120
0085          WRITE(LUS,8000)
0086          GO TO 120
0087      ENDIF
0088      C
0089      C      Output DELSUB/daily summaries

```

```

0090 C
0091 CALL DDSUM(JH)
0092 IF (IERROR.EQ. 1) GO TO 120
0093 WRITE(LUS,8200)
0094 READ(LUR,*)
0095 WRITE(LUS,*)
0096 GO TO 120
0097 200 WRITE(LUS,8000)
0098 RETURN
0099 -----
0100 C FORMAT Statements
0101 C-----
0102 8000 FORMAT(/80('-',)/)
0103 8010 FORMAT(' SCAN (Option No. 2)')
0104 8020 FORMAT(' The SCAN options are:',/,
0105 !           '-1) Return to DATAOUT command level',/,
0106 !           '0) Look at the initial conditions',/,
0107 !           '<10-2*TD>X,I<ID>' to 'I<ID>' Look at the end-of-day summary for',
0108 !           ' chosen day',/,
0109 !           '<9-ID>X,' ,I<ID>,' Look at the end-of-year summary',/,
0110 !           ' Enter the desired option ==> ',%)
0111 8030 FORMAT(/' The chosen day ('I3,') is greater than DAYEND+1 ('
0112 !           I3,'). Try again...'/)
0113 8040 FORMAT(/' This file contains data for DELSUB (time) periods.',/
0114 !           ' The options are:',/,
0115 !           'T0,'1 to',I5,T15') summary of the chosen time period',/
0116 !           'T0,I5,T15') overall summary of the chosen day',/,
0117 !           ' Enter the desired choice ==> ',%)
0118 8250 FORMAT(/' Option ',I5,' does not exist. Try again...'/)
0119 8260 FORMAT(80('-',)/' Press <RTN> to get SCAN options ==> ',%)
0120 END

```



```

0001      SUBROUTINE SUMMARY
0002  C-----
0003  C      Version 2.0:
0004  C
0005  C      Called by DATAOUT subroutines HARDCOPY, LISTDATA, and SCAN
0006  C
0007  C      Reads and outputs the year-end summary data found in the last
0008  C      record of an UNSATH *.RES file
0009  C-----
0010      INCLUDE 'BOUT.INC/NOLIST'
0034      READ(LUI,REC=MAXREC,ERR=200) IDAY,G,IPLANT,TPET,TPT,TTRA,TPE,TE,
0035      ! TETRA,TRUNOF,TINF,TTIM,TRAIN,APLIED,TTIRRI,TMOIST,TERR,
0036      ! TSTP,(TQ(I),TQH(I),I=1,NPT),TAST,TUBC,TRN,TSHF,TSEN,TLE,
0037      ! THBE,TSDB
0038      WRITE(LOUT,6000) DOV,TITLE,IPLANT,TPET,TPT,TTRA,TPE,TE,TETRA,
0039      ! TRUNOF,TINF,TQ(NPT),APLIED,TRAIN,TTIRRI,TMOIST,
0040      ! TERR,TSTP,TAST,TSDB,TUBC,TTIM
0041  C
0042  C      TQH(NPT) and THBE are converted from J/cm2 to J/m2
0043  C
0044      IF (IHEAT.EQ. 1) WRITE(LOUT,6010) TRN,TSHF,TSEN,TQH(NPT)*1.D4,
0045      ! TLE,THBE*1.D4
0046      SFLOW = TINF-TE
0047  C
0048  C      Convert TSHF (J/m2) to SHFLOW (J/cm2)
0049  C
0050      SHFLOW = TSHF*1.D-4
0051      WRITE(LOUT,6020) TTIM
0052      WRITE(LOUT,6030) Z(1),SFLOW,(0.5*(Z(I)+Z(I+1)),TQ(I),I=1,NPT-1),
0053      ! Z(NPT),TQ(NPT)
0054      IF (IHEAT.EQ. 1) THEN
0055          WRITE(LOUT,6025) TTIM
0056          WRITE(LOUT,6030) Z(1),SHFLOW,(0.5*(Z(I)+Z(I+1)),TQH(I),
0057          ! I=1,NPT-1),Z(NPT),TQH(NPT)
0058      ENDIF
0059      100 RETURN
0060      200 WRITE(LUS,6040) MAXREC
0061      GO TO 100
0062  C-----
0063  C      FORMAT Statements
0064  C-----
0065      6000 FORMAT(/80('-')/T30'UNSAT-H Version 'F3.1/,
0066      ! T30' SIMULATION SUMMARY'// Title: '/1X,A70,/,80('-')/,//,
0067      ! ' Transpiration Scheme is: = ',I4/
0068      ! ' Potential Evapotranspiration = ',1PE11.4,T55'[cm]'/
0069      ! ' Potential Transpiration = ',E11.4,T55'[cm]'/
0070      ! ' Actual Transpiration = ',E11.4,T55'[cm]'/
0071      ! ' Potential Evaporation = ',E11.4,T55'[cm]'/
0072      ! ' Actual Evaporation = ',E11.4,T55'[cm]'/
0073      ! ' Evaporation during Growth = ',E11.4,T55'[cm]'/
0074      ! ' Total Runoff = ',E11.4,T55'[cm]'/
0075      ! ' Total Infiltration = ',E11.4,T55'[cm]'/
0076      ! ' Total Drainage at Base of Profile = ',E11.4,T55'[cm]'/
0077      ! ' Total Applied Water = ',E11.4,T55'[cm]'/
0078      ! ' Actual Rainfall = ',E11.4,T55'[cm]'/
0079      ! ' Actual Irrigation = ',E11.4,T55'[cm]'/
0080      ! ' Total Final Moisture Storage = ',E11.4,T55'[cm]'/
0081      ! ' Mass Balance Error = ',E11.4,T55'[cm]'/
0082      ! ' Total Successful Time Steps = ',I9/
0083      ! ' Total Attempted Time Steps = ',I9/
0084      ! ' Total Time Step Reductions (DHMAX) = ',I9/
0085      ! ' Total Changes in Surface Boundary = ',I9/
0086      ! ' Total Time Actually Simulated = ',E11.4,T55'[days]')
0087      6010 FORMAT(
0088      ! ' Total Net Radiation = ',1PE11.4,T55'[J/m2]'/,
0089      ! ' Total Soil-Surface Heat Flow = ',E11.4,T55'[J/m2]'/,

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0090      ! ' Total Sensible Heat Flow      = ',E11.4,T55'[J/m2]'/,
0091      ! ' Total Bottom Heat Flow        = ',E11.4,T55'[J/m2]'/,
0092      ! ' Total Latent Heat Flow         = ',E11.4,T55'[J/m2]'/,
0093      ! ' Heat Balance Error             = ',E11.4,T55'[J/m2]')
0094 0020  FORMAT(///' Total water flow (cm) across different depths',
0095      !      ' at the end of',1PE11.4,' days: '//
0096      !      3(5X,'DEPTH',8X,'FLOW',3X),/,
0097      !      3(4X,'-----',3X,'-----'))
0098 0025  FORMAT(///' Total heat flow (J/cm2) across different depths',
0099      !      ' at the end of',1PE11.4,' days: '//
0100      !      3(5X,'DEPTH',8X,'FLOW',3X),/,
0101      !      3(4X,'-----',3X,'-----'))
0102 0030  FORMAT(3(3X,0P,F8.3,1P,E14.4))
0103 0040  FORMAT(/' The end-of-year summary record ('I5,') could not',
0104      !      ' be read. SUMMARY aborted.',/)
0105      END

```


APPENDIX B

INPUT MANUAL

APPENDIX B

INPUT MANUAL

1.0 OPTIONS, CONSTANTS, AND LIMITS

Record No.	FORMAT	Column No.	Variable	Description
1	A80	1-80	TITLE	Problem description or identifier. This variable is passed through to the output file.
2	10I5	1- 5	IPLANT	Plant option (0) No plants (1) Plants
		6-10	LOWER	Lower boundary condition option (1) Unit gradient (2) Constant head (the initial value is maintained). A value of zero would correspond to a static water table (3) Specified bottom flux (4) Impermeable boundary
		11-15	NGRAV	Orientation of the profile (0) Horizontal (1) Vertical
		16-20	ISWDIF	Option for time step control (0) Check all nodes to see if the fractional change in THETA of every node is less than DMAXBA (1) Reduce the time step if the mass balance for the whole profile exceeds DMAXBA
		21-25	IHEAT	Option for simulating heat flow (0) No heat flow (1) Heat flow simulated
		26-30	UPPERH	Option for the upper boundary condition for heat flow (0) Flux that is calculated based on weather and soil parameters (1) Constant temperature (specified in initial conditions) (2) Variable temperature (must specify TSMEAN and TAMP) (3) Specified heat flux (must specify QHTOP). Any convective flow (e.g., heat associated with precipitation) will be added to QHTOP.
		31-35	LOWERH	Option for the lower boundary condition for heat flow (1) Temperature gradient (must specify TGRAD) (2) Constant temperature (specified in initial conditions) (3) Constant heat flux (must specify QHLEAK)
3	6I5, F10.0	1- 5	NPRINT	Option for level of output (0) Daily summaries and end-of-simulation summary (1) DELSUB and daily summaries and end-of-simulation summary. Use of option (1) may result in large *.RES output files if DAYEND-NDAY is large
		6-10	DAYEND	Ending day of the simulation. When ET_OPT = 1, DAYEND must be a Day of the Year
		11-15	NDAYS	Number of days for which data are provided. NDAYS cannot exceed 365
		16-20	NYEARS	Number of years for the simulation to be run. A value of 1 will result in a single-year simulation

Record No.	FORMAT	Column No.	Variable	Description
4	10I5	21-25	IRAIN	Option for water application information (0) Enter Records 65-67 (1) Use the daily precipitation values that are included with the meteorological data. Starting at 0000 hr, precipitation is applied at the rate of 1 cm/hr until the amount to be applied is less than 1 cm, after which the remainder is applied over the next hour (option ET OPT must equal 1, indicating the presence of meteorological data)
		26-30	ICONVH	Option to allow convective heat flow via water flow (0) No convective flow allowed (1) Convective flow allowed. Use caution when solving convection-dominated problems because there is no upstream weighting.
		31-40	OUTTIM	Determines the size of the DELSUB period; if MPRINT equals 1, OUTTIM is also the time interval for generating output. If equal to zero, OUTTIM is reset to the DELMAX value. For values of OUTTIM greater than 1.0, 24/OUTTIM must produce an integer value. Values cannot be greater than 24. For values of OUTTIM less than 1.0, 1.0/OUTTIM must produce an integer value if using hourly precipitation and evaporation data.
		1- 5	NSURPE	Option to allow evaporation when there are no plants (0) No evaporation (1) Evaporation
		6-10	NFHOUR	Option to distribute the daily potential evapotranspiration (PET) value over the 24 hours of the day (1) User supplies 24 hourly factors (2) Hourly factors are generated with a sine wave function for the hours between 0000 and 1800, while the remaining hourly factors are set equal to 0.01
		11-15	ITOPBC	Option for the surface-boundary condition (0) Flux (1) Constant head. If this option is chosen, specify the constant surface head value, HTOP
		16-20	ET_OPT	Option to input daily meteorological data (0) No meteorological data (use potential evapotranspiration data) (1) Daily meteorological data are entered (NSURPE must equal 1)
		21-25	ICLOUD	Option to use cloud cover data from the meteorological record (applicable when IHEAT = 1 and UPPERK = 0) (0) No. Cloud cover calculated from measured and potential solar radiation. (1) Yes, use the cloud cover data provided
5	10I5	1- 5	KDPT	Options for describing the soil hydraulic properties (1) Polynomial (2) Haverkamp (3) Brooks-Corey (4) van Genuchten
		6-10	KEST	Option for estimating the liquid conductivity at the midpoint between nodes (1) Arithmetic mean with an option for upstream weighting (see WTF parameter). A value of 0.5 for WTF yields an unweighted arithmetic mean. (2) Harmonic mean (3) Geometric mean
		11-15	IVAPOR	Option to allow vapor flow. If chosen, values must be supplied for TORT, TSOL, and VAPDIF (Record 8)

Record No.	FORMAT	Column No.	Variable	Description
		16-20	SH_OPT	Option for the upper surface head limit when IHEAT = 0 (0) Use the constant upper value of surface head, HDRY (1) Calculate a daily HDRY value based on atmospheric humidity (requires ET_OPT equal 1)
		21-25	INMAX	Number of iterations allowed for solving the water flow equation. A value of 2 is the minimum allowed. Caution: INMAX steps will be taken.
		26-30	INHMAX	Number of iterations allowed for solving the heat flow equation. A value of 1 is the minimum allowed. A value of 2 or more is preferred when UPPERH = 2. Caution: INHMAX steps will be taken.
6	3F10.0	1-10	HIRRI	Minimum head to which the soil can wet up (units: cm)
		11-20	HDRY	Maximum head to which the soil can dry out when IHEAT = 0 and SH_OPT = 0 (units: cm)
		21-30	HTOP	Constant head value of the surface node when the ITOPBC = 1 option is chosen (units: cm)
		31-40	DHMAX	If DHMAX is positive, each potential head solution is checked to see if the change in head of any node exceeds DHMAX. If so, the time step size is reduced by the factor DHFACT and re-solved. This option was added especially for instances when SH_OPT = 1 or when IHEAT = 1 and UPPERH = 0 (units: cm)
7	4F10.0	1-10	DMAXBA	Time step control parameter. If ISWDIF = 0, DMAXBA is the maximum allowable fractional change in the water content of any node [suggested value is 0.01 (no units)]. If ISWDIF = 1, DMAXBA is the maximum allowable mass balance error (units: cm)
		11-20	DELMAX	Maximum allowable time step, normally 1 hr. The value of DELMAX must be less than or equal to OUTTIM, otherwise DELMAX is set equal to OUTTIM (units: hr)
		21-30	DELMIN	Minimum allowable time step; must be $\leq$ DELMAX (units: hr)
		31-40	STOPHR	Stopping time when IDAY = DAYEND and NPRINT = 1. This feature is useful for stopping a simulation at a time other than the end of a day. A particular instance for using STOPHR would be for simulating a time period less than a day. A normal value of STOPHR is 24.
8	4F10.0	1-10	TORT	Tortuosity
		11-20	TSOIL	Average temperature of the soil for use in calculations of isothermal vapor flow (units: K)
		21-30	VAPDIF	Diffusion coefficient of vapor in air (units: cm ² /s)
		31-40	QHTOP	Specified surface heat flux when UPPERH = 3 (units: W/m ²)
9	4F10.0	1-10	TGRAD	Temperature gradient at the bottom boundary when IHEAT = 1 (units: K/cm)
		11-20	TSMEAN	Daily mean air temperature when UPPERH = 2; temperature of infiltrating water when UPPERH = 3 (units: K)
		21-30	TSAMP	Daily air temperature amplitude about TSMEAN when UPPERH equals 2 (units: K)
		31-40	QHLEAK	Heat flux at the bottom boundary when LOWERH = 3 (units: J/cm ²)
10	4F10.0	1-10	WTF	Weighting factor (from 0.0 to 1.0) used to weight the conductivity of the upstream node in the calculation of conductivities between nodes. A value of 0.5 weights the nodes equally. WTF applies only when KEST is 1.
		11-20	RFACT	Maximum time-step factor. The time step can potentially be increased by this factor following the completion of a successful time step
		21-30	RAINIF	Rainfall initiation factor. At the start of water application event, the time step will be reduced by the RAINIF factor
		31-40	DHFACT	Time step reduction factor if DHMAX > 0.

Record No.	FORMAT	Column No.	Variable	Description
11	2I5	1- 5	MATN	Number of different soil materials
		6-10	NPT	Number of nodes
12	4(I4, F10.0)	1- 5	MAT(1)	Soil material identification number for the given node
		6-10	Z(1)	Depth of node below the surface (units: cm)
			•	
			•	
			•	
			MAT(4)	
			Z(4)	

Note: Repeat Record 12 until NPT pairs of MAT and Z values have been entered

2.0 SOIL PROPERTY DESCRIPTION

Note: Records 13-21 are entered only if KOPT = 1 (polynomial description)

Record No.	FORMAT	Column No.	Variable	Description
13	2I5	1- 5	MAXSUB	Maximum number of subdivisions of any given soil property description (limited by M2 in BVAR.INC)
		6-16	MAXPOL	Maximum degree of soil property polynomials (limited by M3 in BVAR.INC, but with a maximum limit of 5)
14	A60	1-60	DUMMY	Dummy title that can be used to describe the soil type and indicate that what follows are water retention parameters
15	1X,I5, 2F15.0	2- 8	NSUBTH	Number of subdivisions of the water retention curve for that particular material
		7-21	AIRINT	Air entry head (units: cm)
		22-36	THET	Saturated water content (units: cm ³ /cm ³)
16	1X,2I5, 2F15.0	2- 8	II	Index of the water retention polynomial
		7-11	NDEGTH	Number of polynomial coefficients, or polynomial degree + 1
		12-26	XX	Minimum head for which the given polynomial applies (units: cm)
		27-41	XDIVTH	Maximum head for which the given polynomial applies (units: cm)
17	5F15.0	1-15	CREGTH	Polynomial coefficients for describing water retention

Note: Enter NDEGTH values of CREGTH

Note: Repeat the sequence of Records 16-17 NSUBTH times

18	A60	1-60	DUMMY	Dummy title that can be used to describe the soil type and indicate that what follows are conductivity parameters
19	1X,I5, 2F15.0	2- 8	NSUBKH	Number of subdivisions of conductivity curve for that particular material
		7-21	AIRINK	Air entry head (units: cm)
		22-36	SK	Saturated hydraulic conductivity (units: cm/hr)
20	1X,2I5, 2F15.0	2- 8	II	Index of the conductivity polynomial
		7-11	NDEGKH	Number of polynomial coefficients, or polynomial degree + 1
		12-26	XX	Minimum head for which the given polynomial applies
		27-41	XDIVKH	Maximum head for which the given polynomial applies
21	5F15.0	1-15	CREQKH	Polynomial coefficients for describing conductivity

Note: Enter NDEGKH values of CREQKH

Note: Repeat the sequence of Records 20-21 NSUBK times

Enter Records 22-25 if KOPT = 2 (Haverkamp functions)

22	A60	1-60	DUMMY	Dummy title that can be used to describe the soil type and indicate that what follows are water retention parameters
23	6F10.0	1-10	THET	Saturated water content (units: cm ³ /cm ³)
		11-20	THTR	Residual water content (units: cm ³ /cm ³)
		21-30	AIRINT	Air entry head (units: cm)
		31-40	ALPHA	Coefficient of Haverkamp function (Haverkamp et al. 1977)
		41-50	BETA	Coefficient of Haverkamp function
		51-60	RETDPT	Retention option (1) function operates on head value (2) function operates on ln(head) value

Record No.	FORMAT	Column No.	Variable	Description
24	A66	1-66	DUMMY	Dummy title that can be used to describe the soil type and indicate that what follows are conductivity parameters
25	4F16.	1-16	AIRINK	Air entry head (units: cm)
		11-26	SK	Saturated hydraulic conductivity (units: cm/hr)
		21-36	A	Coefficient of Haverkamp function
		31-46	B	Coefficient of Haverkamp function

Enter Records 28-29 if KOPT = 3 (Brooks-Corey functions)

26	A66	1-66	DUMMY	Dummy title that can be used to describe the soil type and indicate that what follows are water retention parameters
27	4F16.6	1-16	THET	Saturated water content (units: cm ³ /cm ³)
		11-26	THTR	Residual water content (units: cm ³ /cm ³)
		21-36	AIRINT	Air entry head (units: cm)
		31-46	B	Coefficient of Brooks-Corey function (see Campbell 1974)
28	A66	1-66	DUMMY	Dummy title that can be used to describe the soil type and indicate that what follows are conductivity parameters
29	5F16.6	1-16	KMODEL	Conductivity model option: (1) Burdine (2) Mualem
		11-26	SK	Saturated hydraulic conductivity (units: cm/hr)
		21-36	AIRINK	Air entry head (units: cm)
		31-46	B	Coefficient of Brooks-Corey function (see Campbell 1974)
		41-56	EPIT	Exponent of the pore interaction term. Values of 2 and 6.5 are standard for the Burdine and Mualem models, respectively.

Enter Records 30-33 if KOPT = 4 (van Genuchten functions)

30	A66	1-66	DUMMY	Dummy title that can be used to describe the soil type and indicate that what follows are water retention parameters
31	4F16.6	1-16	THET	Saturated water content (units: cm ³ /cm ³)
		11-26	THTR	Residual water content (units: cm ³ /cm ³)
		21-36	ALPHA	Coefficient of van Genuchten function (units: 1/cm)
		31-46	VGN	The "n" exponent
32	A66	1-66	DUMMY	Dummy title that can be used to describe the soil type and indicate that what follows are conductivity parameters
33	5F16.6	1-16	KMODEL	Conductivity model options (1) Burdine (m = 1-2/n) (2) Mualem (m = 1-1/n)
		11-26	SK	Saturated hydraulic conductivity (units: cm/hr)
		21-36	ALPHA	Coefficient of van Genuchten function (units: 1/cm)
		31-46	VGN	The "n" exponent
		41-56	EPIT	Exponent of the pore interaction term. Values of 2 and 6.5 are standard for the Burdine and Mualem models, respectively.

Note: Repeat the appropriate soil property descriptions MATN times

Record No.	FORMAT	Column No.	Variable	Description
Enter Records 34-37 if IHEAT = 1				
34	A80	1-80	DUMMY	Dummy title that can be used to describe the soil type and indicate that what follows are thermal conductivity and heat capacity parameters. Coefficients for the thermal conductivity equation can be found in Cass, Campbell, and Jones (1984) Soil Sci. Soc. Amer. J. 48:25-32.
35	8F10.0	1-10	TCON(1,J)	Coefficient A in thermal conductivity Equation (4.22)
		11-20	TCON(2,J)	Coefficient B in thermal conductivity Equation (4.22)
		21-30	TCON(3,J)	Coefficient C in thermal conductivity Equation (4.22)
		31-40	TCON(4,J)	Coefficient D in thermal conductivity Equation (4.22)
		41-50	TCON(5,J)	Coefficient E in thermal conductivity Equation (4.22)
		51-80	CHS	Volumetric heat capacity of the soil particles (units: J/cm ³ K)
36	A80	1-80	DUMMY	Dummy title that can be used to describe the soil type and indicate that what follows are parameters that define the vapor flow enhancement factor. Coefficients for the enhancement factor equation can be found in Cass, Campbell, and Jones (1984) Soil Sci. Soc. Amer. J. 48:24-32.
37	8F10.0	1-10	EF(1,J)	Coefficient A in enhancement factor Equation (4.22)
		11-20	EF(2,J)	Coefficient B in enhancement factor Equation (4.22)
		21-30	EF(3,J)	Coefficient C in enhancement factor Equation (4.22)
		31-40	EF(4,J)	Coefficient D in enhancement factor Equation (4.22)
		41-50	EF(5,J)	Coefficient E in enhancement factor Equation (4.22)

Note: Repeat Records 34-37 MATN times

Note: For Record 37, set coefficient A to 1.0 and B through E to zero to achieve an enhancement factor of 1.0 (i.e., no enhancement)

3.0 INITIAL CONDITIONS

Record No.	FORMAT	Column No.	Variable	Description
38	I5	1- 5	NDAY	Day for which end-of-day head values are specified as initial conditions. For example, when NDAY = 0, the initial head values are for the end of the day before simulation day 1. NDAY = 90 would indicate that the initial head values are from the end of day 90 and will serve as initial head values for day 91
39	4F14.0	1-14	H(1)	Initial suction head. Values must be $\leq$ HDRY when IHEAT = 0 (units: cm)
		•		
		•		
		•	H(4)	

Note: Repeat Record 39 until NPT values of H have been entered

Enter Record 40 if IHEAT = 1

40	4F14.0	1-14	T(1)	Initial temperature (units: K)
		•		
		•		
		•	T(4)	

Note: Repeat Record 40 until NPT values of T have been entered

4.0 PLANT INFORMATION

Record No.	FORMAT	Column No.	Variable	Description
Enter Record 41 if IPLANT = 1. Note that the plant option is not available if IHEAT = 1				
41	8I5	1- 5	LEAF	Option for leaf area index (LAI) (0) LAI values not needed (i.e., NFPET = 2) (1) User supplies LAI values for the year (Records 42-43) (2) User supplies a subroutine (inoperative)
		8-10	NFR00T	Option for root growth (1) Exponential relationship (2) User supplies a subroutine (inoperative)
		11-15	NUPTAK	Option for plant water uptake (1) Sink term approximation proposed by Feddes, Kowalik, and Zaradny (1978). Requires entry of HW, HD, and HN values (Record 46) (2) User supplies a subroutine (inoperative)
		16-20	NFPET	Option for partitioning PET into transpiration (PT) and evaporation (PE) components (1) User supplies daily PET values and program partitions it into PT and PE based on LAI and equation by Ritchie and Burnett (1971) (2) User supplies daily PET values and program partitions it into PT and PE based on the cheatgrass data of Hinds (1975)
		21-25	NSOW	(When NFPET=2) Day of the year on which seeds germinate. Must be less than day 91 or greater than day 273.
		26-30	NHRYST	(When NFPET=2) Day of the year on which plants cease transpiring. Must be between days 151 and 243.
Enter Records 42 and 43 if LEAF = 1				
42	I5,F5.0	1- 5	NPOINT	Number of changes in the LAI relationship when LEAF = 1
		6-10	BARE	Fraction of soil surface that is bare of plants
43	5(I5, F5.0)	1- 5	NGROW(1)	Day of the year on which the LAI is changed to the corresponding FLAI value
		6-10	FLAI(1)	Leaf area index on the corresponding NGROW day
		.	.	.
		41-45	NGROW(5)	
		46-50	FLAI(5)	
Note: Repeat Record 43 until NPOINT pairs of NGROW, FLAI values have been entered				
Enter Records 44-45 if NFR00T = 1				
44	3F10.0	1-10	AA	Coefficient a in the root growth equation (Equation 4.24)
		11-20	B1	Coefficient b in the root growth equation (Equation 4.24)
		21-30	B2	Coefficient c in the root growth equation (Equation 4.24)
45	10I5	1- 5	NTR00T(1)	Growth day on which roots reach the corresponding node
		.	.	.
		46-50	NTR00T(10)	
Note: Repeat Record 45 until NPT values of NTR00T have been entered				

Record No.	FORMAT	Column No.	Variable	Description
Enter Record 46 if NUPTAK = 1				
46	3F10.0	1-10	HW	Head corresponding to water content below which plants wilt and stop transpiring. HW must be less than HDRY. (units: cm)
		11-20	HD	Head corresponding to water content below which plant transpiration starts to decrease (units: cm)
		21-30	HN	Head corresponding to water content above which plants do not transpire because of anaerobic conditions (units: cm)
Repeat Record 46 MATN times.				
Enter Record 47 if NFPET = 2				
47	2F10.0	1-10	BIOMAS	Plant shoot biomass scaling factor used in adjusting the transpiration component of PET. The base value is 220 g/m ² . A lower value will result in lower transpiration and higher evaporation, while a higher value will result in higher transpiration and lower evaporation (units: g/m ²)
		11-20	BARE	Fraction of soil surface that is bare of plants

5.0 BOUNDARY CONDITIONS

Record No.	FORMAT	Column No.	Variable	Description
Enter Record 48 if NFHOUR = 1				
48	8F7.0	1- 8	FPET(1)	Hourly PET distribution factors. The 24 FPET factors should sum to 1.0
		•		
		•		
		•		
		50-57	FPET(8)	
Note: Repeat Record 48 until 24 FPET values have been added				
Enter Record 49 if ET_DPT = 0				
49	8F7.0	1- 8	PET(1)	Potential evapotranspiration (units: cm/day)
		•		
		•		
		•		
		50-58	PET(8)	
Note: Repeat Record 49 until NDAYS values of PET have been entered				
Enter Record 50 if ET_DPT = 1 and IHEAT = 0				
50	8F10.0	1-10	ALBEDO	Soil surface albedo
		11-20	ALT	Altitude of the site being simulated (units: ft)
		21-30	ZU	Height of the wind speed measurement (units: ft)
		31-40	PMB	Average annual atmospheric pressure (units: mb)
Enter Record 51 if ET_DPT = 1 and IHEAT = 1				
51	8F10.0	1-10	ZH	Roughness length for heat transfer (units: m)
		11-20	ZM	Roughness length for momentum transfer (units: m)
		21-30	ZT	Height of air temperature measurement (units: m)
		31-40	ZU	Height of wind speed measurement (units: m)
		41-50	D	Zero plane displacement height (units: m)
		51-60	LAT	Latitude of the site being simulated (units: degrees)
Enter Record 52 if ET_DPT = 1				
52	8F5.0	1- 5	METDAT(1,J)	Day of the year for which the following data apply
		6-10	METDAT(2,J)	Maximum air temperature (units: °F)
		11-15	METDAT(3,J)	Minimum air temperature (units: °F)
		16-20	METDAT(4,J)	Dew point temperature (units: °F)
		21-25	METDAT(5,J)	Solar radiation (units: langley)
		26-30	METDAT(6,J)	Average wind speed (units: miles/hr)
		31-35	METDAT(7,J)	Average cloud cover (units: tenths)
		36-40	METDAT(8,J)	Precipitation (units: inches)
Note: Repeat Record 52 NDAYS times				

Record No.	FORMAT	Column No.	Variable	Description
Enter Records 53-54 if LOWER = 3				
53	I5	1- 5	NTLEAK	Number of times the flux lower boundary condition changes during the simulation period (limit is 50). Note that for days between flux changes, the bottom flux will be interpolated
54	5(I5, F5.0)	1- 5	NQLEAK(1)	Day on which the bottom boundary flux is changed to the corresponding QLEAK value. Note that a QLEAK value must be specified for the first and last days of the simulation.
		6-10	QLEAK(1)	Bottom boundary flux on the corresponding NQLEAK day (units: cm/day)
		.		
		.		
		.		
		41-45	NQLEAK(5)	
		46-50	QLEAK(5)	

Note: Repeat Record 54 until NTLEAK pairs of data have been entered

Enter Records 55-57 if IRAIN = 0

55	I5	1- 5	NWATER	Total number of days during which there is water application
56	3I5,F6.0	1- 5	IRDAY	Day on which a water application event occurs
		6-10	IRTYPE	Option for type of water application (1) rainfall (2) irrigation (3) constant ponding depth less than 1 day (4) constant ponding depth greater than 1 day
		11-15	NP	Number of times during the day that the water application rate changes
		16-20	EFICEN	Efficiency of the irrigation scheme (i.e., how much of the water actually gets onto the soil surface)
57	F7.0, F8.0)	1- 7	RTIME(1)	Time of day when the water application rate changes (use whole hours only) (units: hr). The exception is when IRTYPE = 4, and then the units are days. If IRTYPE = 4 and RTIME(NP) = 0, ponding is continued for the remainder of the simulation (until DAYEND)
		8-15	AMOUNT(1)	When IRTYPE = 1 or 2, AMOUNT is the rainfall/irrigation amount that falls until the next rate change, [RTIME(I+1)]; when IRTYPE = 3 or 4, AMOUNT is the depth of water ponded on the surface (units: cm)

Note: Repeat Record 57 NP times

Note: Repeat the sequence of Records 56 and 57 NWATER times

APPENDIX C

GLOSSARY OF TERMS

APPENDIX C

GLOSSARY OF TERMS

The following glossary defines the symbols used in the document and the major terms used within the various programs and subroutines of the UNSAT-H code. The glossary has been divided into sections defining symbols, variables, arrays, parameter constants, and functions and subroutines. In some cases, variables are input with one set of units and changed by the code to another set of units. For variables of this type, the units of the changed variables are reported. All units are abbreviated as follows:

cm	centimeter
d	day
g	gram
hr	hour
J	joule
K	Kelvin
km	kilometer
m	meter
mb	millibar
mm	millimeter
s	second

C.1 Equation Symbols

<u>Symbol</u>	<u>Description</u>	<u>Units</u>
A	Coefficient of Haverkamp retention function	cm
A(0)	Amplitude of surface temperature,	K
B	Coefficient of Haverkamp retention function	--
C	Specific moisture capacity	-cm ⁻¹
C _h	Volumetric heat capacity of moist soil	J cm ⁻³ K ⁻¹
C _{ha}	Volumetric heat capacity of air	J m ⁻³ K ⁻¹
C _{hs}	Volumetric heat capacity of soil	J cm ⁻³ K ⁻¹

Symbol	Description	Units
C_{hv}	Volumetric heat capacity of water vapor	$J\ cm^{-3}\ K^{-1}$
C_{hw}	Volumetric heat capacity of water	$J\ cm^{-3}\ K^{-1}$
D	Damping depth	cm
	Drainage	cm
	Vapor diffusivity in soil	$cm^2\ hr^{-1}$
D_a	Diffusivity of water vapor in bulk air	$cm^2\ s^{-1}$
E	Evaporation	cm
G	Surface heat flux density	$J\ s^{-1}\ m^{-2}$
H	Hydraulic head	cm
	Sensible heat flux density	$J\ s^{-1}\ m^{-2}$
HBE	Heat balance error	J/cm^2
J	Day of the year	--
K_L	Liquid conductivity	$cm\ hr^{-1}$
K_S	Saturated hydraulic conductivity	$cm\ hr^{-1}$
K_T	Sum of liquid and isothermal vapor conductivity	$cm\ hr^{-1}$
K_{vh}	Isothermal vapor conductivity	$cm\ hr^{-1}$
K_{vT}	Thermal vapor conductivity	$cm\ hr^{-1}$
LAI	Leaf area index	--
LE	Latent heat flux density	$J\ s^{-1}\ m^{-2}$
L_o	Volumetric latent heat of vaporization of water	$J\ cm^{-3}$
M	Molecular weight of water	$g\ mole^{-1}$
P	Precipitation	cm
PE	Potential evaporation rate	$cm\ hr^{-1}$
PET	Potential evapotranspiration rate	$cm\ hr^{-1}$
PT	Potential transpiration rate	$cm\ hr^{-1}$

Symbol	Description	Units
Q_0	Potential daily solar radiation	$\text{MJ d}^{-1} \text{ m}^{-2}$
R	Gas constant	$\text{erg mole}^{-1} \text{ K}^{-1}$
RDF	Root density function	cm^{-1}
RH	Relative humidity	--
RLD	Root length density	--
R_n	Net radiation	$\text{J s}^{-1} \text{ m}^{-2}$
R_{ni}	Isothermal net radiation	mm d^{-1}
S	Sink term for water withdrawal by plants	hr^{-1}
S_{ext}	Solar constant	$\text{J s}^{-1} \text{ m}^{-2}$
S_h	Heat storage in the soil	J cm^{-3}
S_{pot}	Potential sink term for water withdrawal by plants	hr^{-1}
S_t	Short-wave radiation	$\text{J s}^{-1} \text{ m}^{-2}$
S_w	Water storage in the soil	cm
T	Temperature	K
	Transpiration	cm
$\bar{T}$	Mean surface temperature	K
T_a	Air temperature	K
T_{amp}	Air temperature amplitude	K
T_{mean}	Average of maximum and minimum air temperatures	K
T_o	Reference temperature	K
T_s	Soil surface temperature	K
T_t	Transmission coefficient, i.e., the ratio of measured to potential solar radiation	--
U	24-hr wind run	km d^{-1}
U^*	Friction velocity	m s^{-1}

Symbol	Description	Units
Z	Gravitational head	cm
a	Coefficient of hydraulic property polynomial	--
b	Coefficient of hydraulic property polynomial	--
	Coefficient of Brooks-Corey retention function	--
c	Coefficient of hydraulic property polynomial	--
	Fractional cloud cover	--
d	Zero plane displacement	m
	Coefficient of hydraulic property polynomial	--
e	Coefficient of hydraulic property polynomial	--
	Evaporation flux density	cm hr ⁻¹
	Solar elevation angle (solar altitude)	radian
e _a	Saturation vapor pressure at the mean air temperature	mb
e _d	Actual vapor pressure	mb
g	Gravitational constant	cm s ⁻²
h	Suction head	cm
h _e	Air-entry suction head	cm
h _s	Hour angle	radians
i	Subscript denoting the node number	--
j	Superscript denoting the time for which a solution will be obtained	--
k	von Karman's constant	--
k _h	Thermal conductivity of soil	J cm ⁻¹ hr ⁻¹ K ⁻¹
ℓ	Exponent of the pore interaction term in the Burdine and Mualem conductivity models	--
m	Coefficient of van Genuchten retention function	--
n	Coefficient of van Genuchten retention function	--

Symbol	Description	Units
q_h	Heat flux density	$\text{J cm}^{-2} \text{ hr}^{-1}$
q_l	Flux density of water	cm hr^{-1}
q_v	Flux density of water vapor	cm hr^{-1}
q_{vh}	Isothermal vapor flux density	cm hr^{-1}
q_{vT}	Thermal vapor flux density	cm hr^{-1}
r_h	Boundary layer resistance to heat transfer	s m^{-1}
r_v	Boundary layer resistance to vapor transport	s m^{-1}
s	Slope of the saturation vapor pressure-temperature curve	mb K^{-1}
t	Time	hr
t_d	Time of day	hr
t_o	Solar noon	--
u	Wind speed	m s^{-1}
z	Depth below the soil surface	cm
z_h	Roughness height for sensible heat transport	m
z_m	Roughness height for momentum transfer	m
z_T	Height of air temperature measurement	m
z^u	Height of wind speed measurement	m
α	Coefficient of Haverkamp retention function	cm^{-1}
	Coefficient of Van Genuchten retention function	cm^{-1}
	Tortuosity factor	--
α_f	Factor relating the transpiration rate to the water status in the root zone	--
α_s	Surface albedo	--
β	Coefficient of Haverkamp retention function	--
γ	Psychrometric constant	mb K^{-1}

Symbol	Description	Units
ϵ_a	Atmospheric emissivity	--
ϵ_s	Soil emissivity	--
ϵ_{ac}	Atmospheric emissivity on cloudy days	--
Δ	Change in the associated parameter over an interval of time	--
δ	Solar declination angle	radian
η	Enhancement factor for water vapor transport	
θ	Volumetric water content	$\text{cm}^3 \text{ cm}^{-3}$
θ_1	Water content at the soil surface	$\text{cm}^3 \text{ cm}^{-3}$
θ_d	Water content below which plant transpiration is less than the potential rate	$\text{cm}^3 \text{ cm}^{-3}$
θ_n	Water content above which anaerobic conditions prevail and plants cease transpiration	$\text{cm}^3 \text{ cm}^{-3}$
θ_r	Residual water content	$\text{cm}^3 \text{ cm}^{-3}$
θ_s	Saturated water content	$\text{cm}^3 \text{ cm}^{-3}$
θ_v	Volumetric vapor content expressed as an equivalent water content	$\text{cm}^3 \text{ cm}^{-3}$
θ_w	Water content below which plants cease transpiration	$\text{cm}^3 \text{ cm}^{-3}$
ξ	Stability parameter	m
π	Pi	--
ρ_v	Vapor density	g cm^{-3}
ρ_{va}	Atmospheric vapor density	kg m^{-3}
ρ_{vs}	Saturated vapor density	g cm^{-3}
ρ_{vss}	Vapor density at soil surface	kg m^{-3}
ρ_w	Density of liquid water	g cm^{-3}
σ	Stephan-Boltzmann constant	$\text{J s}^{-1} \text{ m}^{-2} \text{ K}^{-4}$
ϕ	Latitude	degrees

Symbol	Description	Units
ψ	Matric head	cm
ψ_h	Atmospheric stability correction factor for sensible heat transport	--
ψ_m	Atmospheric stability correction factor for momentum transfer	--
ω	Angular frequency of the temperature oscillation	hr ⁻¹

C.2 Variables

Variable	Description	Units
A	Coefficient in Haverkamp conductivity function	--
AA	Coefficient in the exponential root growth equation	--
AIRCON	Air-filled porosity used in vapor flow calculations	--
ALBEDO	Soil surface albedo	--
ALPHA	Coefficient in Haverkamp water retention function	--
ALPHAF	Sink reduction factor, based on the water content of each node	--
ALT	Altitude of the site being simulated	m
APLIED	Cumulative total of rainfall/irrigation amounts as they are input	--
AVC	Average specific moisture capacity over a time step	1/cm
AVCH	Average heat capacity during a time step	J/cm ³ /K
AVETHE	Average water content during a time step	cm ³ /cm ³
B	Coefficient in Brooks-Corey functions and Haverkamp conductivity function	--
BARE	Fraction of soil surface that is bare of plants	--
BETA	Coefficient in Haverkamp water retention function	--
BIOMAS	Plant-shoot biomass scaling factor used in adjusting transpiration	g/m ²
B1	Coefficient in the exponential root growth equation	--
B2	Coefficient in the exponential root growth equation	--
CHA	Volumetric specific heat of air	J/m ³ /K
CHV	Volumetric specific heat of water vapor	J/cm ³ /K
CHW	Volumetric specific heat of water	J/cm ³ /K
CLOUD	Fractional cloud cover	--
COSDEC	Cosine of the solar declination, DEC	--
COSLAT	Cosine of the latitude, LAT, of the site being simulated	--

Variable	Description	Units
D	Zero plane displacement height	m
DAYAST	Cumulative total of attempted time steps for a given day	--
DAYBEG	Beginning simulation day	--
DAYE	Cumulative total of evaporation for a given day	cm
DAYEND	Ending simulation day	--
DAYHBE	Cumulative total of heat balance error for a given day	J/cm ²
DAYINF	Cumulative total of infiltration for a given day	cm
DAYIRR	Cumulative total of irrigation for a given day	cm
DAYLE	Cumulative total of latent heat for a given day	J/m ²
DAYPE	Cumulative total of potential evaporation for a given day	cm
DAYPT	Cumulative total of potential transpiration for a given day	cm
DAYRAN	Cumulative total of rain for a given day	cm
DAYRN	Cumulative total of net radiation for a given day	J/m ²
DAYRUN	Cumulative total of runoff for a given day	cm
DAYSEN	Cumulative total of sensible heat for a given day	J/m ²
DAYSEXT	Total solar radiation received in one day outside of the earth's atmosphere	J/m ² /d
DAYSHF	Cumulative total of surface heat flow for a given day	J/m ²
DAYSTP	Cumulative total of time steps during a given day	--
DAYTIM	Cumulative total of hours successfully simulated in a particular day	hr
DAYTRA	Cumulative total of transpiration for a given day	cm
DAYUBC	Cumulative total of time steps repeated during a day because the upper boundary for water flow changed from a flux to a constant head	--
DEC	Solar declination	radian
DEL	A shortened version of 1/DELSAV for use in calculating the coefficients for the solver (in the predictor-corrector loop)	1/hr
DELMAX	Maximum time step (normally 1 h)	hr
DELMIN	Minimum allowable time step	hr
DELSAV	The size of the time step for the current predictor-corrector loop	hr
DELSUB	Length of a time subdivision of a day, normally equal to DELMAX	hr
DELT	The projected time step	hr
DHFACT	Time step reduction factor when DHMAX is positive	--
DHMAX	If positive, DHMAX is the maximum allowable change in head per iteration for any node. If exceeded, the time step size is reduced by the factor DHFACT and the time step resolved.	--
DIFMAX	If ISWDIF = 0, maximum observed fractional change in THETA for any node.	cm ³ /cm ³
	If ISWDIF = 1, mass balance error that is calculated at the end of each successful time step	cm

Variable	Description	Units
DMAXBA	Time-step control parameter. If ISWDIF = 0, DMAXBA is the maximum allowable fractional change in the water content of any node. If ISWDIF = 1, DMAXBA is the maximum allowable difference between predicted and calculated soil water storage values	cm ³ /cm ³
DOWN	Downstream weighting factor for estimating conductivity at the midpoint between nodes; DOWN = 1.0 - UP	cm
DRYC	Limit of specific moisture capacity when H is set to HDRY	--
DRYK	Limit of conductivity when H is set to HDRY	-1/cm
DRYTH	Limit of water content when H is set to HDRY	cm/hr
DSVDDT	Slope of the saturated vapor density curve	cm ³ /cm ³
DV	Version number of OATAINH	g/cm ³ /K
EFICEN	Efficiency of irrigation (i.e., fraction of applied water that reaches the soil surface)	--
EMISS_A	Emissivity of the atmosphere	--
EMISS_S	Emissivity of the soil surface	--
ET_OPT	Option for daily meteorologic data (0) no meteorologic data (use potential evapotranspiration data) (1) daily meteorologic data	--
FINISH	Logical variable; when true, FINISH stops the simulation	--
FZZ1	Part of solution matrix	--
FZZ2	Part of solution matrix	--
G	Option to orient the soil profile (0) horizontally (1) vertically	--
GRAV	Gravity constant	m/s ²
HD	Head corresponding to water content below which plant transpiration starts to decrease below the potential	cm
HDRY	Maximum head to which the soil can dry out	cm
HEATBAL	Heat balance error for a given time step	J/cm ²
HHPOND	Initial ponding height when IRTYPE = 3 or 4	cm
HIRRI	Minimum head that can occur during rain or irrigation; a negative number indicates a positive pressure	cm
HN	Head corresponding to water content above which plants do not transpire because of anaerobic conditions	cm
HOURL	Cumulative total of time simulated during the day	hr
HPOND	Current ponding height when IRTYPE = 3 or 4	cm

Variable	Description	Units
HS	Angular distance from the meridian of the site being simulated	radian
HSTORE	Change in heat storage in the soil profile over a given time step	J/cm ²
HTIME	Time of day corresponding to the midpoint of a given time step	hr
HTMP	Temporary storage location for head values during extrapolation of head values for property estimation	cm
HTOP	Head value of the surface node when ITOPBC = 1 for a constant head boundary condition	cm
HW	Head corresponding to water content below which plants wilt and stop transpiring	cm
I	Integer index	--
ICLOUD	Option to use cloud cover data (applicable when IHEAT = 1 and UPPERH = 0) (0) cloud cover calculated from measured and potential solar radiation (1) cloud cover data are used	-- --
ICONVH	Option to allow convective flow of heat via water flow (0) no convective transport (1) convective transport	-- --
ID	Index identifying a soil property polynomial in POLYCH, POLYKH, and POLYTH	--
IDAY	Day number	--
IDAYLS	Flag that indicates the last day that a detailed print was generated when DELT became less than DELMIN. Occurs in the time-step control loops. Allows only 1 print per day, then is reset to IDAY	--
IERROR	Sum of nodes for which the capacity was calculated in POLYCH as negative. If greater than zero, the program stops	--
IFILE	Name of the input file (with *.BIN extension)	--
IG0140	Flag in the convergence loop; if set equal to 1, the surface head has exceeded the prescribed limits, been reset to the limiting value, and the time step is re-solved with a held-head condition at the boundary	--
IG0150	Flag in the convergence loop; a value of 1 indicates a time step must be repeated with a smaller size because of either a head change that exceeded DHMAX or a water-balance problem	--
IHEAT	Option to simulate heat flow (0) no heat flow (1) heat flow	-- --

Variable	Description	Units
IHPOND	Flag indicating that there will be ponding during that particular day	--
II	Integer index	--
III	Integer index	--
IN	Iteration number within the UNSATH convergence loop	--
INC	Potential number of coefficients for completely describing any one soil hydraulic property, found in POLYCH, POLYKH, and POLYTH	--
INH	Iteration number within the HEATFLOW convergence loop	--
INMAX	Number of iterations allowed per time step to solve the water flow equations	--
INHMAX	Number of iterations allowed per time step to solve the heat flow equations	--
IP	Index of soil property coefficients, found in POLYCH, POLYKH, and POLYTH	--
IPLANT	Option to include plants (0) no plants (1) plants	-- --
IR	Index number of each rainfall event during a given day	--
IRAIN	Flag indicating water application in the form of rain on day IRDAY=IDAY	--
IRDAY	Day on which a rain/irrigation event occurs	--
IREC	Record counter for control of binary output	--
IRL	Binary record length that depends on the number of nodes	--
IRRI	Flag indicating water application in the form of irrigation or ponding on day IRDAY=IDAY	--
IRTYPE	Option for water application (1) rain (2) irrigation (3) constant ponding depth less than 1 day (4) constant ponding depth greater than 1 day	-- -- -- --
ISATUK	Flag (normally 0) that is set to (1) to initiate a saturated surface condition at the start of a water application event and (2) once the event has been initiated	--
ISAVUP	Saves the UPPER switch so it can be reset correctly if it is changed during the convergence loop	--
ISTART	Array index passed to subroutine TRIDAG (1) flux surface boundary condition (2) constant head surface boundary condition	-- --
ISWDIF	Option for time-step control (0) maximum percent change in THETA (1) mass balance	-- --

Variable	Description	Units
ITOPBC	Option for the surface boundary condition (0) flux (1) constant head, for which the program will require a value for HTOP, the head at the surface	-- --
ITPOND	Index of the next time for changing the ponding depth; used when IRTYPE=4	--
IVAPOR	Option to include isothermal vapor flow; requires values for TORT, VAPDIF, and TSOIL	--
IYEAR	Index of year being simulated	--
J	Integer index	--
KEST	Options for estimating the conductivity between nodes (1) arithmetic mean (2) upstream weighting of arithmetic mean (3) geometric mean	-- -- --
KOPT	Options available to describe soil hydraulic properties (1) polynomials (2) Haverkamp functions (3) Brooks-Corey functions (4) Haverkamp functions except that head in the water retention function is replaced by $\ln(\text{head})$ (5) van Genuchten functions	-- -- -- -- --
LAT	Latitude of the site being simulated	degree
LE	Latent heat flux	J/m ² /s
LEAF	Option for entering leaf area index (LAI) (if IPLANT = 1) (1) User supplies LAI values for the year (2) User supplies a subroutine	-- --
LHVO	Latent heat of vaporization at 273.16K	J/cm ³
LOG10E	Shortened version of $\log(\exp(1))$; used in POLYCH	--
LOWER	Options to describe the lower boundary condition for water flow (1) semi-infinite profile with a unit gradient (2) constant head (e.g., static water table if initial head specified as zero) (3) specified daily bottom flux (4) impermeable boundary	-- -- -- --
LOWERH	Options to describe the lower boundary condition for heat flow (1) temperature gradient (see TGRAD) (2) constant temperature (3) constant heat flux (see QHLEAK)	-- -- --
MATI	Short version of MAT(I)	--

Variable	Description	Units
MATN	Number of different soil materials	--
MAXPOL	Maximum degree of soil property polynomials + 1	--
MAXSUB	Maximum number of subdivisions of any given soil property description. In other words, the maximum number of polynomials needed to completely describe the soil property	--
MDEPTH	Node to which roots have penetrated on a given day	--
METDAY	Day of the year for which the current meteorological data apply	--
MGR	Lumped parameter; molar weight of water times the gravity constant, divided by the universal gas constant	K/cm
MXROOT	Deepest node to which roots will penetrate during the year	--
N	Index of present DELSUB period	--
NCHR	Index of the '.' character position in a file name	--
NDAY	Day for which end-of-day head values are specified as initial conditions	--
NDAYS	Total number of days of available data	--
NEWPON	Time (ITPOND) when the present ponding height should be changed	hr
NFHOUR	Option for distributing the daily potential evapotranspiration (PET) value over the course of the day (1) User supplies 24 hourly values that must sum to 1.0 (2) 24 hourly values are generated, using a sine wave function for the hours 0600 to 1800 and assuming the factors during the remaining hours are 0.01; all factors must sum to 1.0	--
NFPET	Option for defining PET (1) User supplies daily PET values and DATAINH partitions it into PE and PT based on LAI and equation by Ritchie and Burnett (1971) (2) User supplies daily PET values and DATAINH partitions it into PE and PT based on the cheatgrass data of Hinds (1975)	--
NFROOT	Option for defining root growth (1) Exponential relationship (2) User supplies a subroutine	--
NGRAV	Orientation of the profile (0) horizontal (1) vertical	--
NGROW	Growth day, starting from NSOW	day
NHR	Integer indicating the hour of the day	--
NHRVST	Day of the year on which plants cease transpiring	--

Variable	Description	Units
NP	Total number of changes in water-application rate on a given day	--
NPOINT	Number of changes in the LAI relationship when LEAF = 1	--
NPPT	NPT-1	--
NPRINT	Option for level of output (0) daily summaries with end-of-simulation summary (1) DELSUB and daily summaries with end-of-simulation summary; limited to 15 days total because of size of output file	--
NPT	Number of nodes	--
NSINK	Flag indicating whether plants are transpiring during the present time step (0) no transpiration (1) transpiration	--
NSOW	Day of the year on which seeds germinate	--
NSTOP	Output control	--
NSURPE	Option for surface evaporation (0) no evaporation (1) evaporation	--
NTLEAK	Number of times the lower boundary flux condition changes during the simulation period (if LOWER = 3)	--
NTOTAL	Number of time subdivisions in a day. Normally equals 24, but can be more if DELMAX < 1	--
NUPTAK	Option for plant water uptake (1) Sink term approximation proposed by Feddes, Kowalik, and Zaradany (1978); requires HW, HD, and HN (2) User supplies a subroutine	--
NWATER	Total number of days on which rainfall or irrigation occurs	--
NYEARS	Number of years that the simulation will be repeated	--
OFIL	Output file name	--
OLDRAT	Precipitation rate during the previous hour	cm/hr
OUTTIM	Determines the size of the DELSUB period; if NPRINT = 1, OUTTIM is also the time interval for generating output	--
PE	Potential evaporation for the day, equivalent to PEVAPO(IDAY)	cm/day
PESUB	Hourly potential evaporation rate	cm/hr
PET	Daily potential evapotranspiration, the sum of PEVAPO and PTRANS	cm
PI	The constant pi	--
PIRRI	Irrigation rate	cm/hr
PMB	Average annual atmospheric pressure	mb

Variable	Description	Units
PRAIN	Rainfall rate	cm/hr
PSIH	Atmospheric stability correction factor for heat transport	--
PSIM	Atmospheric stability correction factor for momentum transport	--
PT	Potential transpiration for the day, equivalent to PTRANS(IDAY)	cm/day
PTSUB	Hourly potential transpiration rate	cm/hr
QLAST	Liquid flux at the bottom boundary	cm/hr
QHLAST	Heat flux at the bottom boundary	J/cm ² /hr
QHLEAK	Specified heat flux at the bottom boundary when LOWERH = 3	J/cm ² /hr
QHTOP	Specified heat flux when UPPERH = 3	W/m ²
QVH	Vapor flux in response to a suction head gradient	cm/hr
QVT	Vapor flux in response to a temperature gradient	cm/hr
R	Ratio of DMAXBA to DIFMAX; calculated in DELCHK and used to adjust the time step	--
RAINIF	Factor used to shorten the time step at the start of a rain or irrigation event	--
RELHUM	Relative humidity within the soil	%
RFACT	Maximum factor by which the time step can increase following a successful time step	--
RH	Resistance of the atmospheric boundary layer to heat and vapor transport	s/m
RHMEAN	Mean relative humidity of the atmosphere	%
RN	Net radiation flux	J/m ² /s
ROOTS	Total length of roots in the profile	--
RSAVE	Last value of R that was greater than 1	--
RUNOFF	Runoff during a time step	cm
SATC	Negative of the specific water capacity corresponding to a head of HIRRI	-- 1/cm
SATK	Hydraulic conductivity corresponding to a head of HIRRI	cm/hr
SATTH	Water content corresponding to a head of HIRRI	cm ³ /cm ³
SB	Stephan-Boltzmann constant	J/m ² /s/K ⁴
SDATE	Character variable that contains the date the simulation was started	--
SENFLX	Sensible heat flux	J/m ² /s
SEXT	Solar radiation flux at the outer edge of the earth's atmosphere	J/m ² /s
SFLUX	Potential surface flux during a time step, either infiltration or evaporation	cm/hr
SFLUXX	Component of SFLUX that is associated with the linear portion of the H(1) term; used to modify SFLUX in the coefficient matrix when IHEAT = 1 and UPPERH = 0	--
SHFLUX	Heat flux at the soil surface	J/m ² /s

Variable	Description	Units
SH_OPT	Option for specifying HDRY (0) constant throughout the simulation (1) calculated daily based on atmospheric humidity and TSOIL	-- --
SINDEC	Sine of the solar declination, DEC	--
SINLAT	Sine of the latitude, LAT	--
SMOIST	Profile water storage at the end of a time step and before a mass balance check is made	--
SPREV	Water storage in the profile at the beginning of the current DELSUB period	cm
SR	Solar radiation flux at the soil surface	J/m ² /s
SR_FRAC	Ratio of measured to potential solar radiation at the soil surface	--
SR_MEAS	Measured daily solar radiation at the soil surface	J/m ² /d
SR_POT	Potential daily solar radiation at the soil surface	J/m ² /d
SSFLUX	Actual surface flux	cm
START	Logical variable; if true, certain arrays are initialized	--
STIME	Character variable that contains the time the simulation was started	--
STOPHR	Time of day for the simulation to stop when IDAY = ODAYEND and NPRINT = 1	hr
STORE	Initial soil water-storage value	cm
SUBAST	Cumulative total of attempted time steps during a DELSUB period	--
SUBE	Cumulative total of evaporation during a DELSUB period	cm
SUBHBE	Cumulative total of heat balance error during a DELSUB period	J/cm ²
SUBINF	Cumulative total of infiltration during a DELSUB period	cm
SUBIRR	Cumulative total of irrigation during a DELSUB period	cm
SUBLE	Cumulative total of latent heat during a DELSUB period	J/m ²
SUBRN	Cumulative total of net radiation during a DELSUB period	J/m ²
SUBRAN	Cumulative total of precipitation during a DELSUB period	cm
SUBRUN	Cumulative total of runoff during a DELSUB period	cm
SUBSEN	Cumulative total of sensible heat during a DELSUB period	J/m ²
SUBSHF	Cumulative total of surface heat during a DELSUB period	J/m ²
SUBSTP	Cumulative total of time steps during a DELSUB period	
SUBTIM	Cumulative total of actual simulated time	hr

Variable	Description	Units
SUBTRA	Cumulative total of transpiration during a DELSUB period	cm
SUBUBC	Cumulative total of time steps repeated during a DELSUB period because the upper boundary for water flow changed from a flux to a constant head	--
SVD	Saturated vapor density of soil	g/cm ³
SVD_S	Saturated vapor density of the soil surface	g/cm ³
TA	Air temperature	K
TANDEC	Tangent of the solar declination, DEC	--
TANLAT	Tangent of the latitude of the site being simulated	--
TAST	Cumulative total of attempted time steps during the simulation	--
TDEW	Dew point temperature	K
TDONE	Time that has been simulated in a day	hr
TE	Cumulative total of evaporation during the simulation	cm
TEND	Ending time of the current water-application rate	hr
TERR	Mass-balance error at the end of the simulation	cm
TETRA	Cumulative total of evaporation during the simulation on days when transpiration occurs	cm
TGRAD	Surface temperature gradient	K/cm
THBE	Cumulative total of heat balance error	J/cm ²
THDIF	Fractional change in THETA at a given node for a time step; used to control the time step	--
THTR	Residual water content, used in Haverkamp water retention function (Haverkamp et al. 1977)	cm ³ /cm ³
TINF	Cumulative total of yearly infiltration	cm
TITLE	Character variable containing the problem title from the input file	--
TLE	Cumulative total of latent heat during the simulation	J/m ²
TLEFT	Time left until the end of the next time period or flow-rate change	hr
TMAX	Maximum daily air temperature	K
TMAXLAST	Maximum air temperature for the previous day	K
TMEAN	Mean daily air temperature	K
TMEANE	Mean of TMAXLAST and TMIN; used to interpolate air temperature between 0000 h and 0200 h of the current day	K
TMEANL	Mean of TMAX and TMINNEXT; used to interpolate air temperature between 1500 h and 2400 h of the current day	K
TMIN	Minimum daily air temperature	K
TMINNEXT	Minimum air temperature for the next day	K

Variable	Description	Units
TMOIST	Water storage in the profile at the end of a successful time step and the end of the day; referred to as STORAGE in the output	cm
TORT	Pore tortuosity; used when IVAPOR = 1	--
TOTALR	Total amount of water applied (as it is input) for the day	cm
TPE	Cumulative total of yearly potential evaporation during non-infiltration periods	cm
TPET	Cumulative total of daily PET values	cm
TPIY	Combination of $2\pi/365$; used in calculating DEC	
TPREV	Water storage in the profile of the previous day; referred to as PRESTOR in the output	cm
TPT	Cumulative total of potential transpiration during non-infiltration periods	cm
TRAIN	Cumulative total of daily precipitation as applied to the surface	cm
TRANSP	Transpiration rate	cm/hr
TRN	Cumulative total of daily net radiation	J/m ²
TRUNOF	Cumulative total of daily runoff amounts	cm
TS	Soil surface temperature; same as T(1)	K
TSAMP	Amplitude of soil surface temperature variation when UPPERH = 1	K
TSEN	Cumulative total of daily net radiation during the simulation	J/m ²
TSHF	Cumulative total of daily net radiation during the simulation	J/m ²
TSMEAN	Mean soil surface temperature when UPPERH = 1	K
TSOIL	Average soil temperature when IHEAT = 0	K
TSTART	Starting time of the first rainfall/irrigation event for that day	hr
TSTOP	Stopping time of the last rainfall/irrigation event for that day	hr
TSTP	Cumulative total of time steps since the beginning of the simulation, obtained by summing NTSTEP values at the end of each day	--
TSUB	Cumulative total of time completed in a given DELSUB loop	hr
TTIM	Cumulative total of actual time simulated	hr
TTIRRI	Cumulative total of daily irrigation as applied to the surface	cm
TTRA	Cumulative total of daily transpiration	cm
TUBC	Cumulative total of time steps repeated during a simulation because the upper boundary for water flow changed from a flux to a constant head	--
TO	Reference temperature for heat flow calculations	K
UP	Upstream weighting factor for estimating the conductivity at nodal midpoints, used when KEST = 2	--

Variable	Description	Units
UPPER	Flag that indicates the surface boundary condition for water flow; it can change while in the predictor-corrector loop (0) flux (1) constant head	-- --
UPPERH	Flag that indicates the surface boundary condition for heat flow (0) flux (1) constant temperature (2) variable temperature (see TSMEAN and TAMP) (3) specified heat flux (see QHTOP)	-- -- -- --
UV	Version number of UNSATH	--
VC	Combination of variables used in vapor flow calculations	cm/hr
VAPDEN	Saturated vapor density at the soil temperature TSOIL	g/cm ³
VAPDIF	Diffusion coefficient of water vapor in air	cm ² /s
VD_A	Vapor density of the atmosphere	g/cm ³
VD_S	Vapor density of the soil surface	g/cm ³
VGM	Coefficient in the van Genuchten water retention function	--
VGN	Coefficient in the van Genuchten water retention function	--
VK	von Karmen's constant	--
WATDEN	Density of water at the soil temperature TSOIL	g/cm ³
WCOMPR	Compressibility of water, found in POLYCH	1/cm
WIND	Wind speed	m/s
WINDEX	Index of water-application day	--
WTF	Factor for upstream weighting of conductivities	--
ZH	Roughness length for heat transfer	m
ZM	Roughness length for heat transfer	m
ZT	Height of air temperature measurement	m
ZU	Height of wind speed measurement	m

C.3 Arrays

Array	Description	Units
AIRINK	Air entry head of the conductivity function	cm
AIRINT	Air entry head of the soil water retention function	cm
AMOUNT	Water-application amount	cm
A1	Part of the solution matrix	1/cm/hr
A2	Part of the solution matrix	1/cm/hr
A3	Part of the solution matrix	1/cm/hr

Array	Description	Units
C	Negative of the present specific water capacity	1/cm
CC	Negative of the specific water capacity at the end of the previous time step	1/cm
CH	Current value of volumetric specific heat of bulk soil	J/cm ³ /K
CCH	Value of volumetric specific heat of bulk soil at the end of the previous time step	J/cm ³ /K
CHS	Volumetric specific heat of a given soil material	J/cm ³ /K
CHSOIL	Volumetric specific heat of soil material associated with a given node	J/cm ³ /K
CREGKH	Regression coefficients for polynomials used to describe the hydraulic conductivity, KEST = 1	--
CREGTH	Regression coefficients for polynomials used to describe the soil water retention function, KEST = 1	--
DAYMET	Daily meteorological data	--
DAYQ	Cumulative total of water flow between nodes during the day	cm
DAYQH	Cumulative total of heat flow by conduction between nodes	J/cm ²
DAYSINK	Cumulative total of the sink terms for each node during the day	--
ENFACT	Enhancement factors	--
EF	Enhancement factor coefficients	--
FLAI	Leaf area index on the corresponding NGROW day	--
FPET	Hourly PET distribution factors	--
H	Present suction head value	cm
HH	Suction value at the end of the previous time step	cm
IHY	Array containing all of the soil hydraulic property data	--
KH	Thermal conductivity of soil	J/cm/hr/K
KHMID	Thermal conductivity at the midpoint between nodes	J/cm/hr/K
KKHMID	Value of KHMID at the end of the last successful time step	J/cm/hr/K
KKLMID	Value of KLMID at the end of the last successful time step	cm/hr
KKVMID	Value of KVMID at the end of the last successful time step	cm/hr
KKVTMID	Value of KVTMID at the end of the last successful time step	cm/hr
KL	Liquid water conductivity	cm/hr

Array	Description	Units
KLMID	Liquid water conductivity at the midpoint between nodes	cm/hr
KV	Vapor conductivity for a suction gradient	cm/hr
KVMID	Vapor conductivity at the midpoint between nodes and for a suction gradient	cm/hr
KVT	Vapor conductivity for a temperature gradient	cm/hr
KVTMID	Vapor conductivity at the midpoint between nodes and for a temperature gradient	cm/hr
MAT	Identifies the soil material of the specified node	--
NDEGKH	Number of polynomial coefficients for describing hydraulic conductivity in POLYKH	--
NDEGTH	Number of polynomial coefficients for describing the water retention function in POLYCH and POLYTH	--
NGROW	Day of the year on which the LAI is changed to the corresponding FLAI value	day
NQLEAK	Day on which the lower boundary flux is changed to the corresponding QLEAK value	day
NSUBKH	Number of polynomials used to describe hydraulic conductivity in POLYKH	--
NSUBTH	Number of polynomials used to describe the soil water retention function in POLYCH and POLYTH	--
NROOT	Day on which roots reach the given node	--
PEVAPO	Potential evaporation rate for the day	cm/day
PTRANS	Potential transpiration rate for the day	cm/day
QH	Heat flux by conduction within the soil	J/cm ²
QHL	Heat flux by convection via water flow, i.e., QT	J/cm ²
QLEAK	Lower boundary flux of water on the corresponding NQLEAK day	cm/d
QT	Water flux between nodes during a time step	cm/hr
QV	Vapor flux between nodes during a time step	cm/hr
QWLEAK	Lower boundary flux of water on a given day	cm/hr
RATE	Rate of precipitation for hour NHR	cm/hr
RDF	Root-density function	1/cm
RTIME	Time of day when the water-application rate changes	hr
SINK	Rate of water removal by plants from a given node	1/hr
SK	Saturated hydraulic conductivity	cm/hr
SUBQ	Cumulative total of flux amounts between nodes during the present DELSUB period	cm

Array	Description	Units
SUBQH	Cumulative total of heat flux by conduction between nodes during the current DELSUB period	J/cm ²
SUBSNK	Hourly summary of sink term for each node	--
T	Soil temperature	K
TCON	Thermal conductivity of bulk soil	J/cm/K/hr
THET	Saturated water content	cm ³ /cm ³
THETA	Water content	cm ³ /cm ³
THETAD	Water content less than that at which roots will remove water at less than the optimum rate (if NUPTAK = 1)	cm ³ /cm ³
THETAN	Water content above which anaerobic conditions exist and no water will be withdrawn by plants (if NUPTAK = 1)	cm ³ /cm ³
THETAV	Soil vapor content expressed as an equivalent liquid volume	cm ³ /cm ³
THETAW	Water content below which roots will not withdraw water (if NUPTAK = 1)	cm ³ /cm ³
THICK	Node thickness	cm
TQ	Cumulative total of water flow between nodes during a simulation	cm
TQH	Cumulative total of heat flow by conduction between nodes during a simulation	J/cm ²
TTHETA	Soil water content at the end of the previous time step	cm ³ /cm ³
TTHETAV	Soil vapor content at the end of the previous time step	cm ³ /cm ³
WQLEAK	Specified lower boundary flux when LOWER = 3	cm/day
XDIVKH	Upper head limit of range of head values where the given hydraulic conductivity polynomial is valid	cm
XDIVTH	Upper head limit of range of head values where the given water retention polynomial is valid	cm
Z	Depth of node below the surface	cm
ZY	Part of the solution matrix	-1/hr
ZZ	Distance from node I to node I+1	cm

C.4 Parameter Constants

Constant	Description
LUB	Logical unit for binary output
LUI	Logical unit for binary input
LUR	Logical unit for interactive input
LUS	Logical unit for interactive output

Constant	Description
M1	Dimension of node arrays
M2	Dimension of soil types
M3	Dimension of MAXSUB (maximum number of polynomials per soil type)
M4	Dimension of MAXPOL (maximum number of coefficients per soil function). For the van Genuchten function, M4 must be at least 5. For the Haverkamp and Brooks-Corey functions, M4 must be at least 3. For the polynomials, M4 must be 5 or less.

C.5 Functions and Subroutines

Name	Description
B_L_R	Subroutine that calculates the atmospheric boundary layer resistance
CALPET	Subroutine that calculates PET using the Penman Equation in the FAOPET code (Doorenbos and Pruitt 1977)
DATE	Function that returns the date (specific to VAX FORTRAN)
DDSUM	Subroutine that outputs DELSUB and daily simulation summaries
DELCHK	Subroutine to adjust the time step
FUNVD	Function that returns the saturated vapor density (g/cm^3) at the given temperature (K)
HARDCOPY	Subroutine that sends simulation output to a file or printer
HDRYCALC	Subroutine to calculate a value of HDRY based on the temperature of the soil surface and the vapor density of the atmosphere
HEATFLOW	Subroutine that calculates heat flow
INITSUM	Subroutine that outputs a summary of the initial conditions of the simulation
LISTDATA	Subroutine that outputs lists of simulation results as a function of time
MYHRY	Subroutine to calculate 24 hourly values (which sum to 1.0) for partitioning daily PET into hourly PET values
NODEZ	Subroutine that queries the code user for node information for use in output
POLYCH	Subroutine to calculate specific water capacities
POLYKH	Subroutine to calculate hydraulic conductivities
POLYTH	Subroutine to calculate water contents
PROFILER	Subroutine that outputs simulation data as a function of soil depth
READREC	Subroutine that reads the simulation results file
RLD	Function to calculate the root density

<u>Name</u>	<u>Description</u>
SCAN	Subroutine that allows the code user to scan the simulation results on a screen
SUMMARY	Subroutine that outputs the simulation-end summary
THERME	Subroutine that calculates enhancement factors
THERMK	Subroutine that calculates thermal conductivities and heat capacities
TIME	Function that resets the time of day (specific to VAX FORTRAN)
TRIDAG	Subroutine containing the matrix solver

APPENDIX D

INPUT AND OUTPUT LISTINGS FOR EXAMPLE SIMULATIONS

APPENDIX D

INPUT AND OUTPUT LISTINGS FOR EXAMPLE SIMULATIONS

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CLAY.INP: SAMPLE simulation run for MCODE document; 250 nodes
  0  2  1  1  0  0  0  IPLANT,LOWER,MGRAY,ISWDIF,IHEAT,UPPERH,LOWERH
  0  50  50  1  0  0  0.000E+00 NPRINT,DAYEND,NDAYS,NYEARS,IRAIN,ICONVH,OUTTIM
  0  2  1  0  0  NSURPE,NFHOURL,ITOPBC,ET OPT,ICLOUD
  2  3  0  0  2  2  KOPT,KEST,IVAPOR,SH OPT,INMAX,INHMAX
  0.000E+00 2.000E+04 0.0 0.000E+00 HIRRI,HDRI,HTOP,DHMAX
  1.000E-04 0.150E+00 1.250E-02 24.0 DMAXBA,DELMAX,DELMIN,STOPHR
  0.86 280.46 0.24 0.000E+00 TORT,TSOIL,VAPDIF,QHTOP
-1.000E-04 2.000E+02 1.000E+01 0.000E+00 TGRAD,TSMEAN,TSAMP,QHLEAK
  0.5 2.0 1.0E-05 0.000E+00 WTF,RFACT,RAINIF,DHFACT
  1 250 MATN,NPT
  1  0.000 1  1.000 1  2.000 1  3.000 MAT,Z
  1  4.000 1  5.000 1  6.000 1  7.000 MAT,Z
  1  8.000 1  9.000 1 10.000 1 11.000 MAT,Z
  1 12.000 1 13.000 1 14.000 1 15.000 MAT,Z
  1 16.000 1 17.000 1 18.000 1 19.000 MAT,Z
  1 20.000 1 21.000 1 22.000 1 23.000 MAT,Z
  1 24.000 1 25.000 1 26.000 1 27.000 MAT,Z
  1 28.000 1 29.000 1 30.000 1 31.000 MAT,Z
  1 32.000 1 33.000 1 34.000 1 35.000 MAT,Z
  1 36.000 1 37.000 1 38.000 1 39.000 MAT,Z
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  1 64.000 1 65.000 1 66.000 1 67.000 MAT,Z
  1 68.000 1 69.000 1 70.000 1 71.000 MAT,Z
  1 72.000 1 73.000 1 74.000 1 75.000 MAT,Z
  1 76.000 1 77.000 1 78.000 1 79.000 MAT,Z
  1 80.000 1 81.000 1 82.000 1 83.000 MAT,Z
  1 84.000 1 85.000 1 86.000 1 87.000 MAT,Z
  1 88.000 1 89.000 1 90.000 1 91.000 MAT,Z
  1 92.000 1 93.000 1 94.000 1 95.000 MAT,Z
  1 96.000 1 97.000 1 98.000 1 99.000 MAT,Z
  1 100.000 1 101.000 1 102.000 1 103.000 MAT,Z
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  1 140.000 1 141.000 1 142.000 1 143.000 MAT,Z
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  1 164.000 1 165.000 1 166.000 1 167.000 MAT,Z
  1 168.000 1 169.000 1 170.000 1 171.000 MAT,Z
  1 172.000 1 173.000 1 174.000 1 175.000 MAT,Z
  1 176.000 1 177.000 1 178.000 1 179.000 MAT,Z
  1 180.000 1 181.000 1 182.000 1 183.000 MAT,Z

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FIGURE D.1. Listing of Input File CLAY.INP

FIGURE D.1. (contd)

UNSAT-H Version 2.0
INITIAL CONDITIONS

Input Filename: 8DISK3:[HCODE.UNSATH_VERS20.HAVERKAMP]CLAY.INP;15
Results Filename: 8DISK3:[HCODE.UNSATH_VERS20.HAVERKAMP]CLAY.RES;12
Date of Run: 28-DEC-89
Time of Run: 16:30:12
Title:
CLAY.INP: SAMPLE simulation run for HCODE document; 250 nodes

Initial Conditions					Initial Conditions				
NODE	DEPTH (cm)	HEAD (cm)	THETA (vol.)	TEMP (K)	NODE	DEPTH (cm)	HEAD (cm)	THETA (vol.)	TEMP (K)
1	0.000E+00	0.000E+00	0.2376	0.00	2	1.000E+00	0.000E+02	0.2376	0.00
3	2.000E+00	0.000E+02	0.2376	0.00	4	3.000E+00	0.000E+02	0.2376	0.00
5	4.000E+00	0.000E+02	0.2376	0.00	6	5.000E+00	0.000E+02	0.2376	0.00
7	6.000E+00	0.000E+02	0.2376	0.00	8	7.000E+00	0.000E+02	0.2376	0.00
9	8.000E+00	0.000E+02	0.2376	0.00	10	9.000E+00	0.000E+02	0.2376	0.00
11	1.000E+01	0.000E+02	0.2376	0.00	12	1.100E+01	0.000E+02	0.2376	0.00
13	1.200E+01	0.000E+02	0.2376	0.00	14	1.300E+01	0.000E+02	0.2376	0.00
15	1.400E+01	0.000E+02	0.2376	0.00	16	1.500E+01	0.000E+02	0.2376	0.00
17	1.600E+01	0.000E+02	0.2376	0.00	18	1.700E+01	0.000E+02	0.2376	0.00
19	1.800E+01	0.000E+02	0.2376	0.00	20	1.900E+01	0.000E+02	0.2376	0.00
21	2.000E+01	0.000E+02	0.2376	0.00	22	2.100E+01	0.000E+02	0.2376	0.00
23	2.200E+01	0.000E+02	0.2376	0.00	24	2.300E+01	0.000E+02	0.2376	0.00
25	2.400E+01	0.000E+02	0.2376	0.00	26	2.500E+01	0.000E+02	0.2376	0.00
27	2.600E+01	0.000E+02	0.2376	0.00	28	2.700E+01	0.000E+02	0.2376	0.00
29	2.800E+01	0.000E+02	0.2376	0.00	30	2.900E+01	0.000E+02	0.2376	0.00
31	3.000E+01	0.000E+02	0.2376	0.00	32	3.100E+01	0.000E+02	0.2376	0.00
33	3.200E+01	0.000E+02	0.2376	0.00	34	3.300E+01	0.000E+02	0.2376	0.00
35	3.400E+01	0.000E+02	0.2376	0.00	36	3.500E+01	0.000E+02	0.2376	0.00
37	3.600E+01	0.000E+02	0.2376	0.00	38	3.700E+01	0.000E+02	0.2376	0.00
39	3.800E+01	0.000E+02	0.2376	0.00	40	3.900E+01	0.000E+02	0.2376	0.00
41	4.000E+01	0.000E+02	0.2376	0.00	42	4.100E+01	0.000E+02	0.2376	0.00
43	4.200E+01	0.000E+02	0.2376	0.00	44	4.300E+01	0.000E+02	0.2376	0.00
45	4.400E+01	0.000E+02	0.2376	0.00	46	4.500E+01	0.000E+02	0.2376	0.00
47	4.600E+01	0.000E+02	0.2376	0.00	48	4.700E+01	0.000E+02	0.2376	0.00
49	4.800E+01	0.000E+02	0.2376	0.00	50	4.900E+01	0.000E+02	0.2376	0.00
51	5.000E+01	0.000E+02	0.2376	0.00	52	5.100E+01	0.000E+02	0.2376	0.00
53	5.200E+01	0.000E+02	0.2376	0.00	54	5.300E+01	0.000E+02	0.2376	0.00
55	5.400E+01	0.000E+02	0.2376	0.00	56	5.500E+01	0.000E+02	0.2376	0.00
57	5.600E+01	0.000E+02	0.2376	0.00	58	5.700E+01	0.000E+02	0.2376	0.00
59	5.800E+01	0.000E+02	0.2376	0.00	60	5.900E+01	0.000E+02	0.2376	0.00
61	6.000E+01	0.000E+02	0.2376	0.00	62	6.100E+01	0.000E+02	0.2376	0.00
63	6.200E+01	0.000E+02	0.2376	0.00	64	6.300E+01	0.000E+02	0.2376	0.00
65	6.400E+01	0.000E+02	0.2376	0.00	66	6.500E+01	0.000E+02	0.2376	0.00
67	6.600E+01	0.000E+02	0.2376	0.00	68	6.700E+01	0.000E+02	0.2376	0.00
69	6.800E+01	0.000E+02	0.2376	0.00	70	6.900E+01	0.000E+02	0.2376	0.00
71	7.000E+01	0.000E+02	0.2376	0.00	72	7.100E+01	0.000E+02	0.2376	0.00
73	7.200E+01	0.000E+02	0.2376	0.00	74	7.300E+01	0.000E+02	0.2376	0.00
75	7.400E+01	0.000E+02	0.2376	0.00	76	7.500E+01	0.000E+02	0.2376	0.00
77	7.600E+01	0.000E+02	0.2376	0.00	78	7.700E+01	0.000E+02	0.2376	0.00
79	7.800E+01	0.000E+02	0.2376	0.00	80	7.900E+01	0.000E+02	0.2376	0.00
81	8.000E+01	0.000E+02	0.2376	0.00	82	8.100E+01	0.000E+02	0.2376	0.00
83	8.200E+01	0.000E+02	0.2376	0.00	84	8.300E+01	0.000E+02	0.2376	0.00
85	8.400E+01	0.000E+02	0.2376	0.00	86	8.500E+01	0.000E+02	0.2376	0.00
87	8.600E+01	0.000E+02	0.2376	0.00	88	8.700E+01	0.000E+02	0.2376	0.00
89	8.800E+01	0.000E+02	0.2376	0.00	90	8.900E+01	0.000E+02	0.2376	0.00
91	9.000E+01	0.000E+02	0.2376	0.00	92	9.100E+01	0.000E+02	0.2376	0.00
93	9.200E+01	0.000E+02	0.2376	0.00	94	9.300E+01	0.000E+02	0.2376	0.00

FIGURE D.2. Listing of Output File CLAY.OUT

221	2.200E+02	6.000E+02	0.2376	0.00	222	2.210E+02	6.000E+02	0.2376	0.00
223	2.220E+02	6.000E+02	0.2376	0.00	224	2.230E+02	6.000E+02	0.2376	0.00
225	2.240E+02	6.000E+02	0.2376	0.00	226	2.250E+02	6.000E+02	0.2376	0.00
227	2.260E+02	6.000E+02	0.2376	0.00	228	2.270E+02	6.000E+02	0.2376	0.00
229	2.280E+02	6.000E+02	0.2376	0.00	230	2.290E+02	6.000E+02	0.2376	0.00
231	2.300E+02	6.000E+02	0.2376	0.00	232	2.310E+02	6.000E+02	0.2376	0.00
233	2.320E+02	6.000E+02	0.2376	0.00	234	2.330E+02	6.000E+02	0.2376	0.00
235	2.340E+02	6.000E+02	0.2376	0.00	236	2.350E+02	6.000E+02	0.2376	0.00
237	2.360E+02	6.000E+02	0.2376	0.00	238	2.370E+02	6.000E+02	0.2376	0.00
239	2.380E+02	6.000E+02	0.2376	0.00	240	2.390E+02	6.000E+02	0.2376	0.00
241	2.400E+02	6.000E+02	0.2376	0.00	242	2.410E+02	6.000E+02	0.2376	0.00
243	2.420E+02	6.000E+02	0.2376	0.00	244	2.430E+02	6.000E+02	0.2376	0.00
245	2.440E+02	6.000E+02	0.2376	0.00	246	2.450E+02	6.000E+02	0.2376	0.00
247	2.460E+02	6.000E+02	0.2376	0.00	248	2.470E+02	6.000E+02	0.2376	0.00
249	2.480E+02	6.000E+02	0.2376	0.00	250	2.490E+02	6.000E+02	0.2376	0.00

Initial Water Storage = 59.1620 cm

DAILY SUMMARY: Day = 1, Simulated Time = 24.0000 hr

Node Number	=	1	25	50	75	100
Depth (cm)	=	0.00000	24.00000	49.00000	74.00000	99.00000
Water (cm ³ /cm ³)	=	0.49500	0.24216	0.23780	0.23780	0.23760
Head (cm)	=	0.00000E+00	5.47599E+02	6.00000E+02	6.00000E+02	6.00000E+02
Water Flow (cm)	=	3.09577E+00	6.41113E-03	1.59940E-03	1.59940E-03	1.59940E-03

PRESTOR	INFIL	RUNOFF	EVAPD	TRANS	DRAIN	NEWSTOR	STORAGE
59.1620	4.0245	0.0000	0.0000	0.0000	0.0016	63.1848	Versus 63.1832

Mass Balance = 1.6327E-03 cm; Time step attempts = 214 and successes = 196

DAILY SUMMARY: Day = 50, Simulated Time = 24.0000 hr

Node Number	=	1	25	50	75	100
Depth (cm)	=	0.00000	24.00000	49.00000	74.00000	99.00000
Water (cm ³ /cm ³)	=	0.49500	0.49500	0.49500	0.49500	0.49500
Head (cm)	=	0.00000E+00	1.88372E-01	4.00245E-01	6.55827E-01	9.87805E-01
Water Flow (cm)	=	1.07098E+00	1.07098E+00	1.07098E+00	1.07098E+00	1.07098E+00

PRESTOR	INFIL	RUNOFF	EVAPD	TRANS	DRAIN	NEWSTOR	STORAGE
110.5071	1.0710	0.0000	0.0000	0.0000	0.1992	119.3789	Versus 119.3790

Mass Balance = -3.8147E-05 cm; Time step attempts = 160 and successes = 160

FIGURE D.2. (contd)

UNSAT-H Version 2.0
SIMULATION SUMMARY

Title:
CLAY.INP: SAMPLE simulation run for HCODE document; 250 nodes

Transpiration Scheme is: = 0
Potential Evapotranspiration = 0.0000E+00 [cm]
Potential Transpiration = 0.0000E+00 [cm]
Actual Transpiration = 0.0000E+00 [cm]
Potential Evaporation = 0.0000E+00 [cm]
Actual Evaporation = 0.0000E+00 [cm]
Evaporation during Growth = 0.0000E+00 [cm]
Total Runoff = 0.0000E+00 [cm]
Total Infiltration = 0.0000E+01 [cm]
Total Drainage at Base of Profile = 4.4800E-01 [cm]
Total Applied Water = 0.0000E+00 [cm]
Actual Rainfall = 0.0000E+00 [cm]
Actual Irrigation = 0.0000E+00 [cm]
Total Final Moisture Storage = 1.1938E+02 [cm]
Mass Balance Error = 1.4725E-03 [cm]
Total Successful Time Steps = 8038
Total Attempted Time Steps = 8058
Total Time Step Reductions (DHMAX) = 0
Total Changes in Surface Boundary = 0
Total Time Actually Simulated = 5.0000E+01 [days]

Total water flow (cm) across different depths at the end of 5.0000E+01 days:

DEPTH	FLOW	DEPTH	FLOW	DEPTH	FLOW
0.500	6.0668E+01	0.500	6.0538E+01	1.500	6.0201E+01
2.500	6.0023E+01	3.500	5.9785E+01	4.500	5.9507E+01
5.500	5.9250E+01	6.500	5.8992E+01	7.500	5.8734E+01
8.500	5.8477E+01	9.500	5.8220E+01	10.500	5.7982E+01
11.500	5.7705E+01	12.500	5.7447E+01	13.500	5.7190E+01
14.500	5.6933E+01	15.500	5.6675E+01	16.500	5.6418E+01
17.500	5.6160E+01	18.500	5.5903E+01	19.500	5.5645E+01
20.500	5.5388E+01	21.500	5.5131E+01	22.500	5.4873E+01
23.500	5.4616E+01	24.500	5.4358E+01	25.500	5.4101E+01
26.500	5.3844E+01	27.500	5.3586E+01	28.500	5.3329E+01
29.500	5.3071E+01	30.500	5.2814E+01	31.500	5.2557E+01
32.500	5.2299E+01	33.500	5.2042E+01	34.500	5.1784E+01
35.500	5.1527E+01	36.500	5.1270E+01	37.500	5.1012E+01
38.500	5.0755E+01	39.500	5.0497E+01	40.500	5.0240E+01
41.500	4.9983E+01	42.500	4.9725E+01	43.500	4.9468E+01
44.500	4.9210E+01	45.500	4.8953E+01	46.500	4.8690E+01
47.500	4.8438E+01	48.500	4.8181E+01	49.500	4.7923E+01
50.500	4.7666E+01	51.500	4.7409E+01	52.500	4.7151E+01
53.500	4.6894E+01	54.500	4.6636E+01	55.500	4.6379E+01
56.500	4.6122E+01	57.500	4.5864E+01	58.500	4.5607E+01
59.500	4.5349E+01	60.500	4.5092E+01	61.500	4.4835E+01
62.500	4.4577E+01	63.500	4.4320E+01	64.500	4.4062E+01
65.500	4.3805E+01	66.500	4.3548E+01	67.500	4.3290E+01
68.500	4.3033E+01	69.500	4.2775E+01	70.500	4.2518E+01
71.500	4.2261E+01	72.500	4.2003E+01	73.500	4.1748E+01
74.500	4.1488E+01	75.500	4.1231E+01	76.500	4.0974E+01
77.500	4.0716E+01	78.500	4.0459E+01	79.500	4.0201E+01
80.500	3.9944E+01	81.500	3.9687E+01	82.500	3.9429E+01

FIGURE D.2. (contd)

83.500	3.9172E+01	84.500	3.8914E+01	85.500	3.8657E+01
86.500	3.8400E+01	87.500	3.8142E+01	88.500	3.7885E+01
89.500	3.7627E+01	90.500	3.7370E+01	91.500	3.7113E+01
92.500	3.6855E+01	93.500	3.6598E+01	94.500	3.6340E+01
95.500	3.6083E+01	96.500	3.5826E+01	97.500	3.5568E+01
98.500	3.5311E+01	99.500	3.5053E+01	100.500	3.4790E+01
101.500	3.4539E+01	102.500	3.4281E+01	103.500	3.4024E+01
104.500	3.3768E+01	105.500	3.3509E+01	106.500	3.3252E+01
107.500	3.2994E+01	108.500	3.2737E+01	109.500	3.2479E+01
110.500	3.2222E+01	111.500	3.1965E+01	112.500	3.1707E+01
113.500	3.1450E+01	114.500	3.1192E+01	115.500	3.0935E+01
116.500	3.0678E+01	117.500	3.0420E+01	118.500	3.0163E+01
119.500	2.9905E+01	120.500	2.9648E+01	121.500	2.9391E+01
122.500	2.9133E+01	123.500	2.8876E+01	124.500	2.8618E+01
125.500	2.8361E+01	126.500	2.8104E+01	127.500	2.7846E+01
128.500	2.7589E+01	129.500	2.7332E+01	130.500	2.7074E+01
131.500	2.6817E+01	132.500	2.6559E+01	133.500	2.6302E+01
134.500	2.6045E+01	135.500	2.5787E+01	136.500	2.5530E+01
137.500	2.5273E+01	138.500	2.5015E+01	139.500	2.4758E+01
140.500	2.4501E+01	141.500	2.4243E+01	142.500	2.3986E+01
143.500	2.3729E+01	144.500	2.3472E+01	145.500	2.3214E+01
146.500	2.2957E+01	147.500	2.2700E+01	148.500	2.2443E+01
149.500	2.2185E+01	150.500	2.1928E+01	151.500	2.1671E+01
152.500	2.1414E+01	153.500	2.1157E+01	154.500	2.0900E+01
155.500	2.0643E+01	156.500	2.0386E+01	157.500	2.0129E+01
158.500	1.9872E+01	159.500	1.9615E+01	160.500	1.9358E+01
161.500	1.9101E+01	162.500	1.8844E+01	163.500	1.8588E+01
164.500	1.8331E+01	165.500	1.8074E+01	166.500	1.7818E+01
167.500	1.7561E+01	168.500	1.7305E+01	169.500	1.7048E+01
170.500	1.6792E+01	171.500	1.6538E+01	172.500	1.6280E+01
173.500	1.6024E+01	174.500	1.5768E+01	175.500	1.5512E+01
176.500	1.5258E+01	177.500	1.5001E+01	178.500	1.4745E+01
179.500	1.4490E+01	180.500	1.4234E+01	181.500	1.3979E+01
182.500	1.3724E+01	183.500	1.3470E+01	184.500	1.3215E+01
185.500	1.2961E+01	186.500	1.2707E+01	187.500	1.2453E+01
188.500	1.2199E+01	189.500	1.1945E+01	190.500	1.1692E+01
191.500	1.1439E+01	192.500	1.1187E+01	193.500	1.0934E+01
194.500	1.0682E+01	195.500	1.0431E+01	196.500	1.0180E+01
197.500	9.9289E+00	198.500	9.6788E+00	199.500	9.4288E+00
200.500	9.1794E+00	201.500	8.9307E+00	202.500	8.6825E+00
203.500	8.4349E+00	204.500	8.1880E+00	205.500	7.9419E+00
206.500	7.8965E+00	207.500	7.4520E+00	208.500	7.2084E+00
209.500	6.9657E+00	210.500	6.7241E+00	211.500	6.4837E+00
212.500	6.2445E+00	213.500	6.0066E+00	214.500	5.7701E+00
215.500	5.5352E+00	216.500	5.3020E+00	217.500	5.0706E+00
218.500	4.8412E+00	219.500	4.6140E+00	220.500	4.3891E+00
221.500	4.1667E+00	222.500	3.9472E+00	223.500	3.7306E+00
224.500	3.5174E+00	225.500	3.3078E+00	226.500	3.1021E+00
227.500	2.9007E+00	228.500	2.7040E+00	229.500	2.5123E+00
230.500	2.3262E+00	231.500	2.1481E+00	232.500	1.9724E+00
233.500	1.8058E+00	234.500	1.6486E+00	235.500	1.4956E+00
236.500	1.3531E+00	237.500	1.2196E+00	238.500	1.0958E+00
239.500	9.8185E-01	240.500	8.7827E-01	241.500	7.8532E-01
242.500	7.8322E-01	243.500	6.3218E-01	244.500	5.7225E-01
245.500	6.2364E-01	246.500	4.8650E-01	247.500	4.6111E-01
248.500	4.4800E-01	249.000	4.4800E-01		

FIGURE D.2. (contd)

```

VGTESTA.INP: UNSAT-H Version 2.0 Drainage Test (Kool et al. 1985)
0 2 1 0 0 0 0 IPLANT,LOWER,NGRAV,ISWDIF,IHEAT,UPPERH,LOWERH
1 1 1 1 0 0 2.000E-03 NPRINT,DAYEND,NDAYS,NYEARS,IRAIN,ICONVH,OUTTIM
0 2 0 0 0 0 NSURPE,NFHOUR,ITOPBC,ET OPT,ICLOUD
4 3 0 0 3 2 KOPT,KEST,IVAPOR,SH OPT,INMAX,INHMAX
-5.000E+00 2.000E+04 0.0 0.000E+00 HIRRI,HDRY,HTOP,DHMAX
1.000E-04 2.000E-03 5.000E-06 5.000E-01 DMAXBA,DELMAX,DELMIN,STOPHR
0.50 280.48 0.24 0.000E+00 TORT,TSDIL,VAPDIF,QHTOP
-1.000E-04 2.880E+02 1.000E+01 0.000E+00 TGRAD,TSMEAN,TSAMP,QHLEAK
0.5 1.000E 1.0E-05 0.000E+00 WTF,RFACT,RAINIF,DHFACT
2 13 MATN,NPT
1 0.000 1 0.500 1 1.000 1 1.500 MAT,Z
1 2.000 1 2.500 1 3.000 1 3.500 MAT,Z
1 3.750 1 3.900 2 4.000 2 4.250 MAT,Z
2 4.520 MAT,Z
Silt Loam Soil retention
0.388 0.17321 0.04705 1.46097 THET,THTR,A,N
Silt Loam Soil conductivity
2 5.4 0.04705 1.46097 0.5 KMODEL,SK,A,N,EPIT
Ceramic Plate retention
0.388 0.38700 4.705E-06 3.0E+00 THET,THTR,A,N
Ceramic Plate conductivity
2 0.003 4.705E-06 3.0E+00 0.5 KMODEL,SK,A,N,EPIT
0 NDAY
2.000 1.500 1.000 0.500 Initial Conditions
0.000 -0.500 -1.000 -1.500
-1.750 -1.00 -2.000 -2.250
1000.000
0 NWATER

```

FIGURE D.3. Listing of Input File VGTESTA.INP

```

-----
                        UNSAT-H Version 2.0
                        INITIAL CONDITIONS

Input Filename: 8DISK3:[HCODE.UNSATH_VERS20]VGTESTA.INP;40
Results Filename: 8DISK3:[HCODE.UNSATH_VERS20]VGTESTA.RES;57
Date of Run: 28-DEC-89
Time of Run: 21:00:22
Title:
VGTESTA.INP: UNSAT-H Version 2.0 Drainage Test (Kool et al. 1985)
-----

```

Initial Conditions					Initial Conditions				
NODE	DEPTH (cm)	HEAD (cm)	THETA (vol.)	TEMP (K)	NODE	DEPTH (cm)	HEAD (cm)	THETA (vol.)	TEMP (K)
1	0.000E+00	2.000E+00	0.3859	0.00	2	5.000E-01	1.500E+00	0.3866	0.00
3	1.000E+00	1.000E+00	0.3872	0.00	4	1.500E+00	5.000E-01	0.3877	0.00
5	2.000E+00	0.000E+00	0.3880	0.00	6	2.500E+00	-5.000E-01	0.3880	0.00
7	3.000E+00	-1.000E+00	0.3880	0.00	8	3.500E+00	-1.500E+00	0.3880	0.00
9	3.750E+00	-1.750E+00	0.3880	0.00	10	3.900E+00	-1.900E+00	0.3880	0.00
11	4.000E+00	-2.000E+00	0.3880	0.00	12	4.250E+00	-2.250E+00	0.3880	0.00
13	4.520E+00	1.000E+03	0.3880	0.00					

```

-----
Initial Water Storage = 1.7520 cm
-----

```

```

DAILY SUMMARY: Day = 1, Simulated Time = 0.5000 hr
-----
Node Number      =      1          2          3          4          5
Depth (cm)       =      0.00000    0.50000    1.00000    1.50000    2.00000
Water (cm3/cm3)  =      0.29182    0.29175    0.29083    0.28895    0.28588
Head (cm)        =      6.88243E+01  6.89330E+01  7.03225E+01  7.32581E+01  7.83619E+01
Water Flow (cm)  =      2.35182E-02  7.09468E-02  1.19145E-01  1.68630E-01  2.10580E-01

PRESTOR  INFIL  RUNOFF  EVAP0  TRANS  DRAIN  NEWSTOR      STORAGE
1.7520+ 0.0000+ 0.0000+ 0.0000+ 0.0000+ 0.4272 = 1.3248 Versus 1.3241

Mass Balance = 7.2527E-04 cm; Time step attempts =20108 and successes =16552

```

FIGURE D.4. Listing of Output File VGTESTA.OUT

 UNSAT-H Version 2.0
 SIMULATION SUMMARY

Title:
 VGTESTA.INP: UNSAT-H Version 2.0 Drainage Test (Kool et al. 1985)

Transpiration Scheme is: = 0
 Potential Evapotranspiration = 0.0000E+00 [cm]
 Potential Transpiration = 0.0000E+00 [cm]
 Actual Transpiration = 0.0000E+00 [cm]
 Potential Evaporation = 0.0000E+00 [cm]
 Actual Evaporation = 0.0000E+00 [cm]
 Evaporation during Growth = 0.0000E+00 [cm]
 Total Runoff = 0.0000E+00 [cm]
 Total Infiltration = 0.0000E+00 [cm]
 Total Drainage at Base of Profile = 4.2719E-01 [cm]
 Total Applied Water = 0.0000E+00 [cm]
 Actual Rainfall = 0.0000E+00 [cm]
 Actual Irrigation = 0.0000E+00 [cm]
 Total Final Moisture Storage = 1.3241E+00 [cm]
 Mass Balance Error = 7.2627E-04 [cm]
 Total Successful Time Steps = 18552
 Total Attempted Time Steps = 20100
 Total Time Step Reductions (DHMAX) = 0
 Total Changes in Surface Boundary = 0
 Total Time Actually Simulated = 2.0833E-02 [days]

Total water flow (cm) across different depths at the end of 2.0833E-02 days:

DEPTH	FLOW	DEPTH	FLOW	DEPTH	FLOW
0.000	0.0000E+00	0.250	2.3518E-02	0.750	7.0947E-02
1.250	1.1915E-01	1.750	1.8853E-01	2.250	2.1959E-01
2.750	2.7294E-01	3.250	3.2987E-01	3.625	3.7744E-01
3.825	4.0642E-01	3.950	4.2719E-01	4.125	4.2719E-01
4.385	4.2719E-01	4.520	4.2719E-01		

FIGURE D.4. (contd)

[illegible]

8 NWATER

D.13

UNSAT-H Version 2.0
INITIAL CONDITIONS

Input Filename: \$DISK3:[HCODE.UNSATH_VERS20]V20_TEST4.INP;25
Results Filename: \$DISK3:[HCODE.UNSATH_VERS20]V20_TEST4.RES;83
Date of Run: 28-DEC-89
Time of Run: 22:10:10
Title:
V20_TEST4.INP: Verification Test from Campbell (1985)

Initial Conditions					Initial Conditions				
NODE	DEPTH (cm)	HEAD (cm)	THETA (vol.)	TEMP (K)	NODE	DEPTH (cm)	HEAD (cm)	THETA (vol.)	TEMP (K)
1	0.000E+00	1.000E+02	0.1007	288.00	2	1.000E+00	1.000E+02	0.1007	288.00
3	2.000E+00	1.000E+02	0.1007	288.00	4	3.000E+00	1.000E+02	0.1007	288.00
5	4.000E+00	1.000E+02	0.1007	288.00	6	5.000E+00	1.000E+02	0.1007	288.00
7	6.000E+00	1.000E+02	0.1007	288.00	8	7.000E+00	1.000E+02	0.1007	288.00
9	8.000E+00	1.000E+02	0.1007	288.00	10	9.000E+00	1.000E+02	0.1007	288.00
11	1.000E+01	1.000E+02	0.1007	288.00	12	1.100E+01	1.000E+02	0.1007	288.00
13	1.200E+01	1.000E+02	0.1007	288.00	14	1.300E+01	1.000E+02	0.1007	288.00
15	1.400E+01	1.000E+02	0.1007	288.00	16	1.500E+01	1.000E+02	0.1007	288.00
17	1.600E+01	1.000E+02	0.1007	288.00	18	1.700E+01	1.000E+02	0.1007	288.00
19	1.800E+01	1.000E+02	0.1007	288.00	20	1.900E+01	1.000E+02	0.1007	288.00
21	2.000E+01	1.000E+02	0.1007	288.00	22	2.100E+01	1.000E+02	0.1007	288.00
23	2.200E+01	1.000E+02	0.1007	288.00	24	2.300E+01	1.000E+02	0.1007	288.00
25	2.400E+01	1.000E+02	0.1007	288.00	26	2.500E+01	1.000E+02	0.1007	288.00
27	2.600E+01	1.000E+02	0.1007	288.00	28	2.700E+01	1.000E+02	0.1007	288.00
29	2.800E+01	1.000E+02	0.1007	288.00	30	2.900E+01	1.000E+02	0.1007	288.00
31	3.000E+01	1.000E+02	0.1007	288.00	32	3.100E+01	1.000E+02	0.1007	288.00
33	3.200E+01	1.000E+02	0.1007	288.00	34	3.300E+01	1.000E+02	0.1007	288.00
35	3.400E+01	1.000E+02	0.1007	288.00	36	3.500E+01	1.000E+02	0.1007	288.00
37	3.600E+01	1.000E+02	0.1007	288.00	38	3.700E+01	1.000E+02	0.1007	288.00
39	3.800E+01	1.000E+02	0.1007	288.00	40	3.900E+01	1.000E+02	0.1007	288.00
41	4.000E+01	1.000E+02	0.1007	288.00	42	4.100E+01	1.000E+02	0.1007	288.00
43	4.200E+01	1.000E+02	0.1007	288.00	44	4.300E+01	1.000E+02	0.1007	288.00
45	4.400E+01	1.000E+02	0.1007	288.00	46	4.500E+01	1.000E+02	0.1007	288.00
47	4.600E+01	1.000E+02	0.1007	288.00	48	4.700E+01	1.000E+02	0.1007	288.00
49	4.800E+01	1.000E+02	0.1007	288.00	50	4.900E+01	1.000E+02	0.1007	288.00
51	5.000E+01	1.000E+02	0.1007	288.00	52	5.100E+01	1.000E+02	0.1007	288.00
53	5.200E+01	1.000E+02	0.1007	288.00	54	5.300E+01	1.000E+02	0.1007	288.00
55	5.400E+01	1.000E+02	0.1007	288.00	56	5.500E+01	1.000E+02	0.1007	288.00
57	5.600E+01	1.000E+02	0.1007	288.00	58	5.700E+01	1.000E+02	0.1007	288.00
59	5.800E+01	1.000E+02	0.1007	288.00	60	5.900E+01	1.000E+02	0.1007	288.00
61	6.000E+01	1.000E+02	0.1007	288.00	62	6.100E+01	1.000E+02	0.1007	288.00
63	6.200E+01	1.000E+02	0.1007	288.00	64	6.300E+01	1.000E+02	0.1007	288.00
65	6.400E+01	1.000E+02	0.1007	288.00	66	6.500E+01	1.000E+02	0.1007	288.00
67	6.600E+01	1.000E+02	0.1007	288.00	68	6.700E+01	1.000E+02	0.1007	288.00
69	6.800E+01	1.000E+02	0.1007	288.00	70	6.900E+01	1.000E+02	0.1007	288.00
71	7.000E+01	1.000E+02	0.1007	288.00	72	7.100E+01	1.000E+02	0.1007	288.00
73	7.200E+01	1.000E+02	0.1007	288.00	74	7.300E+01	1.000E+02	0.1007	288.00
75	7.400E+01	1.000E+02	0.1007	288.00	76	7.500E+01	1.000E+02	0.1007	288.00
77	7.600E+01	1.000E+02	0.1007	288.00	78	7.700E+01	1.000E+02	0.1007	288.00
79	7.800E+01	1.000E+02	0.1007	288.00	80	7.900E+01	1.000E+02	0.1007	288.00
81	8.000E+01	1.000E+02	0.1007	288.00	82	8.100E+01	1.000E+02	0.1007	288.00
83	8.200E+01	1.000E+02	0.1007	288.00	84	8.300E+01	1.000E+02	0.1007	288.00
85	8.400E+01	1.000E+02	0.1007	288.00	86	8.500E+01	1.000E+02	0.1007	288.00
87	8.600E+01	1.000E+02	0.1007	288.00	88	8.700E+01	1.000E+02	0.1007	288.00
89	8.800E+01	1.000E+02	0.1007	288.00	90	8.900E+01	1.000E+02	0.1007	288.00
91	9.000E+01	1.000E+02	0.1007	288.00	92	9.100E+01	1.000E+02	0.1007	288.00
93	9.200E+01	1.000E+02	0.1007	288.00	94	9.300E+01	1.000E+02	0.1007	288.00

FIGURE D.6. Listing of Output File V20_TEST4.OUT

```

95 9.400E+01 1.000E+02 0.1007 288.00    96 9.500E+01 1.000E+02 0.1007 288.00
97 9.600E+01 1.000E+02 0.1007 288.00    98 9.700E+01 1.000E+02 0.1007 288.00
99 9.800E+01 1.000E+02 0.1007 288.00    100 9.900E+01 1.000E+02 0.1007 288.00
101 1.000E+02 1.000E+02 0.1007 288.00

```

Initial Water Storage = 10.0715 cm

DAILY SUMMARY: Day = 1, Simulated Time = 24.0000 hr

```

Node Number      =      1          6          14          28          41
Depth (cm)       =      0.00000    5.00000    13.00000    27.00000    40.00000
Water (cm3/cm3)  =      0.10071    0.10071    0.10071    0.10071    0.10071
Head (cm)        =  1.00000E+02  1.00000E+02  1.00000E+02  1.00000E+02  1.00000E+02
Water Flow (cm)  =  5.27513E-10 -2.37113E-08  0.00000E+00  0.00000E+00  0.00000E+00
Temperature (K)  =  2.78000E+02  2.81651E+02  2.85967E+02  2.88644E+02  2.88520E+02
Heat Flow (J/cm2) = -7.11682E+01 -2.48204E+01  1.07628E+01  1.38636E+01  3.58265E+00

```

```

PRESTOR INFIL RUNOFF  EVAPO  TRANS  DRAIN  NEWSTOR      STORAGE
10.0715+ 0.0000+ 0.0000 - 0.0000- 0.0000- 0.0000 = 10.0715 Versus 10.0715

```

```

Mass Balance = 1.9073E+00 cm; Time step attempts = 51 and successes = 51
Heat flow parameters (units = J/cm2 unless noted)
RN (J/m2) = 0.0000E+00 SHF (J/m2) = -7.7131E+05 SEN (J/m2) = 0.0000E+00
LE (J/m2) = 0.0000E+00 QH(NPT) = -4.6048E+01 HBE = 6.7985E-01

```

DAILY SUMMARY: Day = 10, Simulated Time = 24.0000 hr

```

Node Number      =      1          6          14          28          41
Depth (cm)       =      0.00000    5.00000    13.00000    27.00000    40.00000
Water (cm3/cm3)  =      0.10071    0.10071    0.10071    0.10071    0.10071
Head (cm)        =  1.00000E+02  1.00000E+02  1.00000E+02  1.00000E+02  1.00000E+02
Water Flow (cm)  =  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
Temperature (K)  =  2.78000E+02  2.81631E+02  2.85920E+02  2.88577E+02  2.88467E+02
Heat Flow (J/cm2) =  3.19574E+01  3.01134E+01  2.58828E+01  2.04382E+01  9.54891E-02

```

```

PRESTOR INFIL RUNOFF  EVAPO  TRANS  DRAIN  NEWSTOR      STORAGE
10.0715+ 0.0000+ 0.0000 - 0.0000- 0.0000- 0.0000 = 10.0715 Versus 10.0715

```

```

Mass Balance = 0.0000E+00 cm; Time step attempts = 24 and successes = 24
Heat flow parameters (units = J/cm2 unless noted)
RN (J/m2) = 0.0000E+00 SHF (J/m2) = 3.1955E+03 SEN (J/m2) = 0.0000E+00
LE (J/m2) = 0.0000E+00 QH(NPT) = -3.9830E+01 HBE = 7.3591E-01

```

FIGURE D.6. (contd)

 UNSAT-H Version 2.0
 SIMULATION SUMMARY

Title:
 V20_TEST4.INP: Verification test from Campbell (1985)

Transpiration Scheme is:	=	0	
Potential Evapotranspiration	=	0.0000E+00	[cm]
Potential Transpiration	=	0.0000E+00	[cm]
Actual Transpiration	=	0.0000E+00	[cm]
Potential Evaporation	=	0.0000E+00	[cm]
Actual Evaporation	=	0.0000E+00	[cm]
Evaporation during Growth	=	0.0000E+00	[cm]
Total Runoff	=	0.0000E+00	[cm]
Total Infiltration	=	0.0000E+00	[cm]
Total Drainage at Base of Profile	=	0.0000E+00	[cm]
Total Applied Water	=	0.0000E+00	[cm]
Actual Rainfall	=	0.0000E+00	[cm]
Actual Irrigation	=	0.0000E+00	[cm]
Total Final Moisture Storage	=	1.0071E+01	[cm]
Mass Balance Error	=	1.9073E-06	[cm]
Total Successful Time Steps	=	267	
Total Attempted Time Steps	=	267	
Total Time Step Reductions (DHMAX)	=	0	
Total Changes in Surface Boundary	=	0	
Total Time Actually Simulated	=	1.0000E+01	[days]
Total Net Radiation	=	0.0000E+00	[J/m2]
Total Soil-Surface Heat Flow	=	-7.6313E+05	[J/m2]
Total Sensible Heat Flow	=	0.0000E+00	[J/m2]
Total Bottom Heat Flow	=	-3.4403E+04	[J/m2]
Total Latent Heat Flow	=	0.0000E+00	[J/m2]
Heat Balance Error	=	7.3051E+04	[J/m2]

Total water flow (cm) across different depths at the end of 1.0000E+01 days:

DEPTH	FLOW	DEPTH	FLOW	DEPTH	FLOW
0.500	0.0000E+00	0.500	5.2751E-10	1.500	-1.1057E-08
2.500	-2.0359E-08	3.500	-1.0123E-08	4.500	1.5373E-08
5.500	-2.3711E-08	6.500	1.0026E-08	7.500	1.0094E-08
8.500	1.9030E-08	9.500	1.1037E-08	10.500	1.0090E-08
11.500	9.5149E-09	12.500	0.0000E+00	13.500	0.0000E+00
14.500	0.0000E+00	15.500	0.0000E+00	16.500	0.0000E+00
17.500	0.0000E+00	18.500	0.0000E+00	19.500	0.0000E+00
20.500	0.0000E+00	21.500	0.0000E+00	22.500	0.0000E+00
23.500	0.0000E+00	24.500	0.0000E+00	25.500	0.0000E+00
26.500	0.0000E+00	27.500	0.0000E+00	28.500	0.0000E+00
29.500	0.0000E+00	30.500	0.0000E+00	31.500	0.0000E+00
32.500	0.0000E+00	33.500	0.0000E+00	34.500	0.0000E+00
35.500	0.0000E+00	36.500	0.0000E+00	37.500	0.0000E+00
38.500	0.0000E+00	39.500	0.0000E+00	40.500	0.0000E+00
41.500	0.0000E+00	42.500	0.0000E+00	43.500	0.0000E+00
44.500	0.0000E+00	45.500	0.0000E+00	46.500	0.0000E+00
47.500	0.0000E+00	48.500	0.0000E+00	49.500	0.0000E+00
50.500	0.0000E+00	51.500	0.0000E+00	52.500	0.0000E+00
53.500	0.0000E+00	54.500	0.0000E+00	55.500	0.0000E+00
56.500	0.0000E+00	57.500	0.0000E+00	58.500	0.0000E+00
59.500	0.0000E+00	60.500	0.0000E+00	61.500	0.0000E+00
62.500	0.0000E+00	63.500	0.0000E+00	64.500	0.0000E+00

FIGURE D.6. (cont'd)

65.500	0.0000E+00	66.500	0.0000E+00	67.500	0.0000E+00
68.500	0.0000E+00	69.500	0.0000E+00	70.500	0.0000E+00
71.500	0.0000E+00	72.500	0.0000E+00	73.500	0.0000E+00
74.500	0.0000E+00	75.500	0.0000E+00	76.500	0.0000E+00
77.500	0.0000E+00	78.500	0.0000E+00	79.500	0.0000E+00
80.500	0.0000E+00	81.500	0.0000E+00	82.500	0.0000E+00
83.500	0.0000E+00	84.500	0.0000E+00	85.500	0.0000E+00
86.500	0.0000E+00	87.500	0.0000E+00	88.500	0.0000E+00
89.500	0.0000E+00	90.500	0.0000E+00	91.500	0.0000E+00
92.500	0.0000E+00	93.500	0.0000E+00	94.500	0.0000E+00
95.500	-2.2217E-06	96.500	-2.2313E-06	97.500	-2.2364E-06
98.500	-2.2241E-06	99.500	-1.3040E-06	100.000	0.0000E+00

Total heat flow (J/cm2) across different depths at the end of 1.0000E+01 days:

DEPTH	FLOW	DEPTH	FLOW	DEPTH	FLOW
0.500	-7.0313E+01	0.500	-7.0350E+01	1.500	-5.9294E+01
2.500	-4.9195E+01	3.500	-3.9959E+01	4.500	-3.1628E+01
5.500	-2.4115E+01	6.500	-1.7461E+01	7.500	-1.1397E+01
8.500	-6.0647E+00	9.500	-1.3902E+00	10.500	2.5974E+00
11.500	6.0650E+00	12.500	9.0248E+00	13.500	1.1447E+01
14.500	1.3395E+01	15.500	1.4998E+01	16.500	1.6241E+01
17.500	1.7187E+01	18.500	1.7742E+01	19.500	1.8118E+01
20.500	1.8248E+01	21.500	1.8174E+01	22.500	1.7898E+01
23.500	1.7539E+01	24.500	1.7006E+01	25.500	1.6475E+01
26.500	1.5831E+01	27.500	1.5061E+01	28.500	1.4245E+01
29.500	1.3394E+01	30.500	1.2532E+01	31.500	1.1659E+01
32.500	1.0800E+01	33.500	9.9490E+00	34.500	9.1090E+00
35.500	8.2910E+00	36.500	7.5099E+00	37.500	6.7577E+00
38.500	6.0433E+00	39.500	5.3823E+00	40.500	4.7202E+00
41.500	4.1219E+00	42.500	3.5805E+00	43.500	3.0280E+00
44.500	2.5429E+00	45.500	2.0878E+00	46.500	1.6736E+00
47.500	1.2889E+00	48.500	9.4527E-01	49.500	6.3242E-01
50.500	3.3820E-01	51.500	8.1879E-02	52.500	-1.5077E-01
53.500	-3.5369E-01	54.500	-5.3630E-01	55.500	-7.0299E-01
56.500	-8.5334E-01	57.500	-9.7920E-01	58.500	-1.0980E+00
59.500	-1.1901E+00	60.500	-1.2895E+00	61.500	-1.3679E+00
62.500	-1.4395E+00	63.500	-1.5010E+00	64.500	-1.5517E+00
65.500	-1.6112E+00	66.500	-1.6497E+00	67.500	-1.6941E+00
68.500	-1.7335E+00	69.500	-1.7762E+00	70.500	-1.8156E+00
71.500	-1.8462E+00	72.500	-1.8880E+00	73.500	-1.9186E+00
74.500	-1.9530E+00	75.500	-1.9938E+00	76.500	-2.0338E+00
77.500	-2.0894E+00	78.500	-2.1100E+00	79.500	-2.1494E+00
80.500	-2.1984E+00	81.500	-2.2507E+00	82.500	-2.2993E+00
83.500	-2.3500E+00	84.500	-2.4092E+00	85.500	-2.4624E+00
86.500	-2.5170E+00	87.500	-2.5773E+00	88.500	-2.6370E+00
89.500	-2.7022E+00	90.500	-2.7708E+00	91.500	-2.8426E+00
92.500	-2.9097E+00	93.500	-2.9868E+00	94.500	-3.0545E+00
95.500	-3.1334E+00	96.500	-3.2125E+00	97.500	-3.2964E+00
98.500	-3.3748E+00	99.500	-3.4483E+00	100.000	-3.4483E+00

FIGURE D.6. (contd)

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N62NP: Repeats PML-5899 run as a check on UNSAT-H Version 2.0
0 1 1 1 0 0 0 IPLANT, LOWER, NGRAV, ISWDIF, IHEAT, UPPERH, LOWERH
0 365 385 1 0 0 0.000E+00 NPRINT, DAYEND, NDAYS, NYEARS, IRAIN, ICONVH, OUTTIM
1 2 0 0 0 NSURPE, NFHOUR, ITOPBC, ET_OPT, ICLOUD
1 3 1 0 2 2 KOPT, KEST, IVAPOR, SH_OPT, INMAX, INHMAX
1.000E+00 1.000E+05 0.0 0.000E+00 HIRRI, HDRY, HTOP, DHMAX
1.000E-04 1.000E+00 1.000E-07 24.0 CMAXBA, DELMAX, DELMIN, STOPHR
0.66 288.48 0.24 0.000E+00 TORT, TSOIL, VAPDIF, QHTOP
-1.000E-04 2.880E+02 1.000E+01 0.000E+00 TGRAD, TSMEAN, TSAMP, QHLEAK
0.5 2.0 1.000E-05 0.000E+00 WTF, RFACT, RAININ, DHFACT
3 37 MATN, NPT
1 0.000 1 0.100 1 0.200 1 0.500 MAT, Z
1 1.000 1 2.000 1 4.000 1 8.000 MAT, Z
1 15.000 1 24.000 1 28.000 2 32.000 MAT, Z
2 36.000 2 44.000 2 52.000 2 80.000 MAT, Z
2 70.000 2 80.000 2 90.000 2 100.000 MAT, Z
2 110.000 2 120.000 2 130.000 2 138.000 MAT, Z
2 143.000 2 147.000 2 149.000 3 151.000 MAT, Z
3 153.000 3 157.000 3 165.000 3 181.000 MAT, Z
3 220.000 3 280.000 3 340.000 3 440.000 MAT, Z
3 540.000 MAT, Z
4 5 MAXSUB, MAXPOL
Material No. 1, COMPGRAV.TH1: Composite soil with 15 % gravel by weight
4 1.0000000E+00 4.2200000E-01 NPOLY, X(1), Y(1)
1 4 1.0000000E+00 1.2650003E+01 I, NDEG(I)+1, XX1, XX2
4.2199999E-01 -2.7673731E-02 -2.3653656E-03 -3.2151621E-02 0.0000000E-01 (COEF(I,J), J=1, NDEG(I)+1)
2 5 1.2650003E+01 2.4420018E+02 I, NDEG(I)+1, XX1, XX2
-1.3883400E-01 1.5021513E+00 -1.4785287E+00 5.4422865E-01 -7.8263125E-02 (COEF(I,J), J=1, NDEG(I)+1)
3 5 2.4420018E+02 7.1970044E+03 I, NDEG(I)+1, XX1, XX2
-1.7589752E+00 2.7017555E+00 -1.3545368E+00 2.8480807E-01 -2.1819080E-02 (COEF(I,J), J=1, NDEG(I)+1)
4 5 7.1970044E+03 8.8326599E+06 I, NDEG(I)+1, XX1, XX2
-3.4936512E-01 3.1459510E-01 -8.4237993E-02 9.1790808E-03 -3.5545405E-04 (COEF(I,J), J=1, NDEG(I)+1)
COMPGRAV.KH1
2 1.0000000E+00 3.8000000E-01 NPOLY, X(1), Y(1)
1 4 1.0000000E+00 4.4980000E+01 I, NDEG(I)+1, XX1, XX2
-4.4369757E-01 -5.8029747E-01 -2.8344643E-01 -2.1685658E-01 0.0000000E-01 (COEF(I,J), J=1, NDEG(I)+1)
2 3 4.4980000E+01 8.8326599E+06 I, NDEG(I)+1, XX1, XX2
2.4089815E+00 -3.4391944E+00 4.3601289E-02 0.0000000E-01 (COEF(I,J), J=1, NDEG(I)+1)
Material No. 2, COMPOS1.TH1: Composite soil
4 1.0000000E+00 4.2200000E-01 NPOLY, X(1), Y(1)
1 3 1.0000000E+00 5.4290004E+00 I, NDEG(I)+1, XX1, XX2
4.2199999E-01 -7.3107332E-03 -3.5250444E-02 0.0000000E-01 (COEF(I,J), J=1, NDEG(I)+1)
2 3 5.4290004E+00 5.6900012E+02 I, NDEG(I)+1, XX1, XX2
4.2632836E-01 -1.9087702E-02 -2.7235843E-02 0.0000000E-01 (COEF(I,J), J=1, NDEG(I)+1)
3 4 5.6900012E+02 1.6770025E+04 I, NDEG(I)+1, XX1, XX2
2.4013359E+00 -1.7952768E+00 4.5785773E-01 -3.9381173E-02 (COEF(I,J), J=1, NDEG(I)+1)
4 4 1.6770025E+04 8.8326599E+06 I, NDEG(I)+1, XX1, XX2
3.8377275E-01 -1.0580593E-01 1.0610908E-02 -3.5818552E-04 (COEF(I,J), J=1, NDEG(I)+1)
COMPOS1.KH1
3 1.0000000E+00 1.0800020E-01 NPOLY, X(1), Y(1)
1 4 1.0000000E+00 1.3260002E+03 I, NDEG(I)+1, XX1, XX2
-9.8857582E-01 -1.0985508E+00 5.8941185E-02 -1.2111288E-01 0.0000000E-01 (COEF(I,J), J=1, NDEG(I)+1)
2 4 1.3260002E+03 7.1970044E+03 I, NDEG(I)+1, XX1, XX2
-6.3407219E-01 8.0421951E-01 -2.0131914E-01 2.0885219E+00 0.0000000E-01 (COEF(I,J), J=1, NDEG(I)+1)
3 4 7.1970044E+03 8.8326599E+06 I, NDEG(I)+1, XX1, XX2
-9.5900745E+00 1.8411379E+00 -8.0871047E-01 2.4653060E-02 0.0000000E-01 (COEF(I,J), J=1, NDEG(I)+1)
Material No. 3, GRAVEL1.TH1: Gravel 0.6-1.3 cm diameter
4 9.9999998E-03 4.1900000E-01 NPOLY, X(1), Y(1)
1 3 9.9999998E-03 7.7430010E-02 I, NDEG(I)+1, XX1, XX2
2.9529411E-01 -9.5836556E-02 -1.0991356E-02 0.0000000E-01 (COEF(I,J), J=1, NDEG(I)+1)
2 3 7.7430010E-02 2.7829993E-01 I, NDEG(I)+1, XX1, XX2
-2.0774645E-01 -1.0013254E+00 -4.2446923E-01 0.0000000E-01 (COEF(I,J), J=1, NDEG(I)+1)
3 5 2.7829993E-01 1.2920002E+01 I, NDEG(I)+1, XX1, XX2

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FIGURE D.7. Listing of Input File N62NP.INP

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5.8681458E-02 -1.1252354E-01 2.0134400E-01 -1.7054841E-01 5.2016903E-02(COEF(I,J), J=1,NDEG(I)+1)
4 5 1.2920002E-01 0.7777891E-00 I, NDEG(I)+1, XX1, XX2
4.5875967E-02 -2.2514006E-02 6.2657609E-03 -7.9328570E-04 3.5441328E-05(COEF(I,J), J=1,NDEG(I)+1)
GRAVEL1.KH1
4 9.9999998E-03 1.2600005E-03 NPOLY, X(1), Y(1)
1 4 9.9999998E-03 2.7820993E-01 I, NDEG(I)+1, XX1, XX2
-2.7429957E+00 -1.0568543E+01 -6.7793403E+00 -1.4704553E+00 0.0000000E-01(COEF(I,J), J=1,NDEG(I)+1)
2 3 2.7820993E-01 4.8420007E+00 I, NDEG(I)+1, XX1, XX2
-1.3305095E+00 -5.0247031E+00 -5.5922753E-01 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
3 3 4.8420007E+00 1.6680004E+01 I, NDEG(I)+1, XX1, XX2
1.8869209E-01 -9.5821028E+00 2.6585794E+00 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
4 4 1.6680004E+01 8.7777891E-00 I, NDEG(I)+1, XX1, XX2
-3.7477951E+00 -3.1739995E+00 2.7821976E-01 -2.2469539E-02 0.0000000E-01(COEF(I,J), J=1,NDEG(I)+1)
0 NDAY
22933.598 2400.732 451.194 205.657 Initial Conditions
142.568 109.128 77.111 60.696
58.325 69.985 81.368 87.254
88.238 85.058 79.992 74.882
68.145 61.825 54.897 47.758
40.082 31.748 22.833 16.331
10.510 6.592 4.817 2.817
2.815 2.812 2.808 2.797
2.781 2.737 2.696 2.638
2.595
0.0000 0.0149 0.1101 0.1104 0.0237 0.0368 0.2147 0.1400
0.1915 0.0964 0.1357 0.0578 0.0157 0.1428 0.1050 0.0805
0.1158 0.0982 0.1097 0.2216 0.0713 0.0694 0.0774 0.1050
0.2072 0.2613 0.2281 0.0883 0.0703 0.0777 0.0937 0.0678
0.0875 0.1119 0.1926 0.2615 0.1271 0.0284 0.0583 0.0089
0.1231 0.1001 0.1181 0.0274 0.3457 0.1219 0.1181 0.1178
0.1168 0.2071 0.3266 0.2582 0.2563 0.3259 0.1955 0.2929
0.2193 0.1765 0.0724 0.1118 0.2551 0.1957 0.1195 0.1159
0.2007 0.2781 0.3815 0.1914 0.2216 0.1848 0.2643 0.3002
0.3615 0.3849 0.3791 0.4040 0.4152 0.3821 0.5206 0.2655
0.4425 0.6500 0.4471 0.4120 0.2278 0.4747 0.3830 0.4189
0.4170 0.4045 0.4545 0.4604 0.3911 0.4639 0.5044 0.6427
0.6853 0.3489 0.6483 0.6142 0.5437 0.8405 0.5206 0.8800
0.7259 0.5357 0.6966 0.6924 0.7958 0.9584 0.5604 0.6518
0.6831 0.8007 0.5017 0.5967 0.5787 0.5999 0.5117 0.5277
0.7238 0.7173 0.4897 0.5890 0.8439 0.2533 0.6350 0.1300
0.4898 0.8331 0.8403 0.4804 0.7181 0.7279 0.8675 0.8353
0.7888 0.7619 0.3187 0.7143 0.8707 0.8251 0.2532 0.0643
0.3957 0.4917 0.8598 1.0391 0.8835 0.8780 0.7340 0.8315
0.4908 0.5168 0.6893 0.7200 0.7571 0.7391 0.9491 1.0695
0.9860 0.8248 0.7786 0.5889 0.8501 0.9943 1.1633 1.1370
0.8122 0.9582 1.0942 1.1848 1.0316 0.8964 1.0351 1.1713
0.9744 0.9160 0.8831 1.2127 1.1724 0.9278 0.7709 0.9968
0.4198 0.8182 0.7056 0.8515 0.8996 1.0218 1.0580 0.9518
1.3075 1.1932 0.8050 1.0623 1.0033 1.1433 0.8163 0.7959
1.0455 0.9644 1.0085 1.0274 0.9932 1.2366 0.9919 0.8420
1.1587 0.8938 0.9756 0.9788 1.0380 0.8886 0.4534 0.7529
0.6019 0.6347 0.2835 0.2899 0.6071 0.8487 0.7368 0.8920
0.7038 0.7292 0.8045 1.0071 0.8073 0.8256 0.8993 0.7871
1.2396 0.8158 0.6938 0.6519 1.1046 0.8168 0.7989 0.7200
0.8089 0.6279 0.6779 0.7519 0.9453 0.8887 0.7373 0.6531
0.8438 0.8117 0.4965 0.5639 0.3982 0.7173 0.4295 0.3861
0.7080 0.5258 0.4855 0.8501 0.7985 0.5096 0.7010 0.8194
0.5424 0.4535 0.5148 0.5989 0.5805 0.5624 0.1884 0.4033
0.3929 0.3779 0.4480 0.4206 0.4443 0.3248 0.3529 0.0328
0.3590 0.4008 0.0784 0.0237 0.1594 0.3569 0.1901 0.2897
0.2281 0.2014 0.1490 0.1847 0.2158 0.3026 0.2456 0.1458
0.1899 0.1318 0.1504 0.1372 0.1367 0.1345 0.0127 0.0422
0.0050 0.1020 0.0623 0.0637 0.1902 0.1864 0.1727 0.0458

```

FIGURE D.7. (contd)

0.1833	0.1800	0.1355	0.0193	0.1011	0.0019	0.0262	0.1038
0.0686	0.0131	0.4085	0.1000	0.1420	0.1672	0.1049	0.1267
0.4766	0.2131	0.1840	0.0726	0.0099	0.0879	0.0707	0.1102
0.1729	0.0212	0.0036	0.0453	0.0409	0.0005	0.0185	0.0000
0.0177	0.0118	0.0162	0.0292	0.0000	0.0096	0.0111	0.0133
0.0061	0.0000	0.0454	0.0777	0.1016	0.0794	0.0583	0.0420
0.0032	0.2195	0.1465	0.1234	0.1344			
62							
3	1	2	1.000				
0.000	0.203						
2.000	0.000						
6	1	2	1.000				
14.000	0.076						
15.000	0.000						
17	1	2	1.000				
4.000	0.051						
5.000	0.000						
37	1	4	1.000				
14.000	0.127						
16.000	0.000						
17.000	0.102						
19.000	0.000						
36	1	2	1.000				
12.000	0.178						
17.000	0.000						
40	1	2	1.000				
13.000	0.040						
17.000	0.000						
42	1	2	1.000				
21.000	0.025						
22.000	0.000						
43	1	2	1.000				
20.000	0.178						
22.000	0.000						
44	1	4	1.000				
15.000	0.203						
18.000	0.000						
19.000	0.025						
20.000	0.000						
46	1	2	1.000				
21.000	0.279						
24.000	0.000						
47	1	2	1.000				
0.000	0.051						
1.000	0.000						
53	1	2	1.000				
11.000	0.025						
12.000	0.000						
50	1	0	1.000				
13.000	0.076						
15.000	0.000						
16.000	0.025						
17.000	0.000						
18.000	0.051						
19.000	0.000						
53	1	2	1.000				
7.000	0.127						
11.000	0.000						
64	1	2	1.000				
14.000	0.025						
15.000	0.000						
67	1	2	1.000				
13.000	0.025						

FIGURE D.7. (contd)

14.000	0.000		
88	1	2	1.000
16.000	0.025		
17.000	0.000		
79	1	2	1.000
17.000	0.025		
18.000	0.000		
80	1	2	1.000
20.000	0.025		
21.000	0.000		
84	1	4	1.000
5.000	0.051		
6.000	0.000		
19.000	0.051		
21.000	0.000		
94	1	2	1.000
14.000	0.229		
10.000	0.000		
98	1	2	1.000
6.000	0.051		
7.000	0.000		
105	1	2	1.000
4.000	0.229		
6.000	0.000		
117	1	2	1.000
1.000	0.350		
8.000	0.000		
123	1	2	1.000
6.000	0.102		
7.000	0.000		
126	1	4	1.000
3.000	0.051		
5.000	0.000		
19.000	0.025		
20.000	0.000		
128	1	8	1.000
6.000	0.102		
7.000	0.000		
8.000	0.127		
11.000	0.000		
13.000	0.533		
16.000	0.000		
129	1	4	1.000
5.000	0.178		
6.000	0.000		
15.000	0.406		
17.000	0.000		
139	1	4	1.000
7.000	0.051		
8.000	0.000		
10.000	0.025		
11.000	0.000		
143	1	4	1.000
3.000	0.432		
7.000	0.000		
8.000	0.102		
10.000	0.000		
144	1	8	1.000
3.000	0.152		
5.000	0.000		
6.000	1.067		
13.000	0.000		
15.000	0.076		

FIGURE D.7. (contd)

17.000	0.000		
154	1	2	1.000
12.000	0.025		
13.000	0.000		
158	1	2	1.000
4.000	0.076		
5.000	0.000		
184	1	4	1.000
16.000	0.025		
18.000	0.000		
21.000	0.178		
22.000	0.000		
215	1	6	1.000
3.000	0.483		
8.000	0.000		
8.000	0.025		
9.000	0.000		
14.000	0.229		
17.000	0.000		
219	1	8	1.000
0.000	0.025		
1.000	0.000		
2.000	0.025		
3.000	0.000		
7.000	0.025		
8.000	0.000		
224	1	2	1.000
4.000	0.457		
7.000	0.000		
253	1	4	1.000
2.000	0.025		
3.000	0.000		
8.000	0.078		
11.000	0.000		
271	1	2	1.000
3.000	0.864		
12.000	0.000		
275	1	4	1.000
21.000	0.025		
22.000	0.000		
23.000	0.025		
24.000	0.000		
280	1	4	1.000
13.000	0.025		
14.000	0.000		
18.000	0.051		
17.000	0.000		
283	1	2	1.000
13.000	0.025		
14.000	0.000		
284	1	2	1.000
8.000	0.880		
13.000	0.000		
285	1	4	1.000
10.000	0.991		
18.000	0.000		
17.000	0.330		
19.000	0.000		
287	1	8	1.000
4.000	0.229		
8.000	0.000		
9.000	0.025		
10.000	0.000		

FIGURE D.7. (contd)

11.000	0.025		
12.000	0.000		
312	1	4	1.000
1.000	0.127		
2.000	0.000		
23.000	0.051		
24.000	0.000		
313	1	2	1.000
0.000	0.203		
2.000	0.000		
315	1	2	1.000
3.000	0.051		
5.000	0.000		
316	1	2	1.000
13.000	0.330		
18.000	0.000		
319	1	2	1.000
7.000	0.127		
9.000	0.000		
334	1	4	1.000
6.000	0.051		
8.000	0.000		
9.000	0.711		
12.000	0.000		
335	1	2	1.000
22.000	0.025		
23.000	0.000		
338	1	2	1.000
14.000	0.025		
15.000	0.000		
344	1	4	1.000
1.000	0.025		
2.000	0.000		
12.000	0.025		
13.000	0.000		
345	1	2	1.000
5.000	0.025		
8.000	0.000		
347	1	6	1.000
2.000	0.203		
6.000	0.000		
19.000	0.078		
21.000	0.000		
22.000	0.127		
24.000	0.000		
348	1	2	1.000
0.000	0.279		
6.000	0.000		
349	1	8	1.000
0.000	0.051		
1.000	0.000		
2.000	0.025		
3.000	0.000		
5.000	0.078		
7.000	0.000		
8.000	0.078		
11.000	0.000		
350	1	8	1.000
13.000	0.025		
14.000	0.000		
17.000	0.078		
19.000	0.000		
23.000	0.025		

FIGURE D.7. (contd)

24.000	0.000			
351	1	4	1.000	
9.000	0.152			
11.000	0.000			
13.000	0.025			
14.000	0.000			
352	1	2	1.000	
13.000	0.051			
15.000	0.000			
353	1	2	1.000	
2.000	0.127			
4.000	0.000			

FIGURE D.7. (contd)

UNSAT-H Version 2.0
INITIAL CONDITIONS

Input Filename: \$DISK3:[HCODE.UNSATH_VERS20]N62NP.INP;18
Results Filename: \$DISK3:[HCODE.UNSATH_VERS20]N62NP.RES;28
Date of Run: 28-DEC-89
Time of Run: 19:00:11
Title:
N62NP: Repeats PNL-5899 run as a check on UNSAT-H Version 2.0

Initial Conditions					Initial Conditions				
NODE	DEPTH (cm)	HEAD (cm)	THETA (vol.)	TEMP (K)	NODE	DEPTH (cm)	HEAD (cm)	THETA (vol.)	TEMP (K)
1	0.000E+00	2.293E+04	0.0533	0.00	2	1.000E+01	2.401E+03	0.0685	0.00
3	2.000E+01	4.512E+02	0.1203	0.00	4	5.000E+01	2.059E+02	0.1490	0.00
5	1.000E+00	1.426E+02	0.1633	0.00	6	2.000E+00	1.031E+02	0.1793	0.00
7	4.000E+00	7.711E+01	0.1969	0.00	8	0.000E+00	6.070E+01	0.2138	0.00
9	1.600E+01	5.833E+01	0.2198	0.00	10	2.400E+01	8.999E+01	0.2035	0.00
11	2.800E+01	8.137E+01	0.1934	0.00	12	3.200E+01	8.725E+01	0.2867	0.00
13	3.600E+01	8.824E+01	0.2881	0.00	14	4.400E+01	8.500E+01	0.2881	0.00
15	5.200E+01	7.999E+01	0.2914	0.00	16	6.000E+01	7.468E+01	0.2950	0.00
17	7.000E+01	6.814E+01	0.2998	0.00	18	8.000E+01	6.163E+01	0.3049	0.00
19	9.000E+01	5.490E+01	0.3107	0.00	20	1.000E+02	4.776E+01	0.3175	0.00
21	1.100E+02	4.006E+01	0.3258	0.00	22	1.200E+02	3.175E+01	0.3362	0.00
23	1.300E+02	2.283E+01	0.3501	0.00	24	1.380E+02	1.533E+01	0.3654	0.00
25	1.430E+02	1.051E+01	0.3784	0.00	26	1.470E+02	8.592E+00	0.3924	0.00
27	1.490E+02	4.617E+00	0.4016	0.00	28	1.510E+02	2.817E+00	0.0354	0.00
29	1.530E+02	2.815E+00	0.0354	0.00	30	1.570E+02	2.812E+00	0.0354	0.00
31	1.650E+02	2.806E+00	0.0354	0.00	32	1.810E+02	2.797E+00	0.0355	0.00
33	2.200E+02	2.761E+00	0.0356	0.00	34	2.800E+02	2.737E+00	0.0356	0.00
35	3.400E+02	2.898E+00	0.0357	0.00	36	4.400E+02	2.638E+00	0.0359	0.00
37	5.400E+02	2.595E+00	0.0360	0.00					

Initial Water Storage = 58.3598 cm

DAILY SUMMARY: Day = 1, Simulated Time = 24.0000 hr

Node Number	=	1	10	13	20	24
Depth (cm)	=	0.00000	24.00000	30.00000	100.00000	138.00000
Water (cm ³ /cm ³)	=	0.15254	0.20397	0.28653	0.31748	0.36540
Head (cm)	=	1.66417E+02	8.95303E+01	8.75181E+01	4.77887E+01	1.53362E+01
Water Flow (cm)	=	-5.01485E-03	1.18898E-02	2.72422E-03	3.98920E-03	4.59738E-03

PRESTOR INFIL RUNOFF EVAPD TRANS DRAIN NEWSTOR STORAGE
58.3598+ 0.0000+ 0.0000- 0.0000- 0.0000- 0.0074 = 58.3516 Versus 58.3515

Mass Balance = 1.0681E-04 cm; Time step attempts = 51 and successes = 51
Evaporation: Potential = 0.0000 cm, Actual = 0.0000 cm

DAILY SUMMARY: Day = 365, Simulated Time = 24.0000 hr

Node Number	=	1	10	13	20	24
Depth (cm)	=	0.00000	24.00000	30.00000	100.00000	138.00000
Water (cm ³ /cm ³)	=	0.04545	0.23209	0.30692	0.31800	0.36525
Head (cm)	=	7.07501E+04	4.81857E+01	5.89092E+01	4.72522E+01	1.54014E+01
Water Flow (cm)	=	-3.83908E-02	2.06529E-02	1.57903E-02	4.74100E-03	4.38226E-03

FIGURE D.8. Listing of Output File N62NP.OUT

PRESTOR INFIL RUNOFF EVAPD TRANS DRAIN NEWSTOR STORAGE
 59.3273+ 0.0000+ 0.0000 - 0.0384- 0.0000- 0.0046 = 59.2842 Versus 59.2843

Mass Balance = -3.8147E-05 cm; Time step attempts = 24 and successes = 24
 Evaporation: Potential = 0.1344 cm, Actual = 0.0384 cm

 UNSAT-H Version 2.0
 SIMULATION SUMMARY

Title:
 N62NP: Repeats PNL-5899 run as a check on UNSAT-H Version 2.0

Transpiration Scheme is: = 0
 Potential Evapotranspiration = 1.6523E+02 [cm]
 Potential Transpiration = 0.0000E+00 [cm]
 Actual Transpiration = 0.0000E+00 [cm]
 Potential Evaporation = 1.6523E+02 [cm]
 Actual Evaporation = 1.2741E+01 [cm]
 Evaporation during Growth = 0.0000E+00 [cm]
 Total Runoff = 0.0000E+00 [cm]
 Total Infiltration = 1.5382E+01 [cm]
 Total Drainage at Base of Profile = 1.6680E+00 [cm]
 Total Applied Water = 1.5382E+01 [cm]
 Actual Rainfall = 1.5382E+01 [cm]
 Actual Irrigation = 0.0000E+00 [cm]
 Total Final Moisture Storage = 5.9284E+01 [cm]
 Mass Balance Error = 4.7344E-02 [cm]
 Total Successful Time Steps = 14786
 Total Attempted Time Steps = 17381
 Total Time Step Reductions (DHMAX) = 0
 Total Changes in Surface Boundary = 7382
 Total Time Actually Simulated = 3.8500E+02 [days]

Total water flow (cm) across different depths at the end of 3.8500E+02 days:

DEPTH	FLOW	DEPTH	FLOW	DEPTH	FLOW
0.000	2.6408E+00	0.050	2.6261E+00	0.150	2.6182E+00
0.350	2.6009E+00	0.750	2.5885E+00	1.500	2.5822E+00
3.000	2.5783E+00	6.000	2.5659E+00	12.000	2.5303E+00
20.000	2.4208E+00	26.000	2.2492E+00	30.000	2.1111E+00
34.000	2.0112E+00	40.000	1.8742E+00	48.000	1.7446E+00
56.000	1.6577E+00	66.000	1.5918E+00	75.000	1.5473E+00
85.000	1.5220E+00	95.000	1.5094E+00	105.000	1.5043E+00
115.000	1.5032E+00	125.000	1.5040E+00	134.000	1.5052E+00
140.500	1.5063E+00	145.000	1.5072E+00	148.000	1.5079E+00
150.000	1.5085E+00	152.000	1.5087E+00	155.000	1.5091E+00
161.000	1.5099E+00	173.000	1.5119E+00	200.500	1.5170E+00
250.000	1.5332E+00	310.000	1.5544E+00	390.000	1.5845E+00
490.000	1.6349E+00	540.000	1.6680E+00		

FIGURE D.8. (contd)

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RHOLYP74.INP: Closed-bottom lysimeter in 200 Area with plants
1 4 1 1 0 0 0 IPLANT, LOWER, NGRAV, ISWDIF, INEAT, UPPERH, LOWERH
0 365 365 1 0 0 0.000E+00 NPRINT, DAYEND, NDAYS, NYEARS, IRAIN, ICONVH, OUTTIM
1 2 0 0 0 NSURPE, NFHOUR, ITOPOBC, ET OPT, ICLCUD
3 3 1 0 2 2 KUPT, KEST, IVAPOR, SK OPT, INMAX, INHMAX
0.000E+00 1.000E+00 0.0 0.000E+00 HIRRI, HDRY, HTOP, DHMAX
1.000E-04 1.000E+00 1.000E-05 24.0 DMAXBA, DELMAX, DELMIN, STOPHR
0.60 280.46 0.24 0.000E+00 TORT, TSDIL, VAPDIF, QHTOP
-1.000E-04 2.800E+02 1.000E+01 0.000E+00 TGRAD, TSMEAN, TSAMP, QHLEAK
0.5 2.0 1.000E+05 0.000E+00 WTF, RFACT, RAINIF, DHFACT
1 43 MATN, NPT
1 0.000 1 0.100 1 0.220 1 0.340 MAT,Z
1 0.400 1 0.600 1 0.840 1 1.100 MAT,Z
1 1.000 1 2.400 1 3.700 1 4.700 MAT,Z
1 0.250 1 0.500 1 12.000 1 17.000 MAT,Z
1 26.000 1 37.000 1 50.000 1 65.000 MAT,Z
1 80.000 1 100.000 1 130.000 1 170.000 MAT,Z
1 220.000 1 270.000 1 330.000 1 390.000 MAT,Z
1 533.000 1 600.000 1 630.000 1 901.000 MAT,Z
1 1143.000 1 1295.000 1 1440.000 1 1500.000 MAT,Z
1 1849.000 1 1700.000 1 1744.000 1 1779.000 MAT,Z
1 1803.000 1 1819.000 1 1829.000 MAT,Z
SOIL WATER CONTENT DATA
0.4142 0.0 29.8 1.63 THET, THTR, AIRINT, B
SOIL CONDUCTIVITY DATA
1 24.8 29.8 1.63 2.0 KMODEL, SK, AIRINT, B, EPIT
0 NDAY
329.025 327.940 327.160 326.721 Initial Conditions
326.462 326.317 326.228 325.997
325.439 324.400 322.842 321.662
319.901 317.326 313.508 308.565
302.286 297.413 297.955 305.454
326.144 352.546 425.380 533.201
692.252 811.017 841.007 845.091
867.077 908.831 968.274 1010.295
1087.087 1274.681 1388.494 1952.624
1312.374 1269.146 1240.555 1209.547
1187.037 1171.491 1181.586
1 1 1 1 121 273 LEAF, NFR00T, NUPTAK, NFPET, NSOW, NHRVST
4 0.94 NP0INT, BARE
120 0.0 182 1.03 243 1.03 274 0.0 FLAI
4.000E+00 3.400E-02 1.000E+00 AA, B1, B2
1 1 1 1 1 1 1 1 NTR00T
2 2 2 3 4 5 8 11 16 20 NTR00T
25 31 40 53 74 105 365 865 365 865 NTR00T
365 365 365 365 365 365 365 365 365 365 NTR00T
365 365 365 NTR00T
2.040E+03 1.500E+03 3.000E+01 THETAW, THETAD, THETAN
0.0000 0.0822 0.0560 0.0162 0.0703 0.0195 0.0225 0.0200
0.0138 0.0267 0.0202 0.0221 0.0832 0.3138 0.4497 0.3908
0.1133 0.1462 0.2107 0.1741 0.1487 0.2448 0.1403 0.1193
0.2710 0.2546 0.2585 0.3790 0.7365 0.2021 0.2348 0.3472
0.3610 0.2774 0.3114 0.2150 0.1378 0.1335 0.0994 0.0972
0.0972 0.0186 0.0398 0.1587 0.4410 0.1367 0.2000 0.2023
0.0582 0.3545 0.2057 0.2693 0.3200 0.1090 0.1868 0.2405
0.2450 0.3117 0.2419 0.3362 0.2932 0.3033 0.6257 0.4737
0.2390 0.2029 0.2874 0.2678 0.2218 0.2870 0.2953 0.3762
0.2205 0.1525 0.2208 0.4557 0.3780 0.4554 0.3100 0.4491
0.4228 0.3545 0.3865 0.3446 0.3090 0.4405 0.7763 0.3347
0.2062 0.4207 0.3997 0.4887 0.5102 0.1972 0.2608 0.5261
0.3766 0.4758 0.4864 0.7811 0.8106 0.9052 0.5271 0.5034

```


0.7427	0.4833	0.5363	0.7689	0.6382	0.6018	0.6049	0.4225
0.1791	0.3818	0.6238	0.5965	0.4217	0.6771	0.5139	0.6180
0.5688	0.5363	0.6892	0.5598	0.6581	0.6802	0.8252	0.8181
0.6825	0.6842	0.6707	0.8018	0.6286	0.6767	0.6430	0.3936
0.4192	0.4126	0.6168	0.6896	0.5698	0.6765	0.6618	0.4952
0.7588	0.8487	0.9255	0.7082	1.0032	0.7988	0.7482	0.7063
0.9405	0.8618	0.2931	0.5451	0.9652	0.9884	0.8043	0.8288
0.7811	0.8813	0.9182	0.9515	1.0859	1.1496	1.0574	1.1998
1.0034	1.3653	1.1136	0.8410	1.2001	1.0165	0.9340	1.0738
0.6078	1.0213	0.8213	0.8861	1.2351	0.9188	0.8875	0.9882
0.7608	0.7978	0.8265	0.8041	0.7158	0.8992	0.5214	0.7088
0.8369	0.9060	0.9983	0.8125	0.7223	0.6451	0.8204	0.8478
0.9482	0.8658	0.9005	0.9319	0.9869	0.9588	0.9416	0.9610
1.0287	0.8720	1.0299	1.0492	0.8015	0.8988	0.9084	0.9415
0.9787	0.9220	0.8292	0.8828	0.8487	0.8318	0.8315	0.8123
0.6673	0.7108	0.7233	0.8320	0.8581	0.7289	0.8308	0.8888
0.6815	0.6658	0.6385	0.7192	0.7914	0.8347	0.7981	0.8829
0.8486	0.6305	0.8475	0.7554	0.7299	0.7748	0.8983	0.8675
0.8788	0.8734	0.5994	0.6108	0.5532	0.5972	0.5658	0.5972
0.6454	0.8577	0.8678	0.6573	0.6488	0.7148	0.8884	0.6558
0.8888	0.6328	0.8248	0.8093	0.5232	0.5092	0.5299	0.5070
0.4888	0.5109	0.4709	0.4529	0.4418	0.3820	0.3948	0.4227
0.4488	0.4282	0.3688	0.3738	0.3582	0.4488	0.4288	0.3932
0.4021	0.3738	0.4288	0.3355	0.3584	0.3831	0.3132	0.2899
0.3048	0.3288	0.2792	0.2523	0.2288	0.3261	0.2185	0.0971
0.1993	0.1998	0.1555	0.0228	0.0687	0.0639	0.0528	0.1715
0.2219	0.2178	0.1838	0.1444	0.1848	0.1320	0.0872	0.0650
0.0418	0.1543	0.1883	0.2592	0.1837	0.1878	0.0748	0.0268
0.1985	0.0839	0.1120	0.0372	0.0893	0.0909	0.0685	0.0135
0.0554	0.1242	0.0837	0.0703	0.0257	0.0717	0.0719	0.1060
0.1818	0.0727	0.0883	0.1199	0.0889	0.0158	0.1759	0.1384
0.0648	0.1207	0.2858	0.1958	0.1071	0.0648	0.0158	0.0270
0.1528	0.1193	0.1012	0.1334	0.0322			

63 NWATER (13.46 CM, 5.30 IN)

2	1	4	1.000
4.000	0.152		
10.000	0.000		
13.000	0.025		
14.000	0.000		
7	1	2	1.000
10.000	0.025		
11.000	0.000		
12	1	2	1.000
1.000	0.432		
8.000	0.000		
14	1	2	1.000
22.000	0.178		
24.000	0.000		
15	1	4	1.000
4.000	0.078		
8.000	0.000		
7.000	0.025		
8.000	0.000		
18	1	4	1.000
3.000	0.610		
8.000	0.000		
9.000	0.025		
10.000	0.000		
24	1	2	1.000
13.000	0.051		
14.000	0.000		
30	1	2	1.000
22.000	0.127		

FIGURE D.9. (contd)

24.000	0.000		
31	1	2	1.000
0.000	0.559		
7.000	0.000		
44	1	2	1.000
23.000	0.025		
24.000	0.000		
46	1	2	1.000
20.000	0.051		
22.000	0.000		
49	1	4	1.000
1.000	0.076		
3.000	0.000		
13.000	0.737		
21.000	0.000		
58	1	2	1.000
20.000	0.152		
24.000	0.000		
60	1	2	1.000
10.000	0.076		
12.000	0.000		
69	1	2	1.000
21.000	0.076		
22.000	0.000		
70	1	8	1.000
4.000	0.025		
5.000	0.000		
16.000	0.102		
19.000	0.000		
20.000	0.025		
21.000	0.000		
23.000	0.102		
24.000	0.000		
71	1	2	1.000
9.000	0.076		
11.000	0.000		
74	1	2	1.000
7.000	0.025		
8.000	0.000		
75	1	2	1.000
8.000	0.051		
9.000	0.000		
86	1	2	1.000
14.000	0.051		
15.000	0.000		
88	1	2	1.000
7.000	0.127		
10.000	0.000		
89	1	8	1.000
3.000	0.483		
9.000	0.000		
10.000	0.025		
11.000	0.000		
13.000	0.076		
14.000	0.000		
94	1	2	1.000
14.000	0.127		
17.000	0.000		
112	1	4	1.000
16.000	0.076		
19.000	0.000		
21.000	0.229		
24.000	0.000		

FIGURE D.9. (contd)

113	1	8	1.000
1.000	0.025		
2.000	0.000		
3.000	0.025		
4.000	0.000		
13.000	0.305		
20.000	0.000		
22.000	0.203		
24.000	0.000		
114	1	2	1.000
0.000	0.025		
7.000	0.000		
115	1	4	1.000
5.000	0.051		
7.000	0.000		
17.000	0.076		
18.000	0.000		
117	1	2	1.000
0.000	0.025		
9.000	0.000		
131	1	2	1.000
2.000	0.051		
4.000	0.000		
137	1	2	1.000
1.000	0.102		
2.000	0.000		
138	1	4	1.000
16.000	0.152		
18.000	0.000		
23.000	0.025		
24.000	0.000		
139	1	2	1.000
0.000	0.025		
1.000	0.000		
141	1	2	1.000
23.000	0.025		
24.000	0.000		
144	1	8	1.000
3.000	0.025		
4.000	0.000		
5.000	0.279		
8.000	0.000		
23.000	0.025		
24.000	0.000		
155	1	4	1.000
12.000	0.254		
16.000	0.000		
17.000	0.051		
19.000	0.000		
189	1	4	1.000
16.000	0.203		
19.000	0.000		
22.000	0.152		
23.000	0.000		
190	1	2	1.000
5.000	0.254		
8.000	0.000		
198	1	2	1.000
2.000	0.051		
3.000	0.000		
200	1	2	1.000
1.000	1.143		
3.000	0.000		

FIGURE D.9. (contd)

269	1	2	1.000
13.000	0.025		
14.000	0.000		
300	1	2	1.000
23.000	0.025		
24.000	0.000		
301	1	6	1.000
0.000	0.025		
1.000	0.000		
11.000	0.025		
12.000	0.000		
15.000	0.432		
23.000	0.000		
304	1	2	1.000
19.000	0.025		
20.000	0.000		
309	1	2	1.000
3.000	0.152		
6.000	0.000		
310	1	4	1.000
6.000	0.025		
7.000	0.000		
13.000	0.035		
23.000	0.000		
311	1	6	1.000
1.000	0.051		
3.000	0.000		
5.000	0.025		
6.000	0.000		
7.000	0.025		
8.000	0.000		
321	1	2	1.000
12.000	0.305		
16.000	0.000		
325	1	6	1.000
0.000	0.051		
9.000	0.000		
17.000	0.025		
18.000	0.000		
19.000	0.025		
20.000	0.000		
327	1	6	1.000
6.000	0.279		
11.000	0.000		
15.000	0.178		
17.000	0.000		
18.000	0.025		
19.000	0.000		
336	1	2	1.000
5.000	0.102		
7.000	0.000		
337	1	8	1.000
2.000	0.305		
7.000	0.000		
8.000	0.051		
9.000	0.000		
10.000	0.025		
11.000	0.000		
21.000	0.203		
24.000	0.000		
338	1	2	1.000
0.000	0.711		
6.000	0.000		

FIGURE D.9. (contd)

340	1	8	1.000
1.000	0.203		
5.000	0.000		
6.000	0.025		
7.000	0.000		
11.000	0.051		
12.000	0.000		
344	1	2	1.000
16.000	0.025		
17.000	0.000		
346	1	2	1.000
18.000	0.152		
18.000	0.000		
348	1	2	1.000
3.000	0.051		
4.000	0.000		
349	1	2	1.000
2.000	0.025		
3.000	0.000		
350	1	2	1.000
20.000	0.025		
21.000	0.000		
353	1	2	1.000
11.000	0.076		
13.000	0.000		
354	1	2	1.000
11.000	0.076		
13.000	0.000		
355	1	2	1.000
5.000	0.025		
6.000	0.000		
359	1	2	1.000
0.000	0.076		
1.000	0.000		
360	1	6	1.000
15.000	0.203		
19.000	0.000		
21.000	0.025		
22.000	0.000		
23.000	0.025		
24.000	0.000		

FIGURE D.9. (contd)

 UNSAT-H Version 2.0
 INITIAL CONDITIONS

Input Filename: \$DISK3:[HCODE.UNSATH_VERS20]RHOLYP74.INP;8
 Results Filename: \$DISK3:[HCODE.UNSATH_VERS20]RHOLYP74.RES;19
 Date of Run: 28-DEC-89
 Time of Run: 20:00:10
 Title:
 RHOLYP74.INP: Closed-bottom lysimeter in 200 Area with plants

Initial Conditions					Initial Conditions				
NODE	DEPTH (cm)	HEAD (cm)	THETA (vol.)	TEMP (K)	NODE	DEPTH (cm)	HEAD (cm)	THETA (vol.)	TEMP (K)
1	0.000E+00	3.290E+02	0.0949	290.65	2	1.000E+01	3.279E+02	0.0951	290.94
3	2.200E+01	3.272E+02	0.0952	291.23	4	3.400E+01	3.267E+02	0.0953	291.62
5	4.800E+01	3.265E+02	0.0954	292.09	6	6.600E+01	3.263E+02	0.0954	292.93
7	8.400E+01	3.262E+02	0.0954	294.32	8	1.180E+02	3.260E+02	0.0955	296.07
9	1.080E+02	3.254E+02	0.0958	298.27	10	2.480E+02	3.244E+02	0.0957	294.31
11	3.760E+02	3.226E+02	0.0960	293.17	12	4.750E+02	3.217E+02	0.0962	292.18
13	6.250E+02	3.199E+02	0.0966	291.40	14	8.500E+02	3.173E+02	0.0970	290.30
15	1.200E+03	3.135E+02	0.0978	289.88	16	1.700E+03	3.086E+02	0.0987	289.36
17	2.500E+03	3.023E+02	0.1000	289.17	18	3.700E+03	2.974E+02	0.1010	289.09
19	5.000E+03	2.960E+02	0.1009	289.06	20	6.500E+03	3.055E+02	0.0993	289.06
21	8.000E+03	3.201E+02	0.0965	289.00	22	1.000E+04	3.528E+02	0.0910	289.09
23	1.300E+04	4.254E+02	0.0811	289.10	24	1.700E+04	5.332E+02	0.0706	289.10
25	2.200E+04	6.023E+02	0.0601	289.16	26	2.700E+04	8.110E+02	0.0546	289.10
27	3.300E+04	8.410E+02	0.0534	289.10	28	3.900E+04	8.451E+02	0.0532	289.10
29	5.330E+04	8.671E+02	0.0524	289.10	30	6.860E+04	9.088E+02	0.0509	289.09
31	8.380E+04	9.683E+02	0.0489	289.09	32	9.910E+04	1.010E+03	0.0477	289.07
33	1.143E+05	1.080E+03	0.0450	289.05	34	1.295E+05	1.275E+03	0.0414	289.10
35	1.448E+05	1.386E+03	0.0392	289.09	36	1.580E+05	1.363E+03	0.0399	289.11
37	1.649E+05	1.312E+03	0.0406	289.06	38	1.709E+05	1.269E+03	0.0415	289.50
39	1.744E+05	1.241E+03	0.0420	288.53	40	1.779E+05	1.210E+03	0.0427	288.50
41	1.803E+05	1.187E+03	0.0432	288.47	42	1.819E+05	1.171E+03	0.0435	288.43
43	1.829E+05	1.162E+03	0.0438	288.40					

Initial Water Storage = 93.8470 cm

NOTE: There are no temperature data when plants are modelled.

 DAILY SUMMARY: Day = 1, Simulated Time = 24.0000 hr

Node Number	=	1	19	22	29	41
Depth (cm)	=	0.00000	50.00000	100.00000	533.00000	1803.00000
Water (cm ³ /cm ³)	=	0.09176	0.09871	0.09190	0.05238	0.04320
Head (cm)	=	3.47682E+02	3.08085E+02	3.46814E+02	8.07065E+02	1.18701E+03
Water Flow (cm)	=	-5.90420E-02	1.05010E-01	1.09308E-01	1.05335E-03	1.23402E-05
Plant Sink (cm)	=	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

PRESTOR	INFIL	RUNOFF	EVAP0	TRANS	DRAIN	NEWSTOR	STORAGE
93.8470	+ 0.0000	+ 0.0000	- 0.0500	- 0.0000	- 0.0000	= 93.7870	Versus 93.7871

Mass Balance = -3.8147E-05 cm; Time step attempts = 44 and successes = 44
 Evaporation: Potential = 0.0000 cm, Actual = 0.0000 cm
 Transpiration: Potential = 0.0000 cm, Actual = 0.0000 cm

FIGURE D.10. Listing of Output File RHOLYP74.OUT

DAILY SUMMARY: Day = 365, Simulated Time = 24.0000 hr

Node Number	=	1	19	22	29	41
Depth (cm)	=	0.00000	50.00000	100.00000	533.00000	1003.00000
Water (cm ³ /cm ³)	=	0.00249	0.05243	0.05025	0.05064	0.04343
Head (cm)	=	1.24303E+05	8.65801E+02	9.27787E+02	7.63213E+02	1.17670E+03
Water Flow (cm)	=	-2.56000E-02	2.25995E-03	5.90184E-04	3.03469E-03	1.21570E-05
Plant Sink (cm)	=	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00

PRESTOR INFIL RUNOFF EVAP0 TRANS DRAIN NEWSTOR STORAGE
 88.9275+ 0.0000+ 0.0000 - 0.0255- 0.0000- 0.0000 = 88.9020 Versus 88.9020

Mass Balance = -6.4087E-04 cm; Time step attempts = 50 and successes = 42

Evaporation: Potential = 0.0322 cm, Actual = 0.0255 cm

Transpiration: Potential = 0.0000 cm, Actual = 0.0000 cm

UNSAT-H Version 2.0
 SIMULATION SUMMARY

Title:
 RHOLYP74.INP: Closed-bottom lysimeter in 200 Area with plants

Transpiration Scheme is:	=	1	
Potential Evapotranspiration	=	1.7494E+02	[cm]
Potential Transpiration	=	2.7426E+00	[cm]
Actual Transpiration	=	2.3732E+00	[cm]
Potential Evaporation	=	1.7220E+02	[cm]
Actual Evaporation	=	1.5999E+01	[cm]
Evaporation during Growth	=	3.7286E+00	[cm]
Total Runoff	=	0.0000E+00	[cm]
Total Infiltration	=	1.3448E+01	[cm]
Total Drainage at Base of Profile	=	0.0000E+00	[cm]
Total Applied Water	=	1.3448E+01	[cm]
Actual Rainfall	=	1.3448E+01	[cm]
Actual Irrigation	=	0.0000E+00	[cm]
Total Final Moisture Storage	=	8.8903E+01	[cm]
Mass Balance Error	=	1.9882E-02	[cm]
Total Successful Time Steps	=	18230	
Total Attempted Time Steps	=	23089	
Total Time Step Reductions (DHMAX)	=	0	
Total Changes in Surface Boundary	=	9924	
Total Time Actually Simulated	=	3.6500E+02	[days]

FIGURE D.10. (contd)

Total water flow (cm) across different depths at the end of 3.6500E+02 days:

DEPTH	FLOW	DEPTH	FLOW	DEPTH	FLOW
0.000	-2.5513E+00	0.050	-2.6071E+00	0.100	-2.5802E+00
0.200	-2.5409E+00	0.410	-2.5235E+00	0.570	-2.4992E+00
0.750	-2.4818E+00	1.010	-2.4037E+00	1.430	-2.4383E+00
2.000	-2.4018E+00	3.120	-2.3445E+00	4.255	-2.2800E+00
5.500	-2.2253E+00	7.375	-2.1430E+00	10.250	-2.0319E+00
14.500	-1.8958E+00	21.000	-1.7168E+00	31.000	-1.4400E+00
43.500	-1.0455E+00	57.500	-5.8178E-01	72.500	-2.3590E-02
90.000	5.9714E-01	115.000	1.4050E+00	150.000	2.2134E+00
195.000	2.7283E+00	245.000	2.7190E+00	300.000	2.4484E+00
300.000	2.1009E+00	401.500	1.4458E+00	600.500	8.1449E-01
702.000	5.7152E-01	914.500	4.3249E-01	1007.000	3.8467E-01
1219.000	3.4903E-01	1371.500	1.9107E-01	1514.000	7.8230E-02
1614.500	4.8473E-02	1679.000	3.2502E-02	1720.500	2.2891E-02
1761.500	1.5419E-02	1791.000	9.0070E-03	1811.000	4.3201E-03
1824.000	1.2128E-03	1829.000	0.0000E+00		

FIGURE D.10.1 (contd)


```

N62NPH: repeats test problem N62NP with UNSAT-H Version 2.0 and heat option
0 1 1 1 0 1 IPLANT,LOWER,NGRAV,ISWDIF,IHEAT,UPPERH,LOWERH
1 148 365 1 0 1 1.000E+00 NPRINT,DAYEND,NDAYS,NYEARS,IRAIN,ICONVH,OUTTIM
1 2 0 1 1 NSURPE,MFHOUR,ITOPBC,ET OPT,ICLOUD
1 3 1 0 3 2 KOPT,KEST,IVAPOR,SH OPT,INMAX,INHMAX
1.000E+00 1.000E+07 0.0 2.000E+04 HIRRI,HORY,HTOP,DHMAX
1.000E-05 2.500E-02 1.000E-06 24.0 DMAXBA,DELMAX,DELMIN,STOP4R
0.68 288.46 0.24 0.000E+00 TORT,TSOIL,VAPDIF,QHTOP
-0.000E-00 2.800E+02 1.000E+01 0.000E+00 TGRAD,TSMEAN,TSAMP,QHLEAK
0.5 1.5 1.000E-05 5.000E-01 WTF,RFACT,RAININ,DHFACT
3 37 MATN,NPT
1 0.000 1 0.100 1 0.200 1 0.500 MAT,Z
1 1.000 1 2.000 1 4.000 1 8.000 MAT,Z
1 16.000 1 24.000 1 28.000 2 32.000 MAT,Z
2 36.000 2 44.000 2 52.000 2 60.000 MAT,Z
2 70.000 2 80.000 2 90.000 2 100.000 MAT,Z
2 110.000 2 120.000 2 130.000 2 138.000 MAT,Z
2 143.000 2 147.000 2 149.000 3 151.000 MAT,Z
3 153.000 3 157.000 3 165.000 3 181.000 MAT,Z
3 220.000 3 280.000 3 340.000 3 440.000 MAT,Z
3 540.000 MAT,Z
4 5 MAXSUB,MAXPOL
Material No. 1, COMPGRAV.TH1: Composite soil with 15 % gravel by weight
4 1.0000000E+00 4.2200000E-01 NPOLY, X(1), Y(1)
1 4 1.0000000E+00 1.2650003E+01 I, NDEG(I)+1, XX1, XX2
4.2199999E-01 -2.7573731E-02 -2.3653656E-03 -3.2151821E-02 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
2 5 1.2650003E+01 2.4420010E+02 I, NDEG(I)+1, XX1, XX2
-1.3883400E-01 1.5021513E-00 -1.4785287E+00 5.4422855E-01 -7.0263125E-02 (COEF(I,J), J=1,NDEG(I)+1)
3 5 2.4420010E+02 7.1970044E+03 I, NDEG(I)+1, XX1, XX2
-1.7589752E+00 2.7017555E+00 -1.3545388E+00 2.8480807E-01 -2.1819080E-02 (COEF(I,J), J=1,NDEG(I)+1)
4 5 7.1970044E+03 8.6326599E+06 I, NDEG(I)+1, XX1, XX2
-3.4936512E-01 3.1459510E-01 -8.4237993E-02 9.1790808E-03 -3.5545405E-04 (COEF(I,J), J=1,NDEG(I)+1)
COMPGRAV.KH1
2 1.0000000E+00 3.8000000E-01 NPOLY, X(1), Y(1)
1 4 1.0000000E+00 4.4980000E+01 I, NDEG(I)+1, XX1, XX2
-4.4389757E-01 -5.8029747E-01 -2.8344643E-01 -2.1885858E-01 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
2 3 4.4980000E+01 8.6326599E+06 I, NDEG(I)+1, XX1, XX2
2.4089615E+00 -3.4391944E+00 4.3801209E-02 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
Material No. 2, COMPOS1.TH1: Composite soil
4 1.0000000E+00 4.2200000E-01 NPOLY, X(1), Y(1)
1 3 1.0000000E+00 5.4290004E+00 I, NDEG(I)+1, XX1, XX2
4.2199999E-01 -7.3107332E-03 -3.5250444E-02 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
2 3 5.4290004E+00 5.8900012E+02 I, NDEG(I)+1, XX1, XX2
4.2632638E-01 -1.9087702E-02 -2.7235843E-02 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
3 4 5.8900012E+02 1.6770025E+04 I, NDEG(I)+1, XX1, XX2
2.4013359E+00 -1.7962708E+00 4.5785773E-01 -3.9381173E-02 (COEF(I,J), J=1,NDEG(I)+1)
4 4 1.6770025E+04 8.6326599E+06 I, NDEG(I)+1, XX1, XX2
3.6377275E-01 -1.0580593E-01 1.0618908E-02 -3.5810552E-04 (COEF(I,J), J=1,NDEG(I)+1)
COMPOS1.KH1
3 1.0000000E+00 1.0800020E-01 NPOLY, X(1), Y(1)
1 4 1.0000000E+00 1.3260002E+03 I, NDEG(I)+1, XX1, XX2
-9.6657502E-01 -1.0985506E+00 5.8941185E-02 -1.2111286E-01 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
2 4 1.3260002E+03 7.1970044E+03 I, NDEG(I)+1, XX1, XX2
-6.3407219E+01 8.0421951E+01 -2.0131914E+01 2.0865219E+00 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
3 4 7.1970044E+03 8.6326599E+06 I, NDEG(I)+1, XX1, XX2
-9.5900745E+00 1.8411379E+00 -8.0871047E-01 2.4053080E-02 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
Material No. 3, GRAVEL1.TH1: Gravel 0.6-1.3 cm diameter
4 9.9999998E-03 4.1900000E-01 NPOLY, X(1), Y(1)
1 3 9.9999998E-03 7.7430010E-02 I, NDEG(I)+1, XX1, XX2
2.9529411E-01 -9.5836568E-02 -1.8991366E-02 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
2 3 7.7430010E-02 2.7829993E-01 I, NDEG(I)+1, XX1, XX2
-2.0774845E-01 -1.0013254E-00 -4.2448923E-01 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
3 5 2.7829993E-01 1.2920002E+01 I, NDEG(I)+1, XX1, XX2

```

FIGURE D.11. Listing of Output File N62NPH.INP

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5.8681458E-02 -1.1252354E-01 2.0134400E-01 -1.7054841E-01 5.2010903E-02(COEF(I,J), J=1,NDEG(I)+1)
4 5 1.2920002E+01 8.7777891E+00 I, NDEG(I)+1, XX1, XX2
4.5875907E-02 -2.2514000E-02 6.2657009E-03 -7.9328578E-04 3.5441328E-05(COEF(I,J), J=1,NDEG(I)+1)
GRAVEL1.KH1
4 0.9999998E-03 1.2600005E+03 NPOLY, X(1), Y(1)
1 4 0.9999998E-03 2.7829993E-01 I, NDEG(I)+1, XX1, XX2
-2.7429957E+00 -1.0560543E-01 -8.7793403E+00 -1.4784553E+00 0.0000000E-01(COEF(I,J), J=1,NDEG(I)+1)
2 3 2.7829993E-01 4.6420007E+00 I, NDEG(I)+1, XX1, XX2
-1.3305095E+00 -5.0247031E+00 -5.5922753E-01 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
3 3 4.6420007E+00 1.6880004E+01 I, NDEG(I)+1, XX1, XX2
1.8889209E-01 -9.5821028E+00 2.8585794E+00 0.0000000E-01 (COEF(I,J), J=1,NDEG(I)+1)
4 4 1.6880004E+01 8.7777891E+00 I, NDEG(I)+1, XX1, XX2
-3.7477951E+00 -3.1739995E+00 2.7821976E-01 -2.2469539E-02 0.0000000E-01(COEF(I,J), J=1,NDEG(I)+1)
Material No. 1, Silt Loam and Gravel Thermal Conductivity Parameters
0.6000e+00 0.8000e+00 4.5000e+00 0.2200e+00 0.0000e+00 2.3900e+00 TCON(A,B,C,D,E),CHS
Material No. 1, Silt Loam and Gravel Enhancement Factor Parameters
1.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 4.0000e+00 EF(A,B,C,D,E)
Material No. 2, Silt Loam Thermal Conductivity Parameters
0.6000e+00 0.8000e+00 4.5000e+00 0.2200e+00 0.0000e+00 2.3900e+00 TCON(A,B,C,D,E),CHS
Material No. 2, Silt Loam Enhancement Factor Parameters
1.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 4.0000e+00 EF(A,B,C,D,E)
Material No. 3, Gravel Thermal Conductivity Parameters
0.6000e+00 0.7000e+00 0.0000e+00 0.2600e+00 3.0000e+00 1.3000e+00 TCON(A,B,C,D,E),CHS
Material No. 3, Gravel Enhancement Factor Parameters
1.0000e+00 0.0000e+00 0.0000e+00 0.0000e+00 3.0000e+00 EF(A,B,C,D,E)
143 (TOSS.OUT file for day 1.43000E+02) NDAY (UNSAT-H V2.0)
7.03527E+01 0.00050E+01 6.67041E+01 6.31829E+01 Head Values
5.86509E+01 5.33590E+01 5.28878E+01 7.30592E+01
7.36407E+01 7.98150E+01 8.25940E+01 8.27130E+01
8.12407E+01 7.76403E+01 7.39738E+01 7.03354E+01
8.56513E+01 8.04913E+01 6.40121E+01 4.78960E+01
4.03359E+01 9.20043E+01 2.30220E+01 1.54730E+01
1.06312E+01 8.70270E+00 4.72414E+00 2.90972E+00
2.91202E+00 2.91000E+00 2.91794E+00 2.91818E+00
2.94394E+00 2.90990E+00 2.98704E+00 2.94597E+00
2.89400E+00
289.10 289.10 289.10 289.10 Initial Temperatures
289.10 289.10 289.10 289.10
289.10 289.10 289.10 289.10
289.10 289.10 289.10 289.10
289.10 289.10 289.10 289.10
289.10 289.10 289.10 289.10
289.10 289.10 289.10 289.10
289.10 289.10 289.10 289.10
289.10
0.00049 0.00049 0.914 15.24 0.00 46.57 ZH,ZM,ZT,ZU,D,LAT
1 33 20 20.9 41. 3.4 7.2 0.00
2 32 30 30.3 49. 2.1 10.0 0.00
3 54 29 33.9 100. 10.3 6.4 0.00
4 48 29 30.6 102. 5.1 7.8 0.00
5 39 29 32.7 64. 3.8 9.0 0.00
6 44 30 35.8 33. 4.0 10.0 0.03
7 63 35 42.9 93. 17.1 8.7 0.00
8 52 30 34.3 57. 7.5 9.8 0.00
9 37 22 10.0 133. 10.1 5.0 0.00
10 28 17 6.5 122. 6.4 5.0 0.00
11 30 20 13.1 113. 0.0 8.0 0.00
12 29 18 17.9 90. 3.3 10.0 0.00
13 32 17 19.3 100. 1.3 5.7 0.00
14 48 19 22.7 152. 11.3 5.1 0.00
15 35 20 15.4 190. 4.7 4.9 0.00
16 29 20 12.1 73. 5.8 8.5 0.00

```

FIGURE D.11. (contd)

17	36	20	17.2	151.	8.5	8.5	0.02
18	26	11	7.8	174.	7.3	6.2	0.00
19	16	7	-1.7	97.	13.1	7.3	0.00
20	20	4	-11.3	168.	17.7	5.8	0.00
21	24	2	-6.6	222.	3.6	0.1	0.00
22	20	-1	-3.9	211.	3.4	5.3	0.00
23	22	7	3.7	153.	3.3	9.4	0.00
24	32	18	9.6	179.	1.8	8.3	0.00
25	58	19	24.8	171.	0.8	9.1	0.00
26	54	47	37.3	31.	14.7	9.0	0.00
27	60	37	37.1	155.	9.7	7.1	0.00
28	51	28	34.0	224.	3.8	3.3	0.00
29	47	24	31.9	212.	3.6	4.4	0.00
30	47	27	31.9	237.	3.3	2.4	0.00
31	47	25	31.9	197.	4.0	7.1	0.00
32	45	27	32.2	173.	2.5	6.5	0.00
33	52	29	34.5	224.	1.9	4.3	0.00
34	60	31	34.8	123.	0.6	4.9	0.00
35	51	31	28.9	238.	5.9	4.5	0.00
36	44	28	18.5	227.	7.3	7.8	0.00
37	38	30	23.5	70.	7.4	9.5	0.09
38	36	27	31.4	70.	6.8	10.0	0.07
39	42	34	35.4	91.	3.2	10.0	0.00
40	41	36	37.6	37.	5.9	9.0	0.37
41	53	29	38.2	268.	4.8	3.6	0.00
42	48	36	38.2	119.	8.7	8.8	0.01
43	49	39	41.0	172.	3.4	9.8	0.07
44	46	38	40.8	70.	5.2	9.3	0.09
45	57	36	34.0	206.	14.8	7.7	0.00
46	48	36	35.1	86.	7.3	9.9	0.11
47	48	38	38.6	187.	3.5	9.7	0.02
48	51	37	39.6	159.	3.2	10.0	0.00
49	52	32	37.8	255.	3.3	5.1	0.00
50	51	37	33.5	139.	9.1	9.4	0.00
51	46	29	15.1	313.	9.8	3.1	0.00
52	51	22	18.6	325.	7.6	3.2	0.00
53	51	37	29.5	160.	11.4	6.2	0.01
54	35	24	8.2	173.	14.2	9.0	0.00
55	31	13	-2.0	378.	5.1	2.3	0.00
56	33	16	2.0	364.	11.0	4.2	0.00
57	32	14	-3.4	394.	0.6	0.0	0.00
58	38	8	2.6	332.	3.5	8.9	0.00
59	27	19	18.2	102.	8.4	9.4	0.06
60	34	15	21.7	322.	5.0	6.0	0.00
61	41	28	19.7	287.	10.0	5.3	0.00
62	45	22	21.8	241.	5.0	8.8	0.00
63	34	28	27.4	187.	9.3	10.0	0.05
64	41	31	33.4	140.	13.5	9.8	0.01
65	53	37	35.5	186.	7.8	9.3	0.00
66	59	32	38.1	402.	4.3	5.5	0.00
67	56	33	29.2	251.	12.9	6.3	0.01
68	42	28	28.3	293.	7.1	7.5	0.01
69	45	28	26.1	326.	4.8	7.3	0.00
70	45	27	26.9	320.	5.4	4.7	0.01
71	49	26	22.3	406.	5.7	2.5	0.00
72	51	23	20.0	439.	3.8	8.5	0.00
73	53	28	22.2	439.	4.1	8.6	0.00
74	58	33	27.0	452.	4.7	7.0	0.00
75	59	34	31.3	388.	6.5	7.9	0.00
76	62	39	30.1	413.	6.0	4.7	0.00
77	61	38	29.2	326.	7.3	8.3	0.00
78	58	36	34.2	415.	6.5	8.8	0.00
79	58	42	28.8	271.	14.0	7.8	0.00

FIGURE D.11. (contd)

80	48	32	25.3	265.	8.8	8.7	0.01
81	57	34	29.8	361.	10.9	8.8	0.00
82	58	38	28.9	430.	17.7	6.3	0.00
83	57	44	37.4	169.	18.3	9.5	0.00
84	81	44	39.7	410.	5.5	9.4	0.04
85	56	44	43.1	250.	4.1	10.0	0.00
86	54	38	28.9	311.	14.0	6.2	0.00
87	55	32	22.7	535.	5.4	0.8	0.00
88	60	33	28.1	525.	6.3	2.1	0.00
89	66	34	27.0	533.	4.9	0.0	0.00
90	70	34	29.7	527.	3.9	0.6	0.00
91	71	40	32.9	507.	5.0	1.9	0.00
92	68	38	32.8	526.	6.5	1.1	0.00
93	69	38	35.3	517.	4.7	0.1	0.00
94	72	43	40.3	387.	6.4	8.0	0.09
95	67	42	35.5	466.	7.6	5.2	0.00
96	69	52	42.3	217.	17.3	9.0	0.00
97	62	41	25.4	370.	15.4	6.2	0.00
98	55	41	34.3	350.	5.7	8.3	0.02
99	62	38	29.3	548.	14.0	2.3	0.00
100	64	41	25.9	577.	9.5	0.7	0.00
101	66	35	23.4	564.	5.6	5.1	0.00
102	73	42	28.2	506.	5.7	9.2	0.00
103	77	47	38.8	421.	3.8	9.6	0.00
104	83	56	40.9	492.	10.2	9.4	0.00
105	86	42	33.0	597.	13.0	4.1	0.09
106	69	34	28.2	622.	6.5	0.2	0.00
107	78	49	31.8	609.	7.5	0.2	0.00
108	63	45	36.1	594.	6.7	4.5	0.00
109	77	49	37.8	370.	14.7	8.1	0.00
110	66	47	29.4	633.	16.6	2.6	0.00
111	70	45	34.8	548.	5.6	5.1	0.00
112	81	45	34.0	640.	4.4	3.7	0.00
113	81	48	36.0	487.	6.8	7.8	0.00
114	68	43	32.1	483.	16.6	6.2	0.00
115	64	37	26.8	551.	7.2	0.9	0.00
116	62	41	31.6	422.	12.3	0.1	0.00
117	62	40	38.5	429.	10.3	6.2	0.14
118	58	39	24.8	481.	11.4	6.0	0.00
119	63	35	26.5	463.	9.5	4.2	0.00
120	65	38	32.0	476.	7.3	9.2	0.00
121	69	47	40.2	503.	13.5	8.1	0.00
122	69	50	35.1	551.	9.1	6.8	0.00
123	67	38	35.7	370.	12.0	5.9	0.04
124	61	32	21.0	602.	8.2	5.0	0.00
125	66	40	25.8	595.	5.7	8.5	0.00
126	55	46	42.2	226.	6.6	10.0	0.03
127	61	41	32.9	541.	5.9	8.5	0.00
128	54	46	45.6	169.	5.3	9.0	0.30
129	68	47	46.6	369.	7.8	8.8	0.23
130	66	44	36.6	646.	6.0	4.7	0.00
131	69	46	31.0	643.	12.3	4.2	0.00
132	63	36	30.4	530.	5.8	4.5	0.00
133	65	43	30.1	728.	6.5	2.6	0.00
134	71	45	32.8	684.	9.4	1.5	0.00
135	67	50	34.0	490.	10.7	4.5	0.00
136	77	52	37.1	653.	9.3	4.2	0.00
137	73	53	35.9	475.	11.1	7.0	0.00
138	71	46	30.8	576.	6.5	7.3	0.00
139	56	45	38.7	187.	11.4	9.5	0.03
140	70	52	39.8	431.	12.9	7.6	0.00
141	77	50	36.4	710.	9.9	3.1	0.00
142	72	43	39.3	585.	6.0	8.0	0.00

FIGURE D.11. (contd)

143	50	51	47.1	195.	8.6	10.0	0.21
144	54	49	49.1	67.	6.5	10.0	0.51
145	65	49	48.3	428.	3.9	9.3	0.00
146	74	46	48.2	616.	2.9	3.8	0.00
147	81	55	47.2	655.	11.1	4.0	0.00
148	78	53	48.6	709.	15.0	5.4	0.00
149	71	45	33.5	848.	11.5	7.5	0.00
150	70	44	33.4	725.	6.0	0.9	0.00
151	70	49	34.9	568.	8.3	8.3	0.00
152	74	52	35.1	687.	6.8	7.6	0.00
153	70	47	42.2	249.	11.8	9.4	0.00
154	62	39	31.8	486.	10.7	4.0	0.01
155	66	42	31.4	646.	7.2	7.5	0.00
156	68	50	35.5	509.	10.5	7.1	0.03
157	75	46	34.7	769.	7.2	0.0	0.00
158	83	49	37.5	725.	5.5	0.8	0.00
159	90	53	44.7	670.	9.9	5.3	0.00
160	82	55	36.1	758.	12.1	1.7	0.00
161	77	54	34.7	764.	11.3	1.1	0.00
162	61	53	35.8	758.	6.8	0.0	0.00
163	78	56	36.6	498.	11.3	3.6	0.00
164	76	47	43.2	520.	8.3	6.2	0.00
165	78	52	49.4	634.	4.9	6.7	0.00
166	90	63	48.8	628.	10.9	4.7	0.00
167	90	59	42.0	751.	13.5	0.0	0.00
168	84	59	39.9	786.	13.5	0.3	0.00
169	84	48	38.3	759.	7.0	0.4	0.00
170	90	53	38.3	765.	8.6	0.0	0.00
171	90	62	39.8	707.	10.3	3.7	0.00
172	88	63	35.1	760.	11.8	1.1	0.00
173	86	64	39.9	732.	7.0	5.7	0.00
174	92	61	41.6	526.	4.8	4.5	0.00
175	96	67	47.3	638.	8.1	0.9	0.00
176	94	62	43.9	625.	14.0	3.4	0.00
177	76	54	36.5	773.	11.9	0.1	0.00
178	80	53	39.9	728.	10.6	1.5	0.00
179	84	56	38.5	706.	6.5	5.5	0.00
180	94	64	41.3	739.	10.1	6.4	0.00
181	89	58	34.6	754.	12.3	1.5	0.00
182	75	51	35.5	767.	12.7	1.2	0.00
183	75	45	30.3	747.	6.1	3.4	0.00
184	83	53	31.7	752.	9.6	2.5	0.00
185	72	55	38.6	269.	5.5	7.4	0.00
186	76	53	42.7	627.	12.0	3.0	0.00
187	76	50	41.0	548.	9.0	4.8	0.00
188	85	56	40.4	739.	6.6	1.9	0.00
189	92	61	41.5	698.	7.1	1.0	0.00
190	93	66	46.6	667.	10.0	1.0	0.00
191	93	59	39.5	680.	9.2	5.3	0.00
192	92	58	39.6	686.	6.7	8.0	0.00
193	91	64	36.4	706.	15.8	1.9	0.00
194	82	61	41.7	724.	16.7	0.0	0.00
195	84	56	41.5	730.	8.1	1.6	0.00
196	86	60	41.9	785.	12.1	1.9	0.00
197	86	56	42.4	703.	9.5	6.4	0.00
198	75	56	37.3	737.	16.0	3.7	0.00
199	78	51	38.0	680.	7.5	5.3	0.00
200	88	53	40.9	656.	6.5	3.3	0.00
201	96	64	41.6	704.	8.8	2.2	0.00
202	96	67	42.8	703.	7.5	0.0	0.00
203	101	74	45.8	689.	7.1	0.9	0.00
204	104	74	43.6	686.	7.0	1.1	0.00
205	104	76	48.7	611.	6.5	4.8	0.00

FIGURE D.11. (contd)

206	103	78	46.5	584.	9.3	9.1	0.00
207	102	74	43.2	656.	6.0	4.0	0.00
208	100	69	47.3	665.	4.5	2.2	0.00
209	102	74	47.4	678.	9.4	3.5	0.00
210	99	67	46.3	683.	5.9	0.0	0.00
211	101	73	44.0	687.	6.6	1.6	0.00
212	101	70	46.3	629.	7.0	4.1	0.00
213	100	68	45.4	623.	7.3	7.1	0.00
214	92	65	43.8	547.	6.5	0.4	0.00
215	76	60	55.5	280.	10.0	0.9	0.20
216	76	60	45.8	452.	13.3	6.6	0.00
217	79	58	48.7	454.	6.0	0.4	0.00
218	79	62	49.0	464.	7.1	9.6	0.00
219	68	61	53.9	151.	7.7	10.0	0.03
220	75	54	56.7	175.	5.0	9.0	0.00
221	82	58	51.3	478.	6.9	5.7	0.00
222	87	59	41.0	660.	7.3	2.3	0.00
223	93	58	42.0	655.	4.6	0.6	0.00
224	87	65	54.5	559.	11.8	4.9	0.18
225	84	57	45.0	660.	5.6	0.4	0.00
226	93	57	42.4	649.	4.9	0.0	0.00
227	98	61	41.2	643.	5.6	0.0	0.00
228	93	65	47.0	662.	12.4	3.5	0.00
229	84	57	46.0	603.	10.5	1.1	0.00
230	83	56	47.0	564.	8.3	8.7	0.00
231	88	59	51.1	611.	5.5	3.0	0.00
232	93	62	54.5	617.	8.3	0.2	0.00
233	83	62	41.0	607.	17.9	4.5	0.00
234	82	58	48.0	620.	9.0	0.8	0.00
235	86	58	41.9	614.	5.6	0.2	0.00
236	94	54	48.7	608.	4.1	0.0	0.00
237	92	64	43.1	584.	14.1	0.7	0.00
238	76	56	38.5	465.	14.0	2.8	0.00
239	79	60	39.4	521.	11.8	5.0	0.00
240	77	60	42.7	511.	7.7	6.8	0.00
241	79	53	43.2	592.	6.1	0.2	0.00
242	85	58	39.8	586.	4.7	0.5	0.00
243	92	57	40.2	580.	5.2	0.0	0.00
244	92	59	40.1	580.	6.7	0.0	0.00
245	88	65	31.9	492.	10.8	2.5	0.00
246	84	54	28.5	564.	5.6	2.0	0.00
247	86	53	27.9	583.	6.9	0.0	0.00
248	91	54	32.5	579.	4.7	0.0	0.00
249	96	58	35.8	568.	8.5	0.0	0.00
250	78	52	33.1	582.	12.8	0.2	0.00
251	70	42	26.6	558.	4.2	1.5	0.00
252	78	40	26.8	544.	4.7	3.7	0.00
253	70	56	48.4	107.	12.5	9.0	0.04
254	72	47	35.4	527.	10.2	6.1	0.00
255	89	46	37.2	404.	3.4	0.1	0.00
256	73	54	49.5	287.	6.1	9.0	0.00
257	79	54	43.2	481.	11.0	3.3	0.00
258	79	48	35.8	520.	4.7	1.5	0.00
259	82	48	33.3	510.	2.8	1.3	0.00
260	87	52	33.8	503.	7.0	0.0	0.00
261	90	60	40.5	446.	9.7	3.9	0.00
262	85	57	48.0	443.	4.3	4.0	0.00
263	90	62	47.5	444.	8.0	4.1	0.00
264	88	67	47.7	448.	6.3	1.5	0.00
265	88	54	48.1	442.	7.2	0.0	0.00
266	84	53	43.5	440.	4.0	0.0	0.00
267	87	54	43.4	446.	5.5	0.0	0.00
268	89	64	44.4	434.	6.5	0.0	0.00

FIGURE D.11. (contd)

269	88	58	43.8	392.	5.8	8.3	0.00
270	74	59	43.8	227.	11.0	7.7	0.00
271	82	58	47.5	97.	9.4	7.9	0.34
272	68	49	44.9	345.	10.3	3.3	0.00
273	71	43	45.8	418.	5.5	6.3	0.00
274	75	58	45.2	398.	5.3	1.3	0.00
275	76	52	47.8	348.	6.5	7.2	0.02
276	88	48	41.8	376.	7.0	5.7	0.00
277	88	49	36.3	368.	7.8	3.3	0.00
278	88	39	35.3	398.	4.8	2.5	0.00
279	85	46	37.4	288.	5.8	7.8	0.00
280	52	37	48.2	88.	3.5	6.5	0.03
281	83	38	39.9	328.	10.9	6.8	0.00
282	82	47	42.1	224.	12.1	10.8	0.00
283	58	45	43.3	188.	1.2	18.8	0.01
284	52	42	44.9	45.	4.7	9.3	0.26
285	57	48	43.2	38.	18.2	9.9	0.52
286	61	47	48.8	241.	10.7	6.8	0.00
287	88	47	44.8	182.	9.5	9.8	0.11
288	83	42	37.4	288.	8.3	1.3	0.00
289	83	36	37.4	318.	4.3	3.2	0.00
290	83	36	42.1	313.	3.4	5.8	0.00
291	88	39	45.3	182.	3.8	7.5	0.00
292	85	41	47.8	383.	4.5	2.3	0.00
293	71	42	48.8	283.	3.2	7.4	0.00
294	72	48	47.8	217.	7.2	8.1	0.00
295	76	48	45.7	285.	3.2	5.8	0.00
296	88	41	48.2	289.	3.5	8.1	0.00
297	88	45	48.8	284.	6.5	8.8	0.00
298	88	48	44.9	254.	3.8	4.3	0.00
299	82	39	44.9	188.	4.8	8.8	0.00
300	82	42	48.2	241.	8.8	1.8	0.00
301	84	41	48.3	251.	5.4	1.3	0.00
302	84	43	47.3	254.	4.8	1.9	0.00
303	47	43	45.8	49.	1.2	18.8	0.00
304	52	48	48.9	83.	3.8	18.8	0.00
305	58	49	48.2	55.	3.8	18.8	0.00
306	52	49	42.8	49.	5.3	18.8	0.00
307	51	48	41.8	34.	2.5	18.8	0.00
308	58	45	42.5	88.	2.5	18.8	0.00
309	58	48	38.8	148.	18.8	5.4	0.00
310	88	36	34.4	235.	4.9	3.3	0.00
311	53	35	35.3	282.	5.3	7.7	0.00
312	51	48	44.5	92.	2.9	18.8	0.07
313	81	48	41.4	191.	7.7	5.8	0.00
314	58	38	38.8	131.	9.3	7.8	0.00
315	58	45	42.8	188.	7.8	7.8	0.02
316	48	33	38.5	47.	7.5	8.8	0.13
317	58	34	37.8	163.	4.5	7.8	0.00
318	48	31	35.4	45.	1.5	9.2	0.00
319	44	33	38.9	73.	3.1	9.1	0.05
320	47	33	33.8	191.	3.8	8.4	0.00
321	44	32	33.9	128.	4.8	8.1	0.00
322	38	25	31.1	183.	2.3	7.3	0.00
323	87	36	41.8	118.	25.8	8.7	0.00
324	82	43	41.8	58.	12.8	8.9	0.00
325	58	39	32.8	184.	8.4	8.8	0.00
326	53	31	29.5	187.	7.7	3.9	0.00
327	48	38	28.9	182.	4.4	5.8	0.00
328	54	27	32.2	186.	7.1	8.5	0.00
329	85	58	38.7	44.	18.9	9.9	0.00
330	55	37	34.5	183.	9.9	8.8	0.00
331	58	38	28.8	142.	7.7	6.3	0.00

FIGURE D.11. (contd)

332	44	25	22.8	173.	3.8	2.1	0.00
333	33	18	23.2	94.	2.4	7.0	0.00
334	48	33	31.9	48.	9.5	8.3	0.30
335	40	30	29.3	94.	4.5	8.8	0.01
336	40	34	33.6	103.	7.1	8.5	0.00
337	40	32	26.4	117.	8.1	8.8	0.00
338	37	33	32.1	28.	4.1	9.8	0.01
339	30	33	34.1	87.	3.8	8.9	0.00
340	46	28	34.8	140.	3.0	7.1	0.00
341	44	31	35.5	90.	2.9	9.6	0.00
342	42	32	37.0	69.	6.3	8.9	0.00
343	41	36	37.1	46.	3.1	9.8	0.00
344	39	36	37.3	25.	1.4	10.0	0.02
345	40	37	36.4	30.	2.8	10.0	0.01
346	38	36	33.9	20.	0.0	10.0	0.00
347	38	35	34.8	42.	2.2	10.0	0.18
348	41	36	37.0	65.	2.0	9.8	0.11
349	45	35	40.0	38.	3.0	9.1	0.09
350	44	38	40.6	40.	7.0	10.0	0.05
351	46	42	43.4	37.	1.4	10.0	0.07
352	45	40	42.3	49.	2.5	9.8	0.02
353	46	36	40.3	73.	3.8	7.5	0.05
354	35	36	32.5	35.	2.0	9.4	0.00
355	48	33	35.1	58.	5.8	7.5	0.00
356	45	28	27.0	142.	6.0	2.9	0.00
357	39	24	20.3	104.	0.8	0.1	0.00
358	32	20	17.0	152.	5.6	5.4	0.00
359	32	18	17.3	149.	5.2	4.5	0.00
360	30	17	16.5	133.	4.2	6.4	0.00
361	43	22	24.3	73.	3.0	9.6	0.00
362	50	30	32.4	38.	13.3	9.3	0.00
363	46	30	32.4	31.	9.0	10.0	0.00
364	52	37	35.0	14.	10.9	8.1	0.00
365	55	36	36.9	138.	5.7	7.7	0.00
62							
3	1	2	1.000				
0.000	0.203						
2.000	0.000						
6	1	2	1.000				
14.000	0.076						
15.000	0.000						
17	1	2	1.000				
4.000	0.051						
5.000	0.000						
37	1	4	1.000				
14.000	0.127						
16.000	0.000						
17.000	0.102						
19.000	0.000						
38	1	2	1.000				
12.000	0.178						
17.000	0.000						
40	1	2	1.000				
13.000	0.940						
17.000	0.000						
42	1	2	1.000				
21.000	0.025						
22.000	0.000						
43	1	2	1.000				
20.000	0.178						
22.000	0.000						
44	1	4	1.000				
15.000	0.203						

NWATER

FIGURE D.11. (contd)

18.000	0.000
19.000	0.025
20.000	0.000
46	1 2 1.000
21.000	0.279
24.000	0.000
47	1 2 1.000
0.000	0.051
1.000	0.000
53	1 2 1.000
11.000	0.025
12.000	0.000
59	1 6 1.000
13.000	0.078
15.000	0.000
16.000	0.025
17.000	0.000
18.000	0.051
19.000	0.000
63	1 2 1.000
7.000	0.127
11.000	0.000
64	1 2 1.000
14.000	0.025
15.000	0.000
67	1 2 1.000
13.000	0.025
14.000	0.000
68	1 2 1.000
16.000	0.025
17.000	0.000
76	1 2 1.000
17.000	0.025
18.000	0.000
80	1 2 1.000
20.000	0.025
21.000	0.000
84	1 4 1.000
5.000	0.051
6.000	0.000
19.000	0.051
21.000	0.000
94	1 2 1.000
14.000	0.229
16.000	0.000
98	1 2 1.000
6.000	0.051
7.000	0.000
105	1 2 1.000
4.000	0.229
6.000	0.000
117	1 2 1.000
1.000	0.358
6.000	0.000
123	1 2 1.000
6.000	0.102
7.000	0.000
126	1 4 1.000
3.000	0.051
5.000	0.000
19.000	0.025
20.000	0.000
128	1 6 1.000

FIGURE D.11. (contd)

6.000	0.102		
7.000	0.000		
8.000	0.127		
11.000	0.000		
13.000	0.533		
15.000	0.000		
129	1	4	1.000
5.000	0.178		
6.000	0.000		
15.000	0.406		
17.000	0.000		
139	1	4	1.000
7.000	0.051		
8.000	0.000		
10.000	0.025		
11.000	0.000		
143	1	4	1.000
3.000	0.432		
7.000	0.000		
8.000	0.102		
10.000	0.000		
144	1	6	1.000
3.000	0.152		
5.000	0.000		
6.000	1.067		
13.000	0.000		
15.000	0.076		
17.000	0.000		
154	1	2	1.000
12.000	0.025		
13.000	0.000		
156	1	2	1.000
4.000	0.076		
5.000	0.000		
164	1	4	1.000
15.000	0.025		
16.000	0.000		
21.000	0.178		
22.000	0.000		
215	1	6	1.000
3.000	0.483		
6.000	0.000		
8.000	0.025		
9.000	0.000		
14.000	0.229		
17.000	0.000		
219	1	6	1.000
0.000	0.025		
1.000	0.000		
2.000	0.025		
3.000	0.000		
7.000	0.025		
8.000	0.000		
224	1	2	1.000
4.000	0.457		
7.000	0.000		
253	1	4	1.000
2.000	0.025		
3.000	0.000		
6.000	0.076		
11.000	0.000		
271	1	2	1.000
3.000	0.664		

FIGURE D.11. (contd)

12.000	0.000		
275	1	4	1.000
21.000	0.025		
22.000	0.000		
23.000	0.025		
24.000	0.000		
280	1	4	1.000
13.000	0.025		
14.000	0.000		
16.000	0.051		
17.000	0.000		
283	1	2	1.000
13.000	0.025		
14.000	0.000		
284	1	2	1.000
8.000	0.000		
13.000	0.000		
285	1	4	1.000
10.000	0.991		
16.000	0.000		
17.000	0.330		
19.000	0.000		
287	1	8	1.000
4.000	0.229		
8.000	0.000		
9.000	0.025		
10.000	0.000		
11.000	0.025		
12.000	0.000		
312	1	4	1.000
1.000	0.127		
2.000	0.000		
23.000	0.051		
24.000	0.000		
313	1	2	1.000
0.000	0.203		
2.000	0.000		
315	1	2	1.000
3.000	0.051		
5.000	0.000		
318	1	2	1.000
13.000	0.330		
16.000	0.000		
319	1	2	1.000
7.000	0.127		
9.000	0.000		
334	1	4	1.000
6.000	0.051		
8.000	0.000		
9.000	0.711		
12.000	0.000		
335	1	2	1.000
22.000	0.025		
23.000	0.000		
338	1	2	1.000
14.000	0.025		
15.000	0.000		
344	1	4	1.000
1.000	0.025		
2.000	0.000		
12.000	0.025		
13.000	0.000		
345	1	2	1.000

FIGURE D.11. (contd)

5.000	0.025		
6.000	0.000		
347	1	0	1.000
2.000	0.203		
6.000	0.000		
19.000	0.076		
21.000	0.000		
22.000	0.127		
24.000	0.000		
348	1	2	1.000
0.000	0.279		
0.000	0.000		
349	1	0	1.000
0.000	0.051		
1.000	0.000		
2.000	0.025		
3.000	0.000		
5.000	0.076		
7.000	0.000		
8.000	0.076		
11.000	0.000		
350	1	0	1.000
13.000	0.025		
14.000	0.000		
17.000	0.076		
19.000	0.000		
23.000	0.025		
24.000	0.000		
351	1	4	1.000
9.000	0.152		
11.000	0.000		
13.000	0.025		
14.000	0.000		
352	1	2	1.000
13.000	0.051		
15.000	0.000		
353	1	2	1.000
2.000	0.127		
4.000	0.000		

FIGURE D.11. (contd)

UNSAT-H Version 2.0
INITIAL CONDITIONS

Input Filename: 8DISK3:[HCODE,UNSAT_H_VERS20]N62NPH.INP;29
Results Filename: 8DISK3:[HCODE,UNSAT_H_VERS20]N62NPH.RES;45
Date of Run: 8-MAY-98
Time of Run: 10:45:32
Title:
N62NPH: repeats test problem N62NP with UNSAT-H Version 2.0 and heat option

Initial Conditions					Initial Conditions				
NODE	DEPTH (cm)	HEAD (cm)	THETA (vol.)	TEMP (K)	NODE	DEPTH (cm)	HEAD (cm)	THETA (vol.)	TEMP (K)
1	0.000E+00	7.035E+01	0.2031	289.10	2	1.000E+01	6.007E+01	0.2055	289.10
3	2.000E+01	6.078E+01	0.2008	289.10	4	5.000E+01	6.318E+01	0.2109	289.10
5	1.000E+00	5.006E+01	0.2164	289.10	6	2.000E+00	5.336E+01	0.2230	289.10
7	4.000E+00	5.289E+01	0.2245	289.10	8	8.000E+00	7.306E+01	0.2005	289.10
9	1.000E+01	7.304E+01	0.2000	289.10	10	2.400E+01	7.982E+01	0.1946	289.10
11	2.000E+01	8.259E+01	0.1924	289.10	12	3.200E+01	8.271E+01	0.2090	289.10
13	3.000E+01	8.124E+01	0.2005	289.10	14	4.400E+01	7.765E+01	0.2029	289.10
15	5.200E+01	7.397E+01	0.2055	289.10	16	6.000E+01	7.034E+01	0.2001	289.10
17	7.000E+01	6.565E+01	0.3017	289.10	18	8.000E+01	6.049E+01	0.3059	289.10
19	9.000E+01	5.461E+01	0.3110	289.10	20	1.000E+02	4.790E+01	0.3174	289.10
21	1.100E+02	4.034E+01	0.3255	289.10	22	1.200E+02	3.200E+01	0.3359	289.10
23	1.300E+02	2.302E+01	0.3498	289.10	24	1.300E+02	1.547E+01	0.3651	289.10
25	1.430E+02	1.063E+01	0.3700	289.10	26	1.470E+02	6.703E+00	0.3920	289.10
27	1.490E+02	4.724E+00	0.4010	289.10	28	1.510E+02	2.910E+00	0.0352	289.10
29	1.530E+02	2.912E+00	0.0352	289.10	30	1.570E+02	2.910E+00	0.0352	289.10
31	1.650E+02	2.918E+00	0.0352	289.10	32	1.810E+02	2.918E+00	0.0352	289.10
33	2.200E+02	2.944E+00	0.0351	289.10	34	2.000E+02	2.970E+00	0.0351	289.10
35	3.400E+02	2.987E+00	0.0350	289.10	36	4.400E+02	2.946E+00	0.0351	289.10
37	5.400E+02	2.894E+00	0.0352	289.10					

Initial Water Storage = 58.2277 cm

DAILY SUMMARY: Day = 144, Simulated Time = 24.0000 hr

Node Number	=	1	10	13	20	24
Depth (cm)	=	0.00000	24.00000	36.00000	100.00000	138.00000
Water (cm ³ /cm ³)	=	0.31291	0.19489	0.29057	0.31736	0.36508
Head (cm)	=	1.93484E+01	7.95141E+01	8.11094E+01	4.78950E+01	1.54720E+01
Water Flow (cm)	=	1.22637E+00	4.09666E+03	2.87126E+03	4.17200E+03	4.01933E+03
Temperature (K)	=	2.84560E+02	2.88198E+02	2.88000E+02	2.89099E+02	2.89101E+02
Heat Flow (J/cm ²)	=	-1.64230E+02	-3.00137E+01	-1.19046E+01	3.12840E+02	-1.52924E+02

PRESTOR INFIL RUNOFF EVAPO TRANS DRAIN NEWSTOR STORAGE
58.2277+ 1.2950+ 0.0000 - 0.0031- 0.0000- 0.0041 = 59.4555 Versus 59.4554

Mass Balance = 1.1826E-04 cm; Time step attempts = 1169 and successes = 1117
Daily meteorological parameters
TMAX (K) = 2.8538E+02 TMIN (K) = 2.8260E+02 VD A (g/cm³) = 9.1063E+00
WIND (m/s) = 2.9055E+00 CLOUD (frac) = 1.0000E+00 SR MEAS (J/m²) = 2.8060E+00
Heat flow parameters (units = J/cm² unless noted)
RX (J/m²) = 1.8978E+00 SHF (J/m²) = -1.4852E+00 SEN (J/m²) = 1.8240E+00
LE (J/m²) = 1.5508E+00 QH(NPT) = 0.0000E+00 HBE = 2.5122E+00

FIGURE D.12. Listing of Output File N62NPH.OUT

DAILY SUMMARY: Day = 148, Simulated Time = 24.0000 hr

Node Number	=	1	10	13	20	24
Depth (cm)	=	0.00000	24.00000	30.00000	100.00000	130.00000
Water (cm ³ /cm ³)	=	0.03148	0.10967	0.29067	0.31730	0.36589
Head (cm)	=	5.12889E+05	7.40642E+01	8.10419E+01	4.78937E+01	1.54890E+01
Water Flow (cm)	=	-2.25434E+01	6.51824E+03	2.99812E+03	4.16886E+03	4.03379E+03
Temperature (K)	=	2.90635E+02	2.94292E+02	2.91393E+02	2.89061E+02	2.89100E+02
Heat Flow (J/cm ²)	=	7.73168E+02	1.37800E+02	6.18534E+01	-1.00617E+00	-3.21804E+02

PRESTOR INFIL RUNOFF EVAPD TRANS DRAIN NEWSTOR STORAGE
 59.1752- 0.0000- 0.0000 - 0.2258- 0.0000- 0.0041 = 58.9453 Versus 58.9454

Mass Balance = -1.2589E-04 cm; Time step attempts = 1160 and successes = 1107
 Daily meteorological parameters

TMAX (K) = 2.9849E+02 TMIN (K) = 2.8094E+02 VD A (g/cm³) = 8.8204E-06
 WIND (m/s) = 1.2963E+00 CLOUD (frac) = 3.8800E-01 SR_MEAS (J/m²) = 2.5790E+07
 Heat flow parameters (units = J/cm² unless noted)
 RN (J/m²) = 1.8110E+07 SHF (J/m²) = 3.0716E+06 SEN (J/m²) = 3.7838E+06
 LE (J/m²) = 5.4749E+06 QH(NPT) = 0.0000E+00 HBE = 9.3990E-01

UNSAT-H Version 2.0
 SIMULATION SUMMARY

Title:
 M62NPH: repeats test problem M62NP with UNSAT-H Version 2.0 and heat option

Transpiration Scheme is:	=	0	
Potential Evapotranspiration	=	0.0000E+00	[cm]
Potential Transpiration	=	0.0000E+00	[cm]
Actual Transpiration	=	0.0000E+00	[cm]
Potential Evaporation	=	0.0000E+00	[cm]
Actual Evaporation	=	5.6523E-01	[cm]
Evaporation during Growth	=	0.0000E+00	[cm]
Total Runoff	=	0.0000E+00	[cm]
Total Infiltration	=	1.2950E+00	[cm]
Total Drainage at Base of Profile	=	1.2203E-02	[cm]
Total Applied Water	=	1.2950E+00	[cm]
Actual Rainfall	=	1.2950E+00	[cm]
Actual Irrigation	=	0.0000E+00	[cm]
Total Final Moisture Storage	=	5.8945E+01	[cm]
Mass Balance Error	=	-1.4114E-04	[cm]
Total Successful Time Steps	=	3283	
Total Attempted Time Steps	=	3419	
Total Time Step Reductions (DHMAX)	=	80	
Total Changes in Surface Boundary	=	0	
Total Time Actually Simulated	=	3.0000E+00	[days]
Total Net Radiation	=	2.7705E+07	[J/m ²]
Total Soil-Surface Heat Flow	=	5.6441E+06	[J/m ²]
Total Sensible Heat Flow	=	0.2812E+06	[J/m ²]
Total Bottom Heat Flow	=	0.0000E+00	[J/m ²]
Total Latent Heat Flow	=	1.3779E+07	[J/m ²]
Heat Balance Error	=	4.9829E+04	[J/m ²]

FIGURE D.12. (contd)

Total water flow (cm) across different depths at the end of 3.0000E+00 days:

DEPTH	FLOW	DEPTH	FLOW	DEPTH	FLOW
0.000	7.2977E-01	0.050	7.3839E-01	0.150	7.5570E-01
0.350	7.9019E-01	0.750	7.9789E-01	1.500	8.0007E-01
3.000	8.0214E-01	6.000	7.2432E-01	12.000	3.1492E-01
20.000	4.5385E-02	26.000	1.5240E-02	30.000	1.0000E-02
34.000	9.0078E-03	40.000	0.0018E-03	48.000	9.3200E-03
50.000	1.0328E-02	65.000	1.1377E-02	75.000	1.2141E-02
85.000	1.2500E-02	95.000	1.2005E-02	105.000	1.2511E-02
115.000	1.2403E-02	125.000	1.2240E-02	134.000	1.2103E-02
140.500	1.2070E-02	145.000	1.2010E-02	148.000	1.1905E-02
150.000	1.1935E-02	152.000	1.1923E-02	155.000	1.1900E-02
161.000	1.1859E-02	173.000	1.1707E-02	200.500	1.1495E-02
250.000	1.0939E-02	310.000	1.0470E-02	390.000	1.0005E-02
490.000	1.1015E-02	540.000	1.2203E-02		

Total heat flow (J/cm2) across different depths at the end of 3.0000E+00 days:

DEPTH	FLOW	DEPTH	FLOW	DEPTH	FLOW
0.000	5.0441E+02	0.050	1.1542E+03	0.150	8.3900E+02
0.350	7.2113E+02	0.750	5.3202E+02	1.500	6.2203E+02
3.000	5.0332E+02	6.000	4.5000E+02	12.000	3.4025E+02
20.000	2.1359E+02	26.000	1.4407E+02	30.000	1.0931E+02
34.000	7.7200E+01	40.000	4.1704E+01	48.000	1.0034E+01
50.000	4.0450E+00	65.000	-2.0231E+00	75.000	-4.5540E+00
85.000	-5.0521E+00	95.000	-3.7505E+00	105.000	-2.5939E+00
115.000	-1.5058E+00	125.000	-1.3140E+00	134.000	-1.0002E-01
140.500	-2.5345E-02	145.000	-3.0019E-01	148.000	-7.1000E-02
150.000	1.4391E-01	152.000	1.0145E-01	155.000	1.9020E-01
161.000	4.4020E-01	173.000	0.5427E-01	200.500	4.0005E-01
250.000	-5.4097E-01	310.000	4.0425E-02	390.000	-0.3000E-02
490.000	2.5021E-01	540.000	0.0000E+00		

FIGURE D.12. (contd)

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