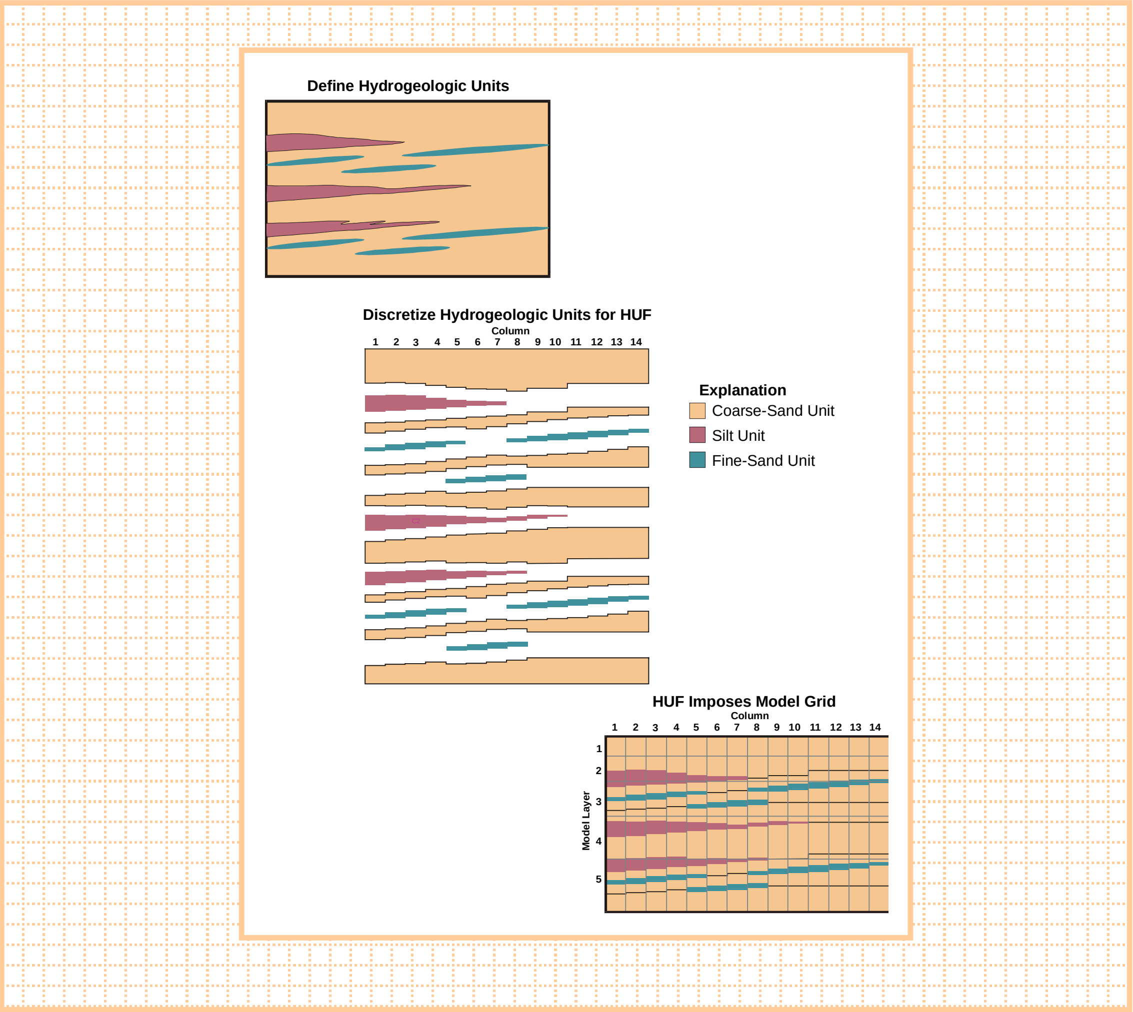
Prepared in cooperation with the
U.S. Department of Energy

MODFLOW-2000, THE U.S. GEOLOGICAL SURVEY MODULAR GROUND-WATER MODEL — DOCUMENTATION OF THE HYDROGEOLOGIC-UNIT FLOW (HUF) PACKAGE

Open-File Report 00-342



U.S. Department of the Interior
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By EVAN R. ANDERMAN[1] *and* MARY C. HILL[2]

U.S. GEOLOGICAL SURVEY

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PREFACE

This report describes the Hydrogeologic-Unit Flow (HUF) Package for the computer program MODFLOW-2000. The performance of the program has been tested in a variety of applications. Future applications, however, might reveal errors that were not detected in the test simulations. Users are requested to notify the U.S. Geological Survey of any errors found in this document or the computer program using the email address available at the web address below. Updates might occasionally be made to both this document and to HUF. Users can check for updates on the Internet at URL http://water.usgs.gov/software/ground_water.html/.

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DOCUMENTATION OF THE HYDROGEOLOGIC-UNIT FLOW (HUF) PACKAGE

By Evan R. Anderman[1] *and* Mary C. Hill[2]

ABSTRACT

This report documents the Hydrogeologic-Unit Flow (HUF) Package for the ground-water modeling computer program MODFLOW-2000. The HUF Package is an alternative internal flow package that allows the vertical geometry of the system hydrogeology to be defined explicitly within the model using hydrogeologic units that can be different than the definition of the model layers. The HUF Package works with all the processes of MODFLOW-2000. For the Ground-Water Flow Process, the HUF Package calculates effective hydraulic properties for the model layers based on the hydraulic properties of the hydrogeologic units, which are defined by the user using parameters. The hydraulic properties are used to calculate the conductance coefficients and other terms needed to solve the ground-water flow equation. The sensitivity of the model to the parameters defined within the HUF Package input file can be calculated using the Sensitivity Process, using observations defined with the Observation Process. Optimal values of the parameters can be estimated by using the Parameter-Estimation Process. The HUF Package is nearly identical to the Layer-Property Flow (LPF) Package, the major difference being the definition of the vertical geometry of the system hydrogeology. Use of the HUF Package is illustrated in two test cases, which also serve to verify the performance of the package by showing that the Parameter-Estimation Process produces the true parameter values when exact observations are used.

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INTRODUCTION

Ground-water flow models are, by definition, simplified representations of often highly complex hydrogeologic flow systems. Generally, incorporating as much available hydrogeologic information as possible into the formulation of the conceptual and numerical models of the flow system is advantageous. This hydrogeologic information takes many forms, including maps that show outcropping surfaces of geologic units and faults, cross sections derived from geophysical surveys and well-bore information that show the likely subsurface location of geologic units and faults, maps of water-table levels, independent point well data, maps showing the hydraulic properties of the subsurface materials. This information is used to classify the geologic units into hydrogeologic units, which are convenient units with which to define hydrologic properties.

Once a conceptual model of the system is defined, the model domain is subdivided horizontally and vertically into discrete blocks to facilitate solution of the ground-water flow equation. Though for simplicity and numerical accuracy, associating individual hydrogeologic units with model layers is advantageous; hydrogeologic units often have characteristics that make them difficult or impossible to represent with any model. For example, hydrogeologic units may be very thin or pinch out or be faulted and discontinuous.   These limitations can be reduced or eliminated by refining the grid representing the system and by using a more flexible grid structure, but fine grids can result in long execution times that would prohibit the many model runs needed to understand system dynamics and the relation of model results to calibration data; flexible grid structures also can produce numerical difficulties.

The solution to this problem has been to group similar hydrogeologic units so that model layers represent more than one unit. Effective model input values are usually calculated outside of the model by using data-manipulation programs that are custom written by the modeler for the situation. This process can be time consuming and subject to introduction of errors.

The U.S. Geological Survey, in cooperation with the U.S. Department of Energy, initiated the development of the Hydrogeologic-Unit Flow (HUF) Package of MODFLOW-2000, which automates this process by allowing the geometry of the hydrogeologic units to be defined independently of the model layers. The HUF Package determines the units that apply to each model layer for each row and column and calculates model-layer horizontal and vertical conductance and specific storage internally. Characteristics for the model grid are obtained by averaging and by using the assumption that the hydrogeologic units that occur within each model finite-difference cell are virtually horizontal. Hydrogeologic units that pinch out and are discontinuous are defined by specifying the top altitude and thickness of hydrogeologic units, based on defined rows and columns of the finite-difference grid. Hydraulic properties are assigned to the hydrogeologic units by using parameters (Harbaugh and others, 2000, p. 12).

One of the advantages of the HUF Package is that it provides a ready tool for the results of sophisticated three-dimensional data-base, data-manipulation, and visualization software, such as Stratamodel, Earthvision, Lynx Geosystems, TechBase, or Integraph Voxel Analyst to be used with MODFLOW-2000. This information can be used in the other flow packages, but some manipulation is needed to translate the information to the correct format.

Dr. Anderman's contribution to the development of the HUF Package and its documentation was funded through U.S. Geological Survey contracts 99CRSA0301, 99CRSA1084, and 00CRSA0825.

Purpose and Scope

This report documents the conceptualization and implementation of the HUF Package. The capabilities of the HUF Package are illustrated through the use of two test cases, which also serve to verify the conceptualization and implementation of the package. The input requirements for the HUF Package are presented in Appendix A. The derivation of equations for the Sensitivity Process part of the HUF Package is presented in Appendix B.

The HUF Package is similar to the Layer-Property Flow (LPF) Package documented in Harbaugh and others (2000) and the Block-Centered Flow (BCF) Package documented in McDonald and Harbaugh (1988) in that it is an internal flow package that calculates the conductance coefficients and other terms needed to solve the flow equation. The principal difference between the HUF Package and the BCF or LPF Packages is that in the HUF Package hydraulic properties are assigned on the basis of hydrogeologic units that are geometrically distinct from the model layers. The conceptual approach and governing equations of the HUF Package are presented in the following sections. Many of the algorithms used in the HUF Package are identical to those in the LPF Package (Harbaugh and others, 2000) and are not described in this report.

The HUF Package supports parameters that are used to define the following hydraulic properties, which are listed with their parameter type: horizontal hydraulic conductivity (HK), horizontal anisotropy (HANI), vertical hydraulic conductivity (VK), vertical anisotropy (VANI), specific storage (SS), and specific yield (SY). One parameter can apply to more than one hydrogeologic unit. This approach is useful, for example, when separately defined units are thought to have similar hydraulic properties. The HUF Package allows the use of multiplication and zone arrays in the definition of parameters. The HUF Package also allows additive-parameters (Harbaugh and others, 2000, p.16) to be used so that hydraulic properties for hydrogeologic units are defined by multiple parameters. Parameters defined in the HUF Package input file can be estimated by using the Parameter-Estimation Process of MODFLOW-2000, and by using observations defined with the Observation-Process capabilities of MODFLOW-2000; both are documented in Hill and others (2000).

The differences between the LPF and HUF Packages are as follows:

(1) As discussed above, in the HUF Package, the vertical geometry of the system hydrogeology is defined separately from the model-layer definition, and the averaging used to obtain model-layer properties is based on the assumption that the hydrogeologic layers are horizontal or nearly horizontal. This assumption affects calculations both in the Ground-Water Flow Process and the Sensitivity Process, as discussed in this report.

(2) HUF uses only harmonic calculation of horizontal conductances.

(3) In the HUF Package, hydraulic characteristics for the hydrogeologic units are required to be specified using parameters; LPF's option of specifying properties through array definition is not available in HUF.

(4) The HUF Package does not support the concept of a quasi-three-dimensional confining layer; confining layers are always represented as individual hydrogeologic units in the HUF Package.

Acknowledgments

The authors acknowledge Richard Waddell of HSI-Geotrans, Inc. for his encouragement to develop the Hydrogeologic-Unit Flow Package. The authors also acknowledge the following U.S. Geological Survey personnel: Frank D'Agnese and Claudia Faunt for their guidance and their examples that guided package development; Ned Banta and Grady O'Brien for their much appreciated debugging of the package; and Wayne Belcher, Arlen Harbaugh, and Celso Puente for their critical reviews that greatly improved the document.

CONCEPTUALIZATION AND IMPLEMENTATION OF THE HYDROGEOLOGIC-UNIT FLOW PACKAGE

The HUF Package links defined hydrogeologic units to the solution of the ground-water flow equation of MODFLOW-2000 (fig. 1). A cross section is shown in figure 1 for illustrative purposes, but the hydrogeologic units are three-dimensional. The progression begins with the definition of hydrogeologic units (fig. 1A), where subsurface deposits have been grouped, based on their hydraulic characteristics, as being part of an aquifer unit, a confining unit, or a sand-lens unit. In this report, the three units are identified as type A, C, or L, where material classified as a certain type is thought to have similar hydraulic characteristics wherever it exists. When using the HUF Package, the criterion of no vertically repeated units needs to be imposed, so that 17 model units would be needed to define this system. The term “model unit” is used to describe the input to the HUF Package; in cases where hydrogeologic units are not repeated vertically, the model unit is identical to the hydrogeologic unit, otherwise a model unit represents one piece of the larger hydrogeologic unit. Different defined model units can, however, be grouped together so that they are assigned the same hydraulic parameters and represent a single hydrogeologic unit. Thus, the HUF Package input files can be constructed such that the system described in figure 1A can be thought of as consisting of three hydrogeologic units defined on the basis of hydraulic characteristics, which is discussed more below.

In the HUF Package, hydrogeologic units are defined by the top altitude and thickness of each hydrogeologic unit for each cell in the model grid. Figure 1B shows one row of the finite-difference grid for which the model layers are not yet defined. The hydrogeologic units are represented within MODFLOW-2000 as follows: for each row and column location, the top altitude and thickness of each hydrogeologic unit has been interpreted as being constant, so that the smooth surfaces of figure 1A are now discrete. If a hydrogeologic unit does not occur at a row and column location, then the thickness needs to be set to zero. This description indicates that given the HUF Package capabilities, the hydrogeologic units need to be defined such that no unit is repeated vertically for a single row, column location. As long as this restriction is observed, some of the 17 hydrogeologic units could be combined. For example, units L1, L2, and L3 in figure 1 cannot be defined as a single hydrogeologic unit in the HUF Package, but L1 and L3 could. Overlying pieces of the same material thus need to be represented as multiple hydrogeologic units, but can be combined under one parameter definition.

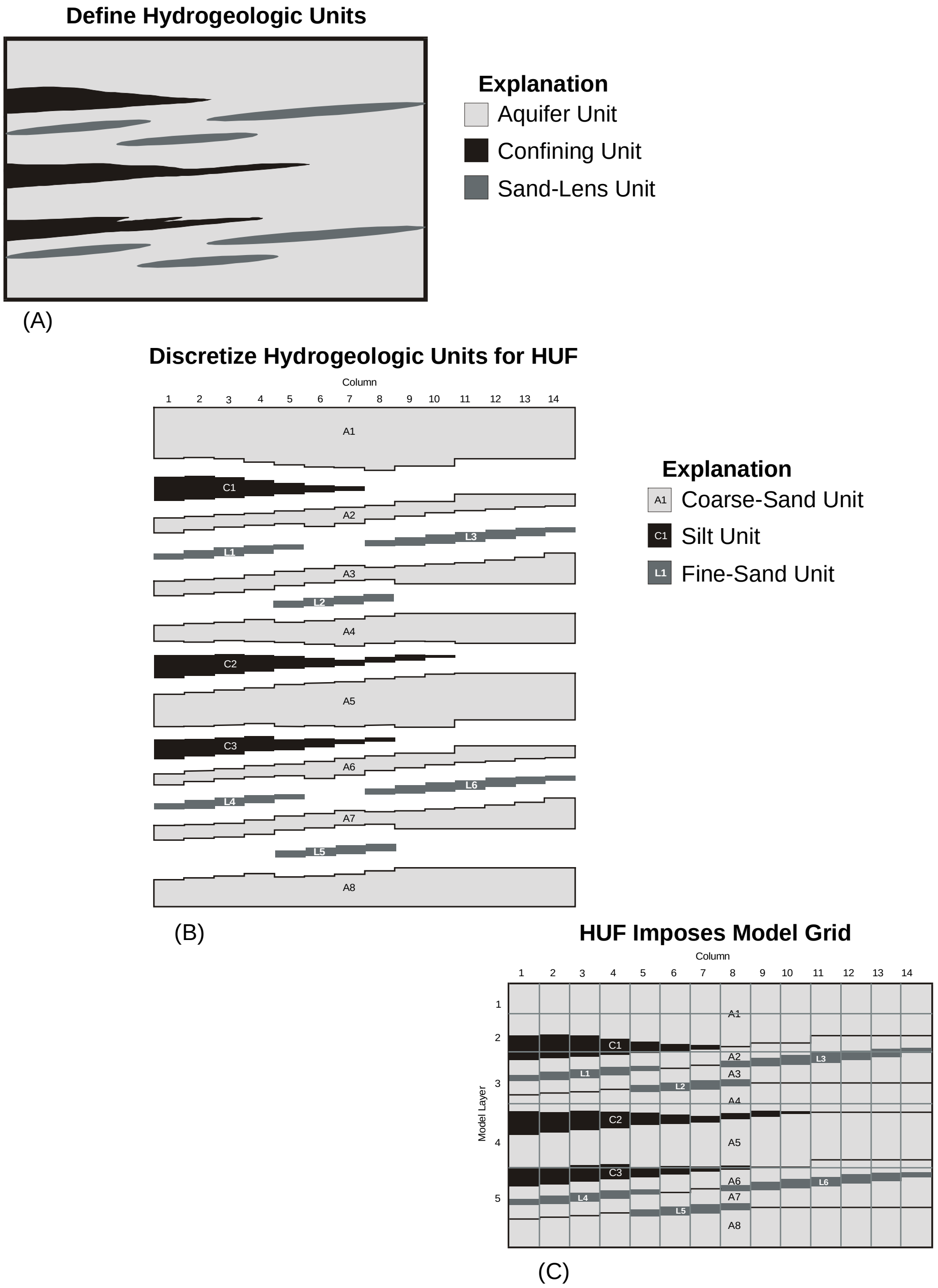

Figure 1. Hypothetical situation involving definition of hydrogeologic units. (A) Definition of hydrogeologic units, which is part of the data preparation step of ground-water model development (the data can be organized using some of the software listed for (B)); (B) Horizontal discretization of hydrogeologic units used to construct the HUF Package input file (the discretization can be performed by software such as Stratamodel, Earthvision, Arcview, and Voxel Analyst, and by some MODFLOW-2000 graphical user interfaces), with the 17 hydrogeologic units shown exploded; (C) Assignment of hydrogeologic units to model layers (performed by the Hydrogeologic-Unit Flow Package).

In the situation shown in figure 1, if each occurrence of the three types of units (A, C, and L) are assigned the same horizontal hydraulic conductivity and the same vertical hydraulic conductivity, six parameters are needed. The parameter for the horizontal hydraulic conductivity of material type A would be defined by listing all of the A hydrogeologic units – A1, A2, A3, and so on. Similarly, the parameter for the vertical hydraulic conductivity of material type A would be defined by listing all of the A hydrogeologic units – A1, A2, A3, and so on. This definition would be repeated for C and L.

The last step of the sequence shown in figure 1 is that the model-layer geometry is superimposed on the subsurface material (fig. 1C). For each finite-difference cell thus defined, the resident hydrogeologic-unit hydraulic properties are used in the HUF Package to calculate the cell hydraulic properties from which the horizontal and vertical conductances and primary storage capacity are calculated. For convertible layers, the location of the water table is accounted for as needed. For the Sensitivity Process of the HUF Package, the right-hand side of the sensitivity equation of Hill and others (2000, p. 68-70) is calculated for the parameters defined for the hydrogeologic units. The equations and procedures used to accomplish these tasks are described in the following sections.

Calculating Conductances

By using hydrogeologic-unit top altitudes and thicknesses, which are part of the input data, the HUF Package determines the hydrogeologic units that apply to each model layer (fig. 1C), calculates the effective hydraulic conductivity for the horizontal and vertical directions for each grid cell, and uses these conductivities to calculate the horizontal and vertical conductances. If the simulation is transient, then the HUF Package also calculates the effective specific storage for the model layers and uses the specific yield for the unit that the water table intersects at any given time step. For convertible layers, the HUF Package accounts for the location of the free water surface during each outer iteration by recalculating all of the conductances and storage coefficients.

Transmissivity and Horizontal Conductances

In the horizontal direction, transmissivities are used in the harmonic mean formulation to calculate the conductances needed for solution, as discussed by Harbaugh and others (2000, p. 25-27) and McDonald and Harbaugh (1988, p. 5-8). The HUF Package does not currently support other conductance calculation methods.

Transmissivity in the row direction $TR_{i,j,k}$ for a cell at row i, column j, and layer k is calculated as:

$$TR_{i,j,k} = \sum_{g=1}^{n} KH_{i,j,g} thk_{g_{i,j,k}} \, , \tag{1}$$

where

n is the number of hydrogeologic units within the finite-difference cell;

$KH_{i,j,g}$ is equal to $\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}$;

Kh_l is the value of horizontal hydraulic conductivity parameter *l*;

$thk_{g_{i,j,k}}$ is the thickness of hydrogeologic unit *g* in cell *i*, *j*, *k*;

p is the number of additive parameters that define the hydraulic conductivity of hydrogeologic unit *g*; and

$m_{l_{i,j,g}}$ is the multiplication factor for parameter *l*.

The value of the multiplication factor $m_{l_{i,j,g}}$ is defined by the multiplication array. If a multiplication array is not specified, then $m_{l_{i,j,g}}$ equals 1.

Horizontal conductance $CR_{i,j+1/2,k}$ for the material between cell centers *i*, *j*, *k* and *i*, *j+1*, *k* is calculated from the transmissivities as described for the LPF Package (Harbaugh and others, 2000, p. 27) as:

$$CR_{i,j+1/2,k} = 2\Delta c_i \frac{TR_{i,j,k} TR_{i,j+1,k}}{TR_{i,j,k}\Delta r_{j+1} + TR_{i,j+1,k}\Delta r_j} \, , \tag{2}$$

where

Δr_j is the cell width of column *j*, and

Δc_i is the cell width of row *i*.

Transmissivity in the column direction $TC_{i,j,k}$ for a cell at row i, column j, and layer k is calculated as:

$$TC_{i,j,k} = \sum_{g=1}^{n} KH_{i.j.g} thk_{g_{i,j,k}} HANI_{i,j,g} \, , \tag{3}$$

where

$HANI_{i,j,g}$ is equal to $\sum_{l=1}^{p} Hani_l m_{l_{i,j,g}}$ or 1 if $Hani_l$ is not defined, and

$Hani_l$ is the value of horizontal anisotropy parameter *l*.

Horizontal conductance in the column direction $CC_{i+1/2,j,k}$ for the material between cell centers i, j, k and i+1, j, k is calculated from the transmissivities as:

$$CC_{i+1/2,j,k} = 2\Delta r_j \frac{TC_{i,j,k} TC_{i+1,j,k}}{TC_{i,j,k}\Delta c_{i+1} + TC_{i+1,j,k}\Delta c_i} . \tag{4}$$

Vertical Conductances

The vertical conductance $CV_{i,j,k+1/2}$ for the material between cell centers i, j, k and i, j, k+1 is calculated as:

$$CV_{i,j,k+1/2} = \frac{\Delta r_j \Delta c_i}{\sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}}}{KV_{i,j,g}}} , \tag{5}$$

where

$thk_{g_{i,j,k+1/2}}$ is the hydrogeologic unit *g* thickness that occurs between the two cell centers,

$KV_{i,j,g}$ is equal to $\sum_{l=1}^{p} Kv_l m_{l_{i,j,g}}$, and

Kv_l is the vertical hydraulic conductivity of parameter *l*.

Storage Terms

For confined cells, the storage capacity of the cell is calculated in a similar manner to effective transmissivity. The primary storage capacity for a given cell is calculated as:

$$SC1_{i,j,k} = \Delta r_j \Delta c_i \sum_{g=1}^{n} SS_{i,j,g} thk_{g_{i,j,k}} , \tag{6}$$

where

$SS_{i,j,g}$ is equal to $\sum_{l=1}^{p} Ss_l m_{l_{i,j,g}}$, and

Ss_l is the specific storage of parameter *l*.

SY parameters are used to calculate the secondary storage-capacity value for each cell as:

$$SC2_{i,j,k} = \Delta r_j \Delta c_i SY_{i,j,g} \,, \tag{7}$$

where

$SY_{i,j,g}$ is equal to $\sum_{l=1}^{p} Sy_l m_{l_{i,j,g}}$, and

Sy_l is the specific yield of parameter *l*.

For cells that contain a water table, the HUF Package was implemented to use the specific yield for the hydrogeologic unit that contains the water table to calculate the storage flow. For transient simulations, if the water table spans several hydrogeologic units during a time step, the specific yield for each of those units is used with the change in saturated thickness of the unit to calculate the storage flow for that particular cell. If the cell converts between a saturated and unsaturated condition during a time step, then the change in storage from both the confined and unconfined parts are included in the storage flow.

Definition of Model Layers

Although the HUF Package allows model layers to be defined independently of hydrogeologic units, careful definition of the model layers is important to represent properly the flow through the simulated area. Specifying model-layer boundaries that coincide with or are parallel to hydrogeologic-unit boundaries is helpful. Further discussion of optimal grid design is beyond the scope of this report.

Interpolation of Hydraulic Heads to Hydrogeologic Units

The HUF Package has an option that allows the modeled hydraulic heads in the hydrogeologic units to be printed and saved in a manner similar to the modeled hydraulic heads. The heads in the hydrogeologic units are interpolated from the heads in the model layers using a linear-interpolation algorithm. The interpolation algorithm is based on the assumption that head varies linearly in the vertical direction within a given hydrogeologic unit and that the vertical flow through each individual unit is equal to the overall flow from one layer to an adjacent layer. The output consists of one array of interpolated-head values for each hydrogeologic unit. The head is assigned the value of HNOFLO (Harbaugh and others, 2000, p. 50) at all locations where a hydrogeologic unit does not exist.

PROGRAM DESCRIPTION

The HUF Package was written within the modular framework of MODFLOW-2000 and works independently of most of the other packages. The flow of subroutines called from the main program by the HUF Package (fig. 2) is similar to the Layer-Property Flow Package and most other packages in that there is a Ground-Water Flow Process (GWF) allocate subroutine (GWF1HUF1AL), a GWF read-and-prepare subroutine (GWF1HUF1RQ), a GWF formulate subroutine (GWF1HUF1FM), several GWF volumetric-budget calculation subroutines (GWF1SHUF1S, GWF1SHUF1F, and GWF1SHUF1B), and subroutines that formulate the right-hand side for calculating sensitivities. Subroutine GWF1HUF1SP, which is part of GWF, takes the parameter definitions and formulates the conductance matrices needed to solve the flow equation. This subroutine is also called from subroutine GWF1HUF1FM to recalculate the conductances for cells in layers with variable saturated thickness. Subroutine GWF1SHUF1S calculates the contribution to the flow in each cell due to storage changes and, for unconfined cells, calls GWF1SHUF1SC2 to calculate the contribution to flow from specific yield. The HUF Package is written in standard FORTRAN77 and should be compatible with any standard FORTRAN77 compiler.

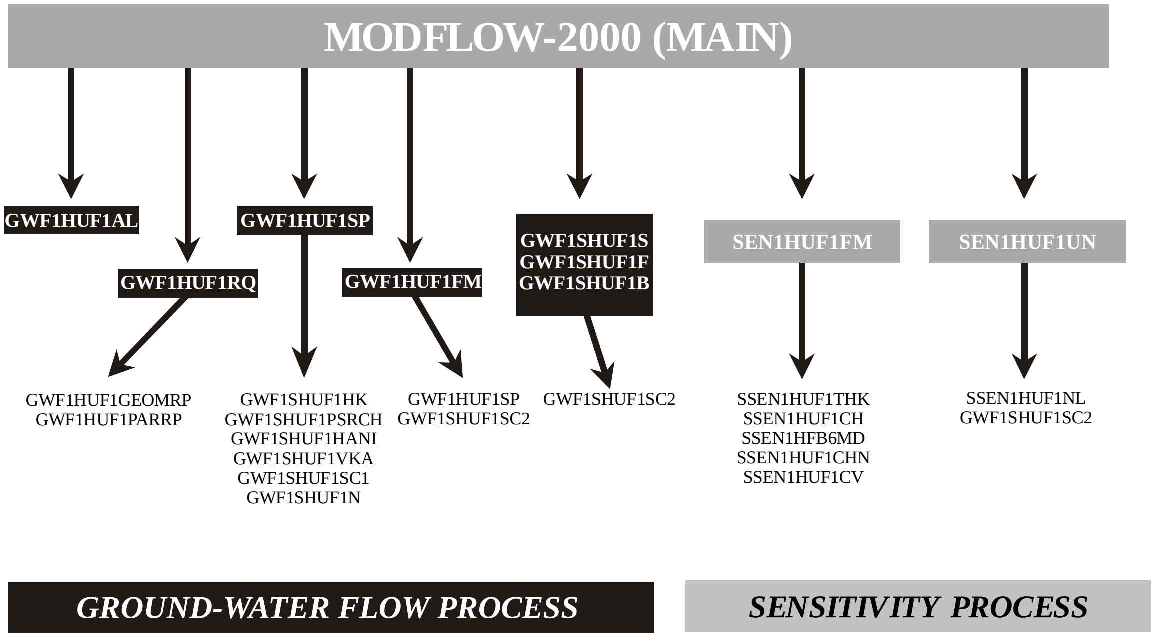

Figure 2. Flowchart of subroutines used by the Hydrogeologic-Unit Flow Package.

SIMULATION EXAMPLES

To test the functionality of the HUF Package, two test cases were developed. Test Case 1 was designed to test the transient capabilities of the HUF Package and is modified from test case 1 of MODFLOW-2000 Observation, Sensitivity, and Parameter-Estimation Processes (Hill and others, 2000). Test Case 2 was designed to test the steady-state capabilities of the HUF Package and is based on test case 1 used for the Advective-Transport Observation (ADV) Package (Anderman and Hill, 1997) and test case 2 of MODFLOW-2000 Observation, Sensitivity, and Parameter-Estimation Processes (Hill and others, 2000). Test Cases 1 and 2 are fully described below; the references are provided for informational purposes only because these test cases have been published previously.

Test Case 1: Transient

Test Case 1 is a system composed of two confined aquifers that are separated by a confining unit (fig. 3). A facies change exists in the lower aquifer where the lower unit thins away from the adjacent hillside and the upper unit thickens. Inflow occurs as areal recharge and as head-dependent flow across the boundary adjacent to the hillside. Outflow occurs as pumpage from wells. A river boundary is present opposite from the hillside. No-flow boundaries are specified on the remaining two sides and on the bottom of the model domain. The system is simulated using three model layers: one for each aquifer and one for the confining unit. Pumpage (Q of fig. 3) consists of four wells completed in layer 3 and one well in layer 1, each pumping 1 cubic meter per second (m^3/s) throughout the simulation. Four stress periods are used to represent 282.8 days.

Four hydrogeologic units were used to represent the hydrogeology of the system. These units correspond to the upper aquifer, confining unit, upper facies of the lower aquifer, and the lower facies of the lower aquifer.

Thirteen parameters were defined using the HUF Package and were included in the parameter estimation (table 1). The four hydrogeologic units were given values of horizontal hydraulic conductivity (HK), vertical hydraulic conductivity (VK), and specific storage (SS) that were different for the aquifers and confining unit. As only the upper aquifer converts from confined to unconfined conditions during the simulation, specific yield (SY) was only assigned to HGU1.

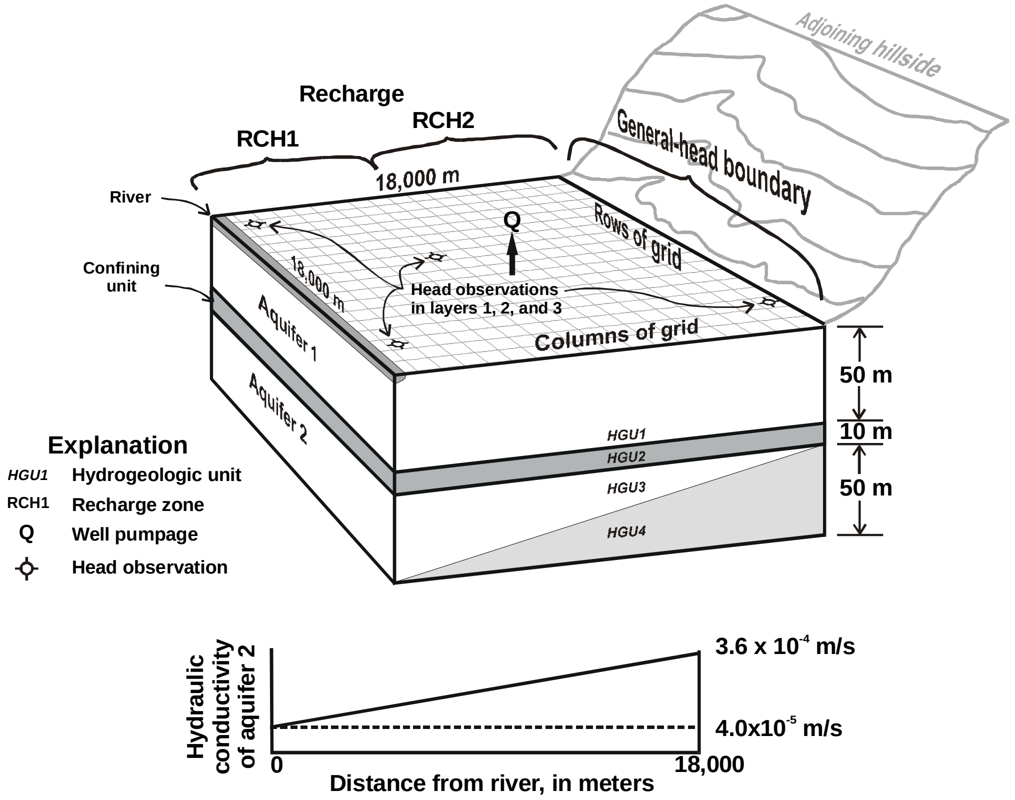

Figure 3. Test Case 1 model grid, boundary conditions, and head-observation locations used in parameter estimation. (From Hill and others, 2000.)

Table 1. Labels, descriptions, and true values for the parameters for Test Case 1
[m/s, meters per second; m, meter; --, no units]

Label	Description	Units	True value
HK1	Horizontal hydraulic conductivity of aquifer 1	m/s	3.0×10^{-4}
HK2	Horizontal hydraulic conductivity of confining unit	m/s	2.0×10^{-7}
HK3	Base horizontal hydraulic conductivity of the upper facies of aquifer 2 (fig. 3)	m/s	4.0×10^{-5}
HK4	Base horizontal hydraulic conductivity of the lower facies of aquifer 2 (fig. 3)	m/s	4.0×10^{-5}
VK1	Vertical hydraulic conductivity of aquifer 1	m/s	3.0×10^{-4}
VK2	Vertical hydraulic conductivity of confining unit	m/s	2.0×10^{-7}
VK3	Base vertical hydraulic conductivity of the upper facies of aquifer 2	m/s	4.0×10^{-5}
VK4	Base vertical hydraulic conductivity of the lower facies of aquifer 2	m/s	4.0×10^{-5}
SS1	Specific storage of aquifer 1	m^{-1}	1.0×10^{-3}
SS2	Specific storage of confining unit	m^{-1}	1.0×10^{-6}
SS3	Specific storage of the upper facies of aquifer 2	m^{-1}	1.0×10^{-3}
SS4	Specific storage of the lower facies of aquifer 2	m^{-1}	1.0×10^{-3}
SY1	Specific yield of aquifer 1	--	0.1

Observations in the parameter estimation consisted of heads observed at 4 different times at 12 locations (fig. 3) and flow from the general-head boundary observed at 4 different times. The observations used in the parameter estimation were computed by a forward simulation with the true parameter values specified in table 1.

By using the HUF Package, the true values were estimated to three significant figures for the HK1, SS1, and SY1 parameters included in the estimation. The parameter-estimation closure criteria TOL (Hill and others, 2000, p. 79) was set to 0.01 and, because of the highly nonlinear nature of this problem, the parameter estimation took 20 iterations to converge. Some insignificant variation was noted in the third significant figure of the estimated values of the remaining parameters. This variation indicates that parameter estimation using the HUF Package is able to reproduce the true parameter values when exact observations are used in the regression and, therefore, provides a test of the sensitivity and regression calculations for steady-state and transient parameters.

Test Case 2: Steady State

Test Case 2 includes features common to a complex three-dimensional ground-water flow model. This test case was developed to test all parameter types and many of the capabilities of the HUF Package. The hydrogeologic units were defined to correspond with the model layers; therefore, Test Case 2 is not a good illustration of how the HUF Package should be used in practice. Ten variants of the basic test case were developed in which the basic test case is modified in that the definition of the hydrogeologic units and(or) the vertical discretization are modified; all other aspects of the system remain the same. The model grid (fig. 4) has a uniform grid spacing of 1,500 meters (m) in both horizontal directions. Constant-head boundaries comprise parts of the western and eastern boundaries, with no flow across the remaining boundaries. Springs are represented using either the Drain or General-Head Boundary Packages of McDonald and Harbaugh (1988) and Harbaugh and others (2000). Wells are present at selected nodes, with pumpage at rates ranging from 100 to 200 m^3/d.

The hydraulic-conductivity distribution of the system can be thought of as being divided vertically into three horizons and horizontally into four zones (fig. 4). All four zones are present in the middle horizon; three are present in the top and bottom horizons (fig. 4). This distribution allows for testing of the HUF Package with hydrogeologic units that extend vertically throughout

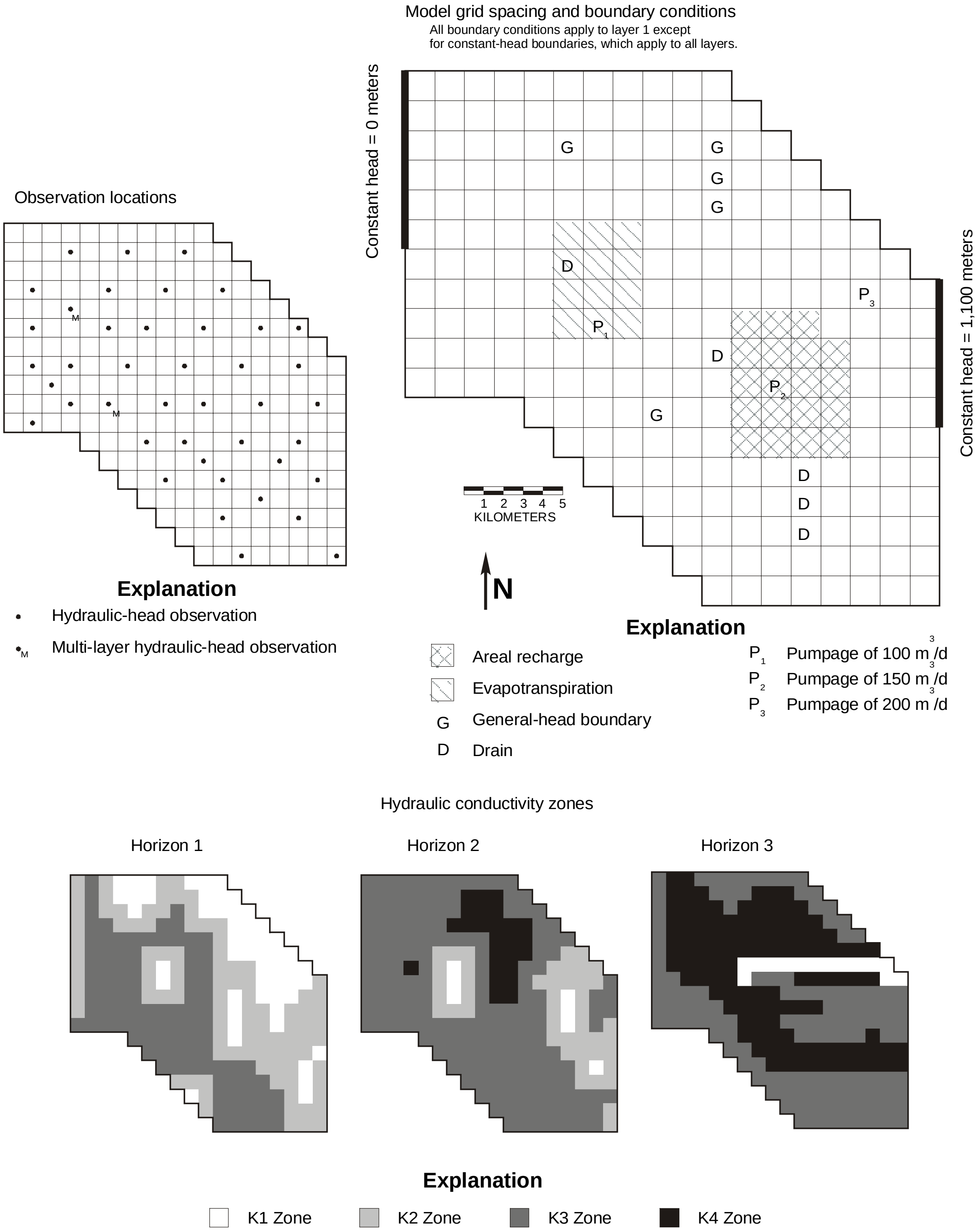

Figure 4. Test Case 2 model grid, boundary conditions, observation locations, and hydraulic conductivity zonation used in parameter estimation. (From Anderman and Hill, 1997.)

Table 2. Labels, descriptions, and true values for the parameters for Test Case 1
[m/d, meters per day; m^2/d, square meters per day; --, no units]

Label	Description	Units	True Value
HK1	Horizontal hydraulic conductivity of zone 1 (fig. 4)	m/d	1.00
HK2	Horizontal hydraulic conductivity of zone 2 (fig. 4)	m/d	$1.00\mathrm{x}10^{-2}$
HK3	Horizontal hydraulic conductivity of zone 3 (fig. 4)	m/d	$1.00\mathrm{x}10^{-4}$
HK4	Horizontal hydraulic conductivity of zone 4 (fig. 4)	m/d	$1.00\mathrm{x}10^{-6}$
HANI	Horizontal anisotropy of the entire model grid, used in Variant 10	--	1.00
Either vertical hydraulic conductivity or vertical anisotropy (see below) are used.			
VK12_1	Vertical hydraulic conductivity of zone 1 for hydrogeologic units in horizons 1 and 2	m/d	$2.50\mathrm{x}10^{-1}$
VK12_2	Vertical hydraulic conductivity of zone 2 for hydrogeologic units in horizons 1 and 2	m/d	$2.50\mathrm{x}10^{-3}$
VK12_3	Vertical hydraulic conductivity of zone 3 for hydrogeologic units in horizons 1 and 2	m/d	$2.50\mathrm{x}10^{-5}$
VK12_4	Vertical hydraulic conductivity of zone 4 for hydrogeologic units in horizons 1 and 2	m/d	$2.50\mathrm{x}10^{-7}$
VK3_1	Vertical hydraulic conductivity of zone 1 for hydrogeologic units in horizon 3	m/d	1.00
VK3_3	Vertical hydraulic conductivity of zone 3 for hydrogeologic units in horizon 3	m/d	$1.00\mathrm{x}10^{-4}$
VK3_4	Vertical hydraulic conductivity of zone 4 for hydrogeologic units in horizon 3	m/d	$1.00\mathrm{x}10^{-6}$
VANI12	Vertical anisotropy of layers 1 and 2	--	4.0
VANI3	Vertical anisotropy of layer 3	--	1.0
RCH	Areal recharge rate applied to the area shown in figure 4	m/d	$3.10\mathrm{x}10^{-4}$
ETM	Maximum evapotranspiration rate applied to area shown in figure 4	m/d	$4.00\mathrm{x}10^{-4}$
GHB	Conductance of head-dependent boundaries G shown in figure 4 represented using the general-head boundary package.	m^2/d	1.00
KDR	Conductance of the head-dependent boundaries D shown in figure 4 using the drain package.	m^2/d	1.00
HFB	Conductance of the hydraulic flow barriers described under Variant 8.	m/d	$1.00\mathrm{x}10^{-6}$

the model or units that are defined over smaller vertical extents. Fifteen parameters of the test case are described (table 2) along with their true (assigned) values.

The hydraulic conductivity field of this problem can be represented in two ways using the HUF Package. First, the hydrogeologic units can be defined using the zones and the horizons, which demonstrates hydrogeologic units that are repeated vertically. This method was used for variant 1, where HGU1_1 represents zone 1 in layer 1, HGU1_2 represents zone 2 in layer 1, and so on. The thicknesses of the hydrogeologic units are nonzero where the zone is present and zero everywhere else in the layer. Alternatively, for variants 2 through 10, the hydrogeologic units are defined on the basis of the horizons; the hydrogeologic units can include parts from more than one zone within the horizon. The appropriate method for representing the hydrogeologic units depends on the situation, as follows. The first method produces more individually defined hydrogeologic units that are then lumped under one parameter; the second method produces fewer individually defined hydrogeologic units that may be more difficult to define.

The definition of hydrogeologic units that were used to define the HK and VK or VANI parameters are shown in figure 5 and table 3. Either vertical hydraulic conductivity or vertical anisotropy were used but not both, although HUF is capable of having both parameter types present to define properties for different hydrogeologic units. The observations (fig. 4) used in the parameter estimation were generated by running the model with the true parameter values; no noise was added. The flows simulated at the hydraulic-head-dependent boundaries (fig. 4) also were used as observations in the parameter estimation.

The definition of the hydrogeologic units and vertical discretization of the particular variants are described in the following sections.

Variant 1 (Base case)

In Variant 1, one hydrogeologic unit is used to represent each of the zones in each of the horizons. Where hydrogeologic units are absent, thickness equals zero; the zone capability of the HUF Package was not used.

Table 3. Hydrogeologic-unit names used (fig. 5) to define horizontal hydraulic-conductivity (HK), vertical hydraulic-conductivity (VK), vertical-anisotropy (VANI), and horizontal-anisotropy (HANI) parameters in Test Case 2

[--, not used]

Parameter	Zone	Variant 1	Variant 2	Variant 3	Variants 4-6, 8	Variant 7	Variant 9	Variant 10
HK1	1	1_1, 2_1, 3_1	1, 2, 3	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5	1, 2, 3, 4, 5
HK2	2	1_2, 2_2, 3_2	1, 2, 3	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5	1, 2, 3, 4, 5
HK3	3	1_3, 2_3, 3_3	1, 2, 3	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5	1, 2, 3, 4, 5
HK4	4	1_4, 2_4, 3_4	1, 2, 3	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5	1, 2, 3, 4, 5
VK12_1	1	1_1, 2_1	1, 2	1, 2, 3, 4	1, 2, 3, 4	--	--	--
VK12_2	2	1_2, 2_2	1, 2	1, 2, 3, 4	1, 2, 3, 4	--	--	--
VK12_3	3	1_3, 2_3	1, 2	1, 2, 3, 4	1, 2, 3, 4	--	--	--
VK12_4	4	1_4, 2_4	1, 2	1, 2, 3, 4	1, 2, 3, 4	--	--	--
VK3_1	1	3_1	3	5, 6	5	--	--	--
VK3_3	3	3_3	3	5, 6	5	--	--	--
VK3_4	4	3_4	3	5, 6	5	--	--	--
VANI12	All	--	--	--	--	1, 2, 3, 4	1, 2, 3, 4	1, 2, 3, 4
VANI3	All	--	--	--	--	5, 6	5	5
HANI1	All	--	--	--	--	--	--	1, 2, 3, 4, 5

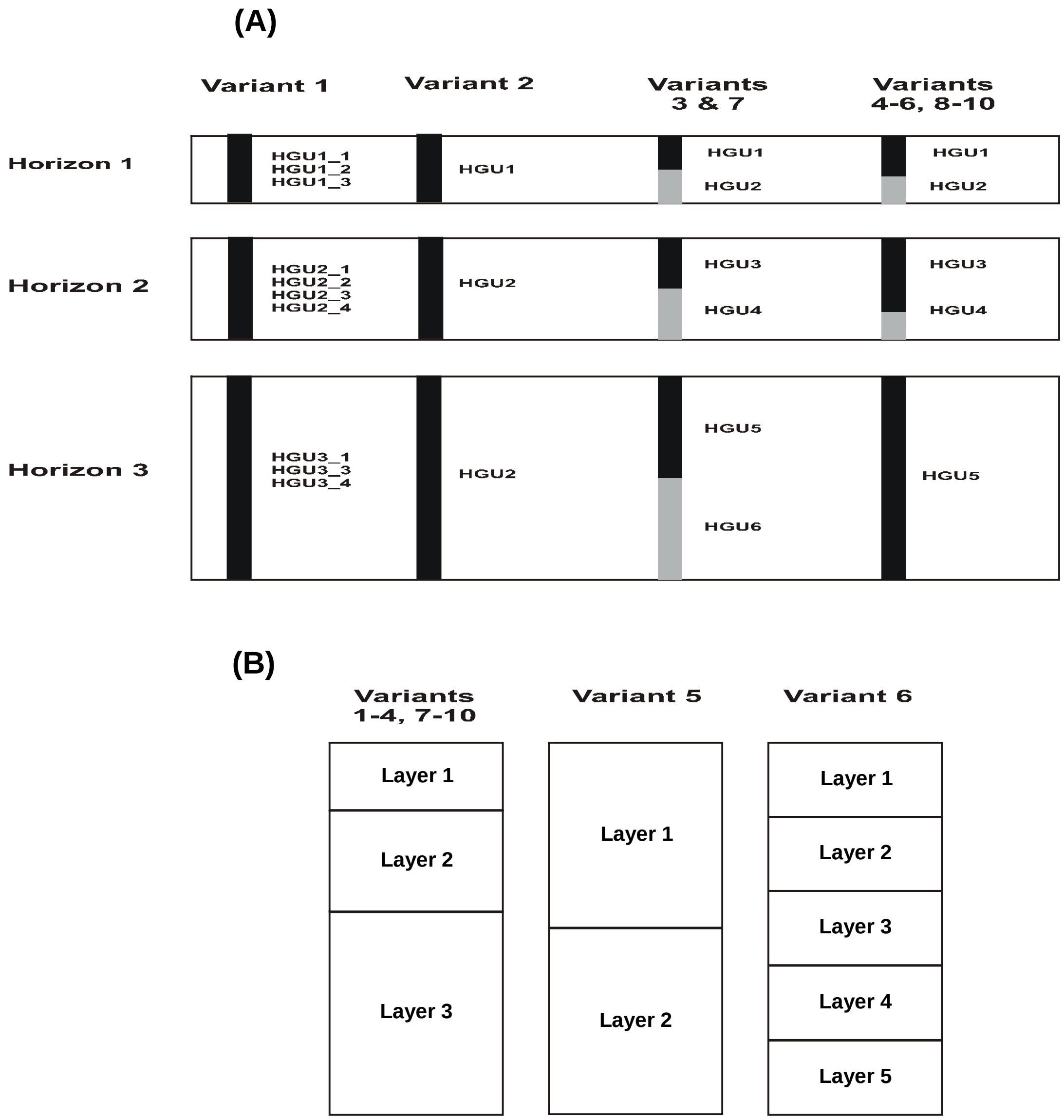

Figure 5. Schematic representation of (A) hydrogeologic units used to represent each of the horizons in the variants of Test Case 2, and (B) model-layer thicknesses.

Variant 2 (Using zone definition)

In Variant 2, one hydrogeologic unit represents each of the horizons, and the different hydraulic-conductivity zones (fig. 3) are defined using the zone arrays of HUF. Variant duplicates Variant 1; the definition of the hydrogeologic units and the geometry of the model layers is identical.

Variant 3 (6 HGU's, equal half layers)

In Variant 3, each of the hydrogeologic units of Variant 2 was cut in half, so that two units were present in each of the three model layers for a total of six hydrogeologic units.

Variant 4 (5 HGU's, complex geometry)

The geometry of the hydrogeologic units was slightly more complex in Variant 4 with five hydrogeologic units present in the three model layers. The units had the following thicknesses, in order from top to bottom: 300, 200, 550, 200, and 1,500 m. Units 1 and 2 are contained in layer 1, units 3 and 4 are contained in layer 2, and unit 5 is contained in layer 3.

Variant 5 (2 model layers)

Identical to Variant 4 except that two equal-thickness model layers are used, each 1,375 m thick. The results from the forward simulation are different than previously obtained so that it was necessary to generate new values to be used as observations.

Variant 6 (5 model layers)

Identical to Variant 4 except that five equal-thickness model layers are used, each 550 m thick. The results from the forward simulation are different than previously obtained so that it was necessary to generate new values to be used as observations.

Variant 7 (Vertical anisotropy parameters)

Identical to Variant 3 except that two VANI parameters are used to represent vertical hydraulic conductivity.

Variant 8 (Hydrologic-Flow Barrier parameter)

Identical to Variant 4 with a hydrologic-flow barrier (HFB) parameter added. Two flow barriers are represented by the HFB parameter; one is located in rows 5 through 9 between columns 2 and 3 of layer 1, the second is located in rows 11 through 15 between columns 10 and 11 of layer 2.

Variant 9 (Variable saturated thickness)

Identical to Variant 4 with parameter definition from Variant 7 except that the layer type is 1 for all layers. Only cells in layer 1 have variable saturated thickness.

Variant 10 (Horizontal anisotropy parameter)

Identical to Variant 4 with parameter definition from Variant 7 and an additional HANI parameter representing horizontal anisotropy for the entire model grid.

Results

MODFLOW-2000 with the HUF Package was able to estimate the true parameter values to three significant digits for all of the variants except for Variant 5. The parameter-estimation closure criteria TOL (Hill and others, 2000, p. 79) was set to 0.01. All of the variants converged except Variant 5. Variant 5 did not converge because all of the VK parameters were highly correlated with one another. With only two numerical layers in the model grid, each vertical conductance value was determined from three VK parameters. Thus, coordinated changes in the VK parameters would result in the same vertical conductance value. For most parameters, the true parameter values were estimated with a precision of three significant figures; for less sensitive parameters, there was some insignificant variation in the third significant figure. The parameter estimation took from 5 to 18 iterations to converge. From these results it can be concluded that parameter estimation using the HUF Package is able to reproduce the true parameter values when exact observations are used in the regression, and this forms a test of the sensitivity and regression calculations.

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APPENDIX A: INPUT INSTRUCTIONS

Input for the Hydrogeologic Unit Flow (HUF) Package is read from the file that has type "HUF" in the name file. Free format is used for reading all values.

FOR EACH SIMULATION

```
 0.   [#Text]
```

Item 0 is optional -- “#” must be in column 1. Item 0 can be repeated multiple times.

```
 1.   IHUFCB   HDRY   NHUF   NPHUF   IOHUF
 2.   LTHUF(NLAY)
 3.   LAYWT(NLAY)
 4.   WETFCT   IWETIT   IHDWET
```

Include Item 4 only if LAYWT indicates at least one wettable layer.

```
 5.   WETDRY(NCOL,NROW)
```

Repeat Item 5 for each layer for which LAYWET is not 0.

Arrays are read by the array-reading utility module, U2DREL.

```
 6.   HGUNAM
 7.   TOP(NCOL,NROW)
 8.   THCK(NCOL,NROW)
```

Repeat Items 6-8 for each hydrogeologic unit to be defined (that is, NHUF times).

```
 9.   HGUNAM   HGUHANI   HGUVANI
```

Repeat Item 9 for each hydrogeologic unit. If HGUNAM is set to “ALL”, HGUHANI and HGUVANI are set for all hydrogeologic units and only one Item 9 is necessary. Otherwise, HGUNAM must correspond to one of the names defined in Item 6, and there must be NHUF repetitions of Item 9. The repetitions can be in any order.

```
10.   PARNAM   PARTYP   Parval   NCLU
11.   HGUNAM   Mltarr   Zonarr   IZ
```

Each Item 11 record is called a parameter cluster. Repeat Item 11 NCLU times.

Repeat Items 10-11 for each parameter to be defined (that is, NPHUF times).

```
12.   ‘PRINT’ HGUNAM   PRINTCODE   PRINTFLAGS
```

Item 12 is optional and is included only for hydrogeologic units for which printing is desired. Item 12 must start with the word PRINT. If HGUNAM is set to ALL, PRINTCODE and PRINTFLAGS are set for all hydrogeologic units, and only one Item 12 is necessary. Otherwise, HGUNAM must correspond to one of the names defined in Item 6.

Explanation of Variables Read by the Hydrogeologic-Unit Flow Package

Text – is a character variable (199 characters) that starts in column 2. Any characters can be included in Text. The “#” character must be in column 1. Text is printed when the file is read.

IHUFCB – is a flag and a unit number.

> 0 –the unit number to which cell-by-cell flow terms will be written when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control (Harbaugh and others, 2000, p. 55). The terms that are saved are storage, constant-head flow, and flow between adjacent cells.

0 – cell-by-cell flow terms will not be written.

< 0 – cell-by-cell flow for constant-head cells will be written in the listing file when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control. Cell-by-cell flow to storage and between adjacent cells will not be written to any file.

HDRY – is the head that is assigned to cells that are converted to dry during a simulation. Although this value plays no role in the model calculations, it is useful as an indicator when looking at the resulting heads that are output from the model. HDRY is thus similar to HNOFLO in the Basic Package, which is the value assigned to cells that are no-flow cells at the start of a model simulation.

NHUF – is the number of hydrogeologic units defined using the HUF package.

NPHUF – is the number of HUF parameters.

IOHUF – is a flag and a unit number.

0 – interpolated heads will not be written.

>0 – calculated heads will be interpolated and written on unit IOHUF for each hydrogeologic unit using the format defined in the output-control file.

LTHUF – is a flag specifying the layer type. Read one value for each layer; each element holds the code for the respective layer. There is a limit of 200 layers. Use as many records as needed to enter a value for each layer.

0 – indicates a confined layer.

not 0 – indicates a convertible layer.

LAYWT – is a flag that indicates if wetting is active. Read one value per layer.

0 – indicates wetting is inactive.

1 – indicates wetting is active.

WETFCT – is a factor that is included in the calculation of the head that is initially established at a cell when the cell is converted from dry to wet. (See IHDWET.)

IWETIT – is the iteration interval for attempting to wet cells. Wetting is attempted every IWETIT iterations. If using the preconditioned conjugate gradient (PCG) solver (Hill, 1990), this applies to outer iterations, not inner iterations. If IWETIT is 0, it is changed to 1.

IHDWET – is a flag that determines which equation is used to define the initial head at cells that become wet:

If IHDWET = 0, equation 3a from McDonald and others (1992) is used:

$$h = BOT + WETFCT\ (h_n - BOT)$$

If IHDWET is not 0, equation 3b from McDonald and others (1992) is used:

$$h = BOT + WETFCT\ (WETDRY)$$

WETDRY – is a combination of the wetting threshold and a flag to indicate which neighboring cells can cause a cell to become wet. If WETDRY < 0, only the cell below a dry cell can cause the cell to become wet. If WETDRY > 0, the cell below a dry cell and the four horizontally adjacent cells can cause a cell to become wet. If WETDRY is 0, the cell cannot be wetted. The absolute value of WETDRY is the wetting threshold. When the sum of BOT and the absolute value of WETDRY at a dry cell is equaled or exceeded by the head at an adjacent cell, the cell is wetted. Read only if LAYTYP is not 0 and LAYWET is not 0.

HGUNAM – is the name of the hydrogeologic unit. This name can consist of up to 10 characters and is not case sensitive.

TOP – is the elevation of the top of the hydrogeologic unit.

THCK – is the thickness of the hydrogeologic unit.

HGUHANI – is a flag and a horizontal anisotropy value for a hydrogeologic unit. Horizontal anisotropy is the ratio of hydraulic conductivity along columns to hydraulic conductivity along rows. Read one value for each hydrogeologic unit unless HGUNAM is set to ALL.

0 – indicates that horizontal anisotropy will be defined using a HANI parameter.

>0 – HGUHANI is the horizontal anisotropy of the entire hydrogeologic unit.

HGUVANI – is a flag that indicates whether array VK is vertical hydraulic conductivity or the ratio of horizontal to vertical hydraulic conductivity. Read only one value for each hydrogeologic unit unless HGUNAM is set to ALL.

0 – indicates VK is hydraulic conductivity (VK parameter must be used).

>0 – indicates VK is the ratio of horizontal to vertical hydraulic conductivity and HGUVANI is the vertical anisotropy of the entire hydrogeologic unit. Value is ignored if a VANI parameter is defined for the corresponding hydrogeologic unit.

PARNAM – is the name of a parameter to be defined. This name can consist of up to 10 characters and is not case sensitive.

PARTYP – is the type of parameter to be defined. For the HUF Package, the allowed parameter types are:

HK – defines variable HK, horizontal hydraulic conductivity.

HANI – defines variable HANI, horizontal anisotropy.

VK – defines variable VK, vertical hydraulic conductivity, for units for which HGUVANI is set to zero.

VANI – defines variable VANI, vertical anisotropy, for units for which HGUVANI is set greater than zero.

SS – defines variable Ss, the specific storage.

SY – defines variable Sy, the specific yield.

Parval – is the initial value of the parameter; however, this value can be replaced by a value specified in the Sensitivity Process input file.

NCLU – is the number of clusters required to define the parameter. Each Item-12 record is a cluster (variables Layer, Mltarr, Zonarr, and IZ).

HGUNAM – is the hydrogeologic unit to which the parameter applies.

Mltarr – is the name of the multiplier array to be used to define array values that are associated with a parameter. The name “NONE” means that there is no multiplier array, and the array values will be set equal to Parval.

Zonarr – is the name of the zone array to be used to define array elements that are associated with a parameter. The name “ALL” means that there is no zone array and that all elements in the hydrogeologic unit are part of the parameter.

IZ – is up to 10 zone numbers (separated by spaces) that define the array elements that are associated with a parameter. The first zero or non-numeric value terminates the list. These values are not used if Zonarr is specified as “ALL”.

PRINTCODE – determines the format for printing the values of the hydraulic-property arrays for the hydrogeologic unit as defined by parameters. The print codes are the same as those used in an array control record (Harbaugh and others, 2000, p. 87).

PRINTFLAGS – determines the hydraulic-property arrays to be printed and must be set to “ALL” or any of the following: “HK”, “HANI”, “VK”, “SS”, or “SY”. Arrays will be printed only for those properties that are listed. When VK is specified, the property printed depends on the setting of HGUVANI.

Test Case 1 Sample Files

Input File

```
# HUF file for Test Case 1
#
  0  -999.  4  16   00    Item 1:  IHUFCB HDRY NHUF NPHUF IOHUF
  1    1    1             Item 2:  LTHUF
  0    0    0             Item 3:  LAYWT
HGU1                      Item 6:  HGUNAM
CONSTANT   150.           Item 7:  TOP
CONSTANT    50.           Item 8:  THCK
HGU2                      Item 6:  HGUNAM
CONSTANT   100.           Item 7:  TOP
CONSTANT    10.           Item 8:  THCK
HGU3                      Item 6:  HGUNAM
CONSTANT    90.           Item 7:  TOP
 INTERNAL      1.00 (15F5.0)    -2    Item 8:  THCK
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
 47.5 45.0 42.5 40.0 37.5 35.0 32.5 30.0 27.5 25.0 22.5 20.0 17.5 15.0 12.5
 10.0  7.5  5.0
HGU4                                                Item 6:  HGUNAM
 INTERNAL      1.00 (15F5.0)                 -2      Item 7:  TOP
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
```

```
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 42.5 45.0 47.5 50.0 52.5 55.0 57.5 60.0 62.5 65.0 67.5 70.0 72.5 75.0 77.5
 80.0 82.5 85.0
 INTERNAL      1.00 (15F5.0)    -2    Item 8:  THCK
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
  2.5  5.0  7.5 10.0 12.5 15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
 40.0 42.5 45.0
ALL  1.0  0                   Item 9:  HGUNAM   HGUHANI   HGUVANI
HK1        HK   3.0E-4   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU1    NONE   ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
HK2        HK   2.0E-7   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU2    NONE   ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
HK3        HK   4.0E-5   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU3    TMULT  ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
HK4        HK   4.0E-5   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU4    TMULT  ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZLU
VKA1       VK   3.0E-4   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU1    NONE   ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
VKA2       VK   2.0E-7   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU2    NONE   ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
VKA3       VK   4.0E-5   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU3    TMULT  ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
VKA4       VK   4.0E-5   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU4    TMULT  ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
SS1        SS   1.0E-3   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU1    NONE   ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
SS2        SS   1.0E-6   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU2    NONE   ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
SS3        SS   1.0E-3   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU3    NONE   ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
SS4        SS   1.0E-3   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU4    NONE   ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
SY1        SY   1.0E-1   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU1    NONE   ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
SY2        SY   1.0E-2   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
```

```
HGU2    NONE   ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
SY3        SY   1.0E-1   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU3    NONE   ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
SY4        SY   1.0E-1   1   Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU4    NONE   ALL           Item 11:  HUFNAM   Mltarr   Zonarr   IZ
PRINT HGU3  20 ALL                  Item 12:  HGUNAM   PRINTCODE   PRINTFLAGS
```

GLOBAL Output File

An example of the excerpted GLOBAL output file for Test Case 1 is shown below. The HUF Package output appears in bold, and three dots (…) indicates omitted output.

```
                                  MODFLOW-2000
      U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
                            VERSION 1.0.2 08/21/2000


 This model run produced both GLOBAL and LIST files.  This is the GLOBAL file.

 GLOBAL LISTING FILE: tc1tr.glo
                         UNIT   3

 OPENING tc1tr.lst
 FILE TYPE:LIST   UNIT   4
# Observation-Process Files

 OPENING tc1tr.obs
 FILE TYPE:OBS   UNIT  40

 OPENING tc1tr.hob
 FILE TYPE:HOB   UNIT  41

 OPENING tc1tr.ogb
 FILE TYPE:GBOB   UNIT  42
# Sensitivity and Parameter-Estimation Process Files
#sen          39  tc1tr.sen
#pes          43  tc1tr.pes
#Flow-Process files

 OPENING tc1tr.bas
 FILE TYPE:BAS6   UNIT   5

 OPENING tc1tr.huf
 FILE TYPE:HUF   UNIT   7

 OPENING tc1tr.wel
 FILE TYPE:WEL   UNIT   8

 OPENING tc1tr.pcg
 FILE TYPE:PCG   UNIT   9

 OPENING tc1tr.dis
 FILE TYPE:DIS   UNIT  10

 OPENING tc1tr.oc
 FILE TYPE:OC   UNIT  11

 OPENING tc1tr.ghb
 FILE TYPE:GHB   UNIT  12

 OPENING tc1tr.riv
 FILE TYPE:RIV   UNIT  13

 OPENING tc1tr.sh
 FILE TYPE:DATA   UNIT  14

 OPENING tc1tr.rch
 FILE TYPE:RCH   UNIT  31

 OPENING tc1tr.mlt
 FILE TYPE:MULT   UNIT  32

 OPENING tc1tr.zon
 FILE TYPE:ZONE   UNIT  33

 DISCRETIZATION INPUT DATA READ FROM UNIT 10
 # DIS file for test case tc1tr
```

Test Case 1 Sample Files – GLOBAL Output File

```
#
   3 LAYERS        18 ROWS        18 COLUMNS
  4 STRESS PERIOD(S) IN SIMULATION
MODEL TIME UNIT IS SECONDS
MODEL LENGTH UNIT IS FEET

THE OBSERVATION PROCESS IS ACTIVE
THE SENSITIVITY PROCESS IS INACTIVE
THE PARAMETER-ESTIMATION PROCESS IS INACTIVE

MODE: FORWARD WITH OBSERVATIONS


ZONE OPTION, INPUT READ FROM UNIT 33
    1 ZONE ARRAYS

MULTIPLIER OPTION, INPUT READ FROM UNIT 32
  2 MULTIPLIER ARRAYS
 Confining bed flag for each layer:
  0   0   0

      9432  ELEMENTS OF GX ARRAY USED OUT OF       9432
       972  ELEMENTS OF GZ ARRAY USED OUT OF        972
      1296  ELEMENTS OF IG ARRAY USED OUT OF       1296

                    DELR =   1000.00

                    DELC =   1000.00

TOP ELEVATION OF LAYER 1 =   150.000

  MODEL LAYER BOTTOM EL. =   100.000     FOR LAYER   1

  MODEL LAYER BOTTOM EL. =   90.0000     FOR LAYER   2

  MODEL LAYER BOTTOM EL. =   40.0000     FOR LAYER   3

STRESS PERIOD     LENGTH       TIME STEPS     MULTIPLIER FOR DELT    SS FLAG
----------------------------------------------------------------------------
       1         87162.00         1                    1.200         TR
       2         261486.0         1                    1.200         TR
       3         522972.0         1                    1.200         TR
       4        2.3567440E+07      9                    1.200         TR

TRANSIENT SIMULATION





           MULT. ARRAY: TMULT
READING ON UNIT  32 WITH FORMAT: (18F3.0)



           MULT. ARRAY: RCHMULT
READING ON UNIT  32 WITH FORMAT: (9F8.0)



            ZONE ARRAY: RCHZONE
READING ON UNIT  33 WITH FORMAT: (18I2)

HUF1 -- HYDROGEOLOGIC-UNIT FLOW PACKAGE, ’ VERSION 0.13-ERA, 9/26/00
INPUT READ FROM UNIT  7
This preliminary version is not to be released
outside the U.S. Geological Survey

# HUF file for Test Case 1
#
HEAD AT CELLS THAT CONVERT TO DRY=  -999.00
Hydrogeologic-Unit Flow Package Active with  16 parameters
   16 Named Parameters
TRANSIENT SIMULATION

  INTERPRETATION OF LAYER FLAGS:
LAYER     LTHUF    LAYER TYPE     LAYWT WETTABILITY
---------------------------------------------------------------------------
   1         1   CONVERTIBLE         0  NON-WETTABLE
```

```
   2         2   CONVERTIBLE         0  NON-WETTABLE
   3         3   CONVERTIBLE         0  NON-WETTABLE

      7776 ELEMENTS IN X ARRAY ARE USED BY HUF
        20 ELEMENTS IN IX ARRAY ARE USED BY HUF

PCG2 -- CONJUGATE GRADIENT SOLUTION PACKAGE, VERSION 2.4, 12/29/98
MAXIMUM OF    500 CALLS OF SOLUTION ROUTINE
MAXIMUM OF      8 INTERNAL ITERATIONS PER CALL TO SOLUTION ROUTINE
MATRIX PRECONDITIONING TYPE :    1
     10916 ELEMENTS IN X ARRAY ARE USED BY PCG
     28000 ELEMENTS IN IX ARRAY ARE USED BY PCG
      1944 ELEMENTS IN Z ARRAY ARE USED BY PCG

OBS1BAS6 -- OBSERVATION PROCESS, VERSION 1.0, 4/27/99
INPUT READ FROM UNIT  40
OBSERVATION GRAPH-DATA OUTPUT FILES WILL NOT BE PRINTED

HEAD OBSERVATIONS -- INPUT READ FROM UNIT  41

NUMBER OF HEADS..................................:   48
  NUMBER OF MULTILAYER HEADS.......................:    0
  MAXIMUM NUMBER OF LAYERS FOR MULTILAYER HEADS....:    0

OBS1GHB6 -- OBSERVATION PROCESS (GENERAL HEAD BOUNDARY FLOW OBSERVATIONS)
VERSION 1.0, 10/15/98
INPUT READ FROM UNIT  42

NUMBER OF FLOW-OBSERVATION GENERAL-HEAD-CELL GROUPS:    1
  NUMBER OF CELLS IN GENERAL-HEAD-CELL GROUPS......:   72
  NUMBER OF GENERAL-HEAD-CELL FLOWS................:    4

   1023 ELEMENTS IN X ARRAY ARE USED FOR OBSERVATIONS
     30 ELEMENTS IN Z ARRAY ARE USED FOR OBSERVATIONS
    503 ELEMENTS IN IX ARRAY ARE USED FOR OBSERVATIONS

COMMON ERROR VARIANCE FOR ALL OBSERVATIONS SET TO:       1.000

     19715  ELEMENTS OF X ARRAY USED OUT OF      19715
      1974  ELEMENTS OF Z ARRAY USED OUT OF       1974
     28523  ELEMENTS OF IX ARRAY USED OUT OF      28523
         0  ELEMENTS OF XHS ARRAY USED OUT OF          1

HEAD OBSERVATION VARIANCES ARE MULTIPLIED BY:       1.000

OBSERVED HEAD DATA -- TIME OFFSETS ARE MULTIPLIED BY:   1.0000

                   REFER.
      OBSERVATION  STRESS    TIME                                  STATISTIC   PLOT
 OBS#    NAME      PERIOD   OFFSET    OBSERVATION  STATISTIC         TYPE      SYM.
    1 W2L             -4    0.000       979.0       5.000       STD. DEV.      1
 TRANSIENT DATA AT THIS LOCATION, ITT =   1
    1 H1_8_8_1         1   0.8716E+05   152.3       1.000       STD. DEV.      1
    2 H1_8_8_2         2   0.2615E+06   152.3       1.000       STD. DEV.      1
    3 H1_8_8_3         3   0.5230E+06   152.2       1.000       STD. DEV.      1
    4 H1_8_8_4         4   0.2357E+08   140.9       1.000       STD. DEV.      1

    5 W2L             -4    0.000       979.0       5.000       STD. DEV.      1
 TRANSIENT DATA AT THIS LOCATION, ITT =   1
    5 H2_8_8_1         1   0.8716E+05   152.3       1.000       STD. DEV.      1
    6 H2_8_8_2         2   0.2615E+06   152.3       1.000       STD. DEV.      1
    7 H2_8_8_3         3   0.5230E+06   152.2       1.000       STD. DEV.      1
    8 H2_8_8_4         4   0.2357E+08   140.1       1.000       STD. DEV.      1

    9 W2L             -4    0.000       979.0       5.000       STD. DEV.      1
 TRANSIENT DATA AT THIS LOCATION, ITT =   1
    9 H3_8_8_1         1   0.8716E+05   152.3       1.000       STD. DEV.      1
   10 H3_8_8_2         2   0.2615E+06   152.2       1.000       STD. DEV.      1
   11 H3_8_8_3         3   0.5230E+06   152.1       1.000       STD. DEV.      1
   12 H3_8_8_4         4   0.2357E+08   139.3       1.000       STD. DEV.      1

   13 W2L             -4    0.000       979.0       5.000       STD. DEV.      1
 TRANSIENT DATA AT THIS LOCATION, ITT =   1
   13 H1_2_2_1         1   0.8716E+05   110.0       1.000       STD. DEV.      1
   14 H1_2_2_2         2   0.2615E+06   110.1       1.000       STD. DEV.      1
   15 H1_2_2_3         3   0.5230E+06   110.3       1.000       STD. DEV.      1
   16 H1_2_2_4         4   0.2357E+08   117.7       1.000       STD. DEV.      1

   17 W2L             -4    0.000       979.0       5.000       STD. DEV.      1
 TRANSIENT DATA AT THIS LOCATION, ITT =   1
   17 H2_2_2_1         1   0.8716E+05   110.0       1.000       STD. DEV.      1
```

```
   18 H2_2_2_2         2   0.2615E+06   110.1       1.000      STD. DEV.      1
   19 H2_2_2_3         3   0.5230E+06   110.2       1.000      STD. DEV.      1
   20 H2_2_2_4         4   0.2357E+08   117.2       1.000      STD. DEV.      1

   21 W2L             -4    0.000       979.0       5.000      STD. DEV.      1
 TRANSIENT DATA AT THIS LOCATION, ITT =   1
   21 H3_2_2_1         1   0.8716E+05   110.0       1.000      STD. DEV.      1
   22 H3_2_2_2         2   0.2615E+06   110.0       1.000      STD. DEV.      1
   23 H3_2_2_3         3   0.5230E+06   110.1       1.000      STD. DEV.      1
   24 H3_2_2_4         4   0.2357E+08   116.6       1.000      STD. DEV.      1

   25 W2L             -4    0.000       979.0       5.000      STD. DEV.      1
 TRANSIENT DATA AT THIS LOCATION, ITT =   1
   25 H1_16_16_1       1   0.8716E+05   176.2       1.000      STD. DEV.      1
   26 H1_16_16_2       2   0.2615E+06   176.2       1.000      STD. DEV.      1
   27 H1_16_16_3       3   0.5230E+06   176.7       1.000      STD. DEV.      1
   28 H1_16_16_4       4   0.2357E+08   240.1       1.000      STD. DEV.      1

   29 W2L             -4    0.000       979.0       5.000      STD. DEV.      1
 TRANSIENT DATA AT THIS LOCATION, ITT =   1
   29 H2_16_16_1       1   0.8716E+05   176.1       1.000      STD. DEV.      1
   30 H2_16_16_2       2   0.2615E+06   176.2       1.000      STD. DEV.      1
   31 H2_16_16_3       3   0.5230E+06   176.7       1.000      STD. DEV.      1
   32 H2_16_16_4       4   0.2357E+08   240.2       1.000      STD. DEV.      1

   33 W2L             -4    0.000       979.0       5.000      STD. DEV.      1
 TRANSIENT DATA AT THIS LOCATION, ITT =   1
   33 H3_16_16_1       1   0.8716E+05   176.1       1.000      STD. DEV.      1
   34 H3_16_16_2       2   0.2615E+06   176.2       1.000      STD. DEV.      1
   35 H3_16_16_3       3   0.5230E+06   176.6       1.000      STD. DEV.      1
   36 H3_16_16_4       4   0.2357E+08   240.3       1.000      STD. DEV.      1

   37 W2L             -4    0.000       979.0       5.000      STD. DEV.      1
 TRANSIENT DATA AT THIS LOCATION, ITT =   1
   37 H1_16_2_1        1   0.8716E+05   110.0       1.000      STD. DEV.      1
   38 H1_16_2_2        2   0.2615E+06   110.1       1.000      STD. DEV.      1
   39 H1_16_2_3        3   0.5230E+06   110.3       1.000      STD. DEV.      1
   40 H1_16_2_4        4   0.2357E+08   117.7       1.000      STD. DEV.      1

   41 W2L             -4    0.000       979.0       5.000      STD. DEV.      1
 TRANSIENT DATA AT THIS LOCATION, ITT =   1
   41 H2_16_2_1        1   0.8716E+05   110.0       1.000      STD. DEV.      1
   42 H2_16_2_2        2   0.2615E+06   110.1       1.000      STD. DEV.      1
   43 H2_16_2_3        3   0.5230E+06   110.2       1.000      STD. DEV.      1
   44 H2_16_2_4        4   0.2357E+08   117.2       1.000      STD. DEV.      1

   45 W2L             -4    0.000       979.0       5.000      STD. DEV.      1
 TRANSIENT DATA AT THIS LOCATION, ITT =   1
   45 H3_16_2_1        1   0.8716E+05   110.0       1.000      STD. DEV.      1
   46 H3_16_2_2        2   0.2615E+06   110.0       1.000      STD. DEV.      1
   47 H3_16_2_3        3   0.5230E+06   110.1       1.000      STD. DEV.      1
   48 H3_16_2_4        4   0.2357E+08   116.6       1.000      STD. DEV.      1


                                                       HEAD CHANGE
                                                        REFERENCE
     OBSERVATION                         ROW     COL   OBSERVATION
 OBS#    NAME        LAY  ROW  COL   OFFSET  OFFSET    (IF > 0)
    1  H1_8_8_1        1    8    8   0.000   0.000          0
    2  H1_8_8_2        1    8    8   0.000   0.000          0
    3  H1_8_8_3        1    8    8   0.000   0.000          0
    4  H1_8_8_4        1    8    8   0.000   0.000          0
    5  H2_8_8_1        2    8    8   0.000   0.000          0
    6  H2_8_8_2        2    8    8   0.000   0.000          0
    7  H2_8_8_3        2    8    8   0.000   0.000          0
    8  H2_8_8_4        2    8    8   0.000   0.000          0
    9  H3_8_8_1        3    8    8   0.000   0.000          0
   10  H3_8_8_2        3    8    8   0.000   0.000          0
   11  H3_8_8_3        3    8    8   0.000   0.000          0
   12  H3_8_8_4        3    8    8   0.000   0.000          0
   13  H1_2_2_1        1    2    2   0.000   0.000          0
   14  H1_2_2_2        1    2    2   0.000   0.000          0
   15  H1_2_2_3        1    2    2   0.000   0.000          0
   16  H1_2_2_4        1    2    2   0.000   0.000          0
   17  H2_2_2_1        2    2    2   0.000   0.000          0
   18  H2_2_2_2        2    2    2   0.000   0.000          0
   19  H2_2_2_3        2    2    2   0.000   0.000          0
   20  H2_2_2_4        2    2    2   0.000   0.000          0
   21  H3_2_2_1        3    2    2   0.000   0.000          0
   22  H3_2_2_2        3    2    2   0.000   0.000          0
   23  H3_2_2_3        3    2    2   0.000   0.000          0
```

```
   24  H3_2_2_4        3    2    2   0.000   0.000        0
   25  H1_16_16_1      1   16   16   0.000   0.000        0
   26  H1_16_16_2      1   16   16   0.000   0.000        0
   27  H1_16_16_3      1   16   16   0.000   0.000        0
   28  H1_16_16_4      1   16   16   0.000   0.000        0
   29  H2_16_16_1      2   16   16   0.000   0.000        0
   30  H2_16_16_2      2   16   16   0.000   0.000        0
   31  H2_16_16_3      2   16   16   0.000   0.000        0
   32  H2_16_16_4      2   16   16   0.000   0.000        0
   33  H3_16_16_1      3   16   16   0.000   0.000        0
   34  H3_16_16_2      3   16   16   0.000   0.000        0
   35  H3_16_16_3      3   16   16   0.000   0.000        0
   36  H3_16_16_4      3   16   16   0.000   0.000        0
   37  H1_16_2_1       1   16    2   0.000   0.000        0
   38  H1_16_2_2       1   16    2   0.000   0.000        0
   39  H1_16_2_3       1   16    2   0.000   0.000        0
   40  H1_16_2_4       1   16    2   0.000   0.000        0
   41  H2_16_2_1       2   16    2   0.000   0.000        0
   42  H2_16_2_2       2   16    2   0.000   0.000        0
   43  H2_16_2_3       2   16    2   0.000   0.000        0
   44  H2_16_2_4       2   16    2   0.000   0.000        0
   45  H3_16_2_1       3   16    2   0.000   0.000        0
   46  H3_16_2_2       3   16    2   0.000   0.000        0
   47  H3_16_2_3       3   16    2   0.000   0.000        0
   48  H3_16_2_4       3   16    2   0.000   0.000        0

GENERAL-HEAD-CELL FLOW OBSERVATION VARIANCES ARE MULTIPLIED BY:       1.000

OBSERVED GENERAL-HEAD-CELL FLOW DATA
-- TIME OFFSETS ARE MULTIPLIED BY:   1.0000

  GROUP NUMBER:   1   BOUNDARY TYPE: GHB   NUMBER OF CELLS IN GROUP:   -18
  NUMBER OF FLOW OBSERVATIONS:     4

                                       OBSERVED
                   REFER.            BOUNDARY FLOW
      OBSERVATION  STRESS    TIME     GAIN (-) OR            STATISTIC   PLOT
 OBS#    NAME      PERIOD   OFFSET     LOSS (+)    STATISTIC     TYPE      SYM.
   49 GHB1              1   0.8716E+05   30.60      0.5000E-01  COEF. VAR.     3
   50 GHB2              2   0.2615E+06   29.20      0.5000E-01  COEF. VAR.     3
   51 GHB3              3   0.5230E+06   26.90      0.5000E-01  COEF. VAR.     3
   52 GHB4              4   0.2357E+08   9.620      0.5000E-01  COEF. VAR.     3

      LAYER  ROW  COLUMN    FACTOR
         1.    1.    18.     1.00
         1.    2.    18.     1.00
         1.    3.    18.     1.00
         1.    4.    18.     1.00
         1.    5.    18.     1.00
         1.    6.    18.     1.00
         1.    7.    18.     1.00
         1.    8.    18.     1.00
         1.    9.    18.     1.00
         1.   10.    18.     1.00
         1.   11.    18.     1.00
         1.   12.    18.     1.00
         1.   13.    18.     1.00
         1.   14.    18.     1.00
         1.   15.    18.     1.00
         1.   16.    18.     1.00
         1.   17.    18.     1.00
         1.   18.    18.     1.00

NQC CAN BE REDUCED FROM   72 TO   18


                                   SOLUTION BY THE CONJUGATE-GRADIENT METHOD
                                  -------------------------------------------
                   MAXIMUM NUMBER OF CALLS TO PCG ROUTINE =      500
                       MAXIMUM ITERATIONS PER CALL TO PCG =        8
                              MATRIX PRECONDITIONING TYPE =        1
       RELAXATION FACTOR (ONLY USED WITH PRECOND. TYPE 1) =    0.10000E+01
PARAMETER OF POLYMOMIAL PRECOND. = 2 (2) OR IS CALCULATED :        2
                        HEAD CHANGE CRITERION FOR CLOSURE =    0.10000E-03
                    RESIDUAL CHANGE CRITERION FOR CLOSURE =    0.10000E-03
           PCG HEAD AND RESIDUAL CHANGE PRINTOUT INTERVAL =      999
    PRINTING FROM SOLVER IS LIMITED(1) OR SUPPRESSED (>1) =        2
                                        DAMPING PARAMETER =    0.10000E+01

WETTING CAPABILITY IS NOT ACTIVE IN ANY LAYER
```

```
 HUF1 -- HYDROGEOLOGIC-UNIT FLOW PACKAGE
 ---------------------------------------------------------------------------

  TOP ELEVATN: HGU1       =   150.000

    THICKNESS: HGU1       =   50.0000

  TOP ELEVATN: HGU2       =   100.000

    THICKNESS: HGU2       =   10.0000

  TOP ELEVATN: HGU3       =   90.0000



              THICKNESS: HGU3
 READING ON UNIT   7 WITH FORMAT: (15F5.0)



            TOP ELEVATN: HGU4
 READING ON UNIT   7 WITH FORMAT: (15F5.0)



              THICKNESS: HGU4
 READING ON UNIT   7 WITH FORMAT: (15F5.0)


   INTERPRETATION OF UNIT FLAGS:
     UNIT      HANI           VK/VANI
 ---------------------------------------------------------------------------
 HGU1        1.000000        VERTICAL K
 HGU2        1.000000        VERTICAL K
 HGU3        1.000000        VERTICAL K
 HGU4        1.000000        VERTICAL K

 PARAMETER NAME:HK1          TYPE:HK   UNITS:   1
 The parameter value from the package file is:  3.00000E-04
UNIT HGU1      CORRESPONDS TO UNIT NO.     1
                LAYER:  1   MULTIPLIER:NONE   ZONE:ALL

 PARAMETER NAME:HK2          TYPE:HK   UNITS:   1
 The parameter value from the package file is:  2.00000E-07
UNIT HGU2      CORRESPONDS TO UNIT NO.     2
                LAYER:  2   MULTIPLIER:NONE   ZONE:ALL

 PARAMETER NAME:HK3          TYPE:HK   UNITS:   1
 The parameter value from the package file is:  4.00000E-05
UNIT HGU3      CORRESPONDS TO UNIT NO.     3
                LAYER:  3   MULTIPLIER:TMULT   ZONE:ALL

 PARAMETER NAME:HK4          TYPE:HK   UNITS:   1
 The parameter value from the package file is:  4.00000E-05
UNIT HGU4      CORRESPONDS TO UNIT NO.     4
                LAYER:  4   MULTIPLIER:TMULT   ZONE:ALL

 PARAMETER NAME:VKA1         TYPE:VK   UNITS:   1
 The parameter value from the package file is:  3.00000E-04
UNIT HGU1      CORRESPONDS TO UNIT NO.     1
                LAYER:  1   MULTIPLIER:NONE   ZONE:ALL

 PARAMETER NAME:VKA2         TYPE:VK   UNITS:   1
 The parameter value from the package file is:  2.00000E-07
UNIT HGU2      CORRESPONDS TO UNIT NO.     2
                LAYER:  2   MULTIPLIER:NONE   ZONE:ALL

 PARAMETER NAME:VKA3         TYPE:VK   UNITS:   1
 The parameter value from the package file is:  4.00000E-05
UNIT HGU3      CORRESPONDS TO UNIT NO.     3
                LAYER:  3   MULTIPLIER:TMULT   ZONE:ALL

 PARAMETER NAME:VKA4         TYPE:VK   UNITS:   1
 The parameter value from the package file is:  4.00000E-05
UNIT HGU4      CORRESPONDS TO UNIT NO.     4
                LAYER:  4   MULTIPLIER:TMULT   ZONE:ALL

 PARAMETER NAME:SS1          TYPE:SS   UNITS:   1
 The parameter value from the package file is:  1.00000E-03
```

```
UNIT HGU1      CORRESPONDS TO UNIT NO.     1
                LAYER:  1   MULTIPLIER:NONE   ZONE:ALL

 PARAMETER NAME:SS2          TYPE:SS   UNITS:   1
 The parameter value from the package file is:  1.00000E-06
UNIT HGU2      CORRESPONDS TO UNIT NO.     2
                LAYER:  2   MULTIPLIER:NONE   ZONE:ALL

 PARAMETER NAME:SS3          TYPE:SS   UNITS:   1
 The parameter value from the package file is:  1.00000E-03
UNIT HGU3      CORRESPONDS TO UNIT NO.     3
                LAYER:  3   MULTIPLIER:NONE   ZONE:ALL

 PARAMETER NAME:SS4          TYPE:SS   UNITS:   1
 The parameter value from the package file is:  1.00000E-03
UNIT HGU4      CORRESPONDS TO UNIT NO.     4
                LAYER:  4   MULTIPLIER:NONE   ZONE:ALL

 PARAMETER NAME:SY1          TYPE:SY   UNITS:   1
 The parameter value from the package file is:  0.10000
UNIT HGU1      CORRESPONDS TO UNIT NO.     1
                LAYER:  1   MULTIPLIER:NONE   ZONE:ALL

 PARAMETER NAME:SY2          TYPE:SY   UNITS:   1
 The parameter value from the package file is:  1.00000E-02
UNIT HGU2      CORRESPONDS TO UNIT NO.     2
                LAYER:  2   MULTIPLIER:NONE   ZONE:ALL

 PARAMETER NAME:SY3          TYPE:SY   UNITS:   1
 The parameter value from the package file is:  0.10000
UNIT HGU3      CORRESPONDS TO UNIT NO.     3
                LAYER:  3   MULTIPLIER:NONE   ZONE:ALL

 PARAMETER NAME:SY4          TYPE:SY   UNITS:   1
 The parameter value from the package file is:  0.10000
UNIT HGU4      CORRESPONDS TO UNIT NO.     4
                LAYER:  4   MULTIPLIER:NONE   ZONE:ALL
 ITRSS           1

Reading PRINTCODE information
UNIT HGU3      CORRESPONDS TO UNIT NO.     3


PRINTCODE FLAGS ARE SET AS FOLLOWS
   UNIT       HK   HANI   VK    SS    SY
------------------------------------------
HGU1           0     0     0     0     0
HGU2           0     0     0     0     0
HGU3          20    20    20    20    20
HGU4           0     0     0     0     0


     0 Well parameters


     0 River parameters


     0 GHB parameters


     2 Recharge parameters

 PARAMETER NAME:RCH1         TYPE:RCH    CLUSTERS:   1
 Parameter value from package file is:   1.00000E-08
                MULTIPLIER ARRAY: NONE    ZONE ARRAY: RCHZONE
                ZONE VALUES:    1

 PARAMETER NAME:RCH2         TYPE:RCH    CLUSTERS:   1
 Parameter value from package file is:   1.50000E-08
                MULTIPLIER ARRAY: NONE    ZONE ARRAY: RCHZONE
                ZONE VALUES:    2

  18 PARAMETERS HAVE BEEN DEFINED IN ALL PACKAGES.
 (SPACE IS ALLOCATED FOR  500 PARAMETERS.)

 ORDERED DEPENDENT-VARIABLE WEIGHTED RESIDUALS
 NUMBER OF RESIDUALS INCLUDED:        52
    -0.932E-02 -0.496E-03 -0.443E-03 -0.443E-03 -0.427E-03 -0.397E-03 -0.397E-03
    -0.397E-03 -0.336E-03 -0.336E-03 -0.328E-03 -0.328E-03 -0.305E-03 -0.298E-03
    -0.275E-03 -0.275E-03 -0.275E-03 -0.244E-03 -0.244E-03 -0.237E-03 -0.237E-03
```

```
   -0.183E-03 -0.183E-03 -0.183E-03 -0.168E-03 -0.145E-03 -0.122E-03 -0.122E-03
   -0.122E-03 -0.916E-04 -0.458E-04 -0.458E-04 -0.305E-04 -0.153E-04  0.610E-04
    0.763E-04  0.763E-04  0.130E-03  0.130E-03  0.145E-03  0.145E-03  0.153E-03
    0.397E-03  0.404E-03  0.427E-03  0.427E-03  0.488E-03  0.133E-02  0.163E-02
    0.265E-02  0.205E-01  0.248E-01

SMALLEST AND LARGEST DEPENDENT-VARIABLE WEIGHTED RESIDUALS

    SMALLEST WEIGHTED RESIDUALS                LARGEST WEIGHTED RESIDUALS
       OBSERVATION     WEIGHTED                   OBSERVATION     WEIGHTED
 OBS#     NAME         RESIDUAL           OBS#     NAME         RESIDUAL
   51  GHB3          -0.93169E-02           49  GHB1           0.24769E-01
   44  H2_16_2_4     -0.49591E-03           50  GHB2           0.20492E-01
   40  H1_16_2_4     -0.44250E-03           52  GHB4           0.26469E-02
   25  H1_16_16_1    -0.44250E-03            4  H1_8_8_4       0.16327E-02
    6  H2_8_8_2      -0.42725E-03           12  H3_8_8_4       0.13275E-02

CORRELATION BETWEEN ORDERED WEIGHTED RESIDUALS AND
NORMAL ORDER STATISTICS (EQ.38 OF TEXT) =    0.333

---------------------------------------------------------------------------
COMMENTS ON THE INTERPRETATION OF THE CORRELATION BETWEEN
WEIGHTED RESIDUALS AND NORMAL ORDER STATISTICS:

The critical value for correlation at the 5% significance level is 0.956

IF the reported CORRELATION is GREATER than the 5% critical value, ACCEPT
the hypothesis that the weighted residuals are INDEPENDENT AND NORMALLY
DISTRIBUTED at the 5% significance level.  The probability that this
conclusion is wrong is less than 5%.

IF the reported correlation IS LESS THAN the 5% critical value REJECT the,
hypothesis that the weighted residuals are INDEPENDENT AND NORMALLY
DISTRIBUTED at the 5% significance level.

The analysis can also be done using the 10% significance level.
The associated critical value is 0.964
---------------------------------------------------------------------------
```

LIST Output File

An example of the excerpted LIST output file for Test Case 1 is shown below. The HUF Package output appears in bold, and three dots (…) indicates omitted output.

```
                                  MODFLOW-2000
      U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
                            VERSION 1.0.2 08/21/2000


 This model run produced both GLOBAL and LIST files.  This is the LIST file.


 # MODULAR MODEL - TWO-LAYER EXAMPLE PROBLEM, TRANSIENT, TEST CASE TC1TR
 #
 THE FREE FORMAT OPTION HAS BEEN SELECTED
    3 LAYERS        18 ROWS        18 COLUMNS
   4 STRESS PERIOD(S) IN SIMULATION

 BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT  5
         15 ELEMENTS IN IR ARRAY ARE USED BY BAS

 WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT  8
 No named parameters
 MAXIMUM OF    5 ACTIVE WELLS AT ONE TIME
         20 ELEMENTS IN RX ARRAY ARE USED BY WEL

 RIV6 -- RIVER PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 13
 No named parameters
 MAXIMUM OF   18 ACTIVE RIVER REACHES AT ONE TIME
        108 ELEMENTS IN RX ARRAY ARE USED BY RIV

 GHB6 -- GHB PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12
 No named parameters
 MAXIMUM OF   36 ACTIVE GHB CELLS AT ONE TIME
        180 ELEMENTS IN RX ARRAY ARE USED BY GHB

 RCH6 -- RECHARGE PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 31
     2 Named Parameters
 OPTION 1 -- RECHARGE TO TOP LAYER
        324 ELEMENTS IN RX ARRAY ARE USED BY RCH
        324 ELEMENTS IN IR ARRAY ARE USED BY RCH

        632  ELEMENTS OF RX ARRAY USED OUT OF        632
        339  ELEMENTS OF IR ARRAY USED OUT OF        339
1
 # MODULAR MODEL - TWO-LAYER EXAMPLE PROBLEM, TRANSIENT, TEST CASE TC1TR
 #

           BOUNDARY ARRAY =             1 FOR LAYER   1

           BOUNDARY ARRAY =             1 FOR LAYER   2

           BOUNDARY ARRAY =             1 FOR LAYER   3

 AQUIFER HEAD WILL BE SET TO  0.0000     AT ALL NO-FLOW NODES (IBOUND=0).



                       INITIAL HEAD FOR LAYER   1
 READING ON UNIT  14 WITH FORMAT: (10F13.0)



                       INITIAL HEAD FOR LAYER   2
 READING ON UNIT  14 WITH FORMAT: (10F13.0)



                       INITIAL HEAD FOR LAYER   3
 READING ON UNIT  14 WITH FORMAT: (10F13.0)

 OUTPUT CONTROL IS SPECIFIED EVERY TIME STEP
 HEAD PRINT FORMAT CODE IS  20    DRAWDOWN PRINT FORMAT CODE IS   0
```

```
 HEADS WILL BE SAVED ON UNIT  19    DRAWDOWNS WILL BE SAVED ON UNIT   0

  HYD. COND. ALONG ROWS FOR UNIT HGU3

             HYD. COND. ALONG ROWS

           1           2           3           4           5           6
           7           8           9          10          11          12
          13          14          15          16          17          18
........................................................................
  1   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  2   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  3   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  4   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  5   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  6   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  7   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  8   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  9   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
 10   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
 11   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
 12   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
 13   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
 14   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
 15   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
 16   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
 17   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
 18   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
      1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
      2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04

 HORIZ. ANI. (COL./ROW) FOR UNIT HGU3

  HORIZ. ANI. (COL./ROW) =   1.00000

    VERTICAL HYD. COND. FOR UNIT HGU3

               VERTICAL HYD. COND.

           1           2           3           4           5           6
           7           8           9          10          11          12
          13          14          15          16          17          18
```

```
 ........................................................................
   1   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
   2   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
   3   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
   4   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
   5   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
   6   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
   7   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
   8   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
   9   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  10   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  11   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  12   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  13   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  14   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  15   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  16   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  17   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04
  18   4.0000E-05  4.0000E-05  8.0000E-05  8.0000E-05  1.2000E-04  1.2000E-04
       1.6000E-04  1.6000E-04  2.0000E-04  2.0000E-04  2.4000E-04  2.4000E-04
       2.8000E-04  2.8000E-04  3.2000E-04  3.2000E-04  3.6000E-04  3.6000E-04

        SPECIFIC STORAGE FOR UNIT HGU3

         SPECIFIC STORAGE =  1.000000E-03


          SPECIFIC YIELD FOR UNIT HGU3

           SPECIFIC YIELD =  0.100000
1
                            STRESS PERIOD NO.   1, LENGTH =   87162.00
                            ----------------------------------------------

                              NUMBER OF TIME STEPS =     1

                               MULTIPLIER FOR DELT =     1.200

                            INITIAL TIME STEP SIZE =   87162.00

 WELL NO.  LAYER   ROW   COL   STRESS RATE
 --------------------------------------------
      1      1      9     10      -1.000
      2      3      9      9      -1.000
      3      3      9     10      -1.000
      4      3     10      9      -1.000
```

```
     5      3     10     10      -1.000

    5 WELLS

REACH NO.  LAYER   ROW   COL     STAGE      CONDUCTANCE     BOTTOM EL.
-------------------------------------------------------------------------
     1      1      1      1       100.0           1.000           90.00
     2      1      2      1       100.0           1.000           90.00
     3      1      3      1       100.0           1.000           90.00
     4      1      4      1       100.0           1.000           90.00
     5      1      5      1       100.0           1.000           90.00
     6      1      6      1       100.0           1.000           90.00
     7      1      7      1       100.0           1.000           90.00
     8      1      8      1       100.0           1.000           90.00
     9      1      9      1       100.0           1.000           90.00
    10      1     10      1       100.0           1.000           90.00
    11      1     11      1       100.0           1.000           90.00
    12      1     12      1       100.0           1.000           90.00
    13      1     13      1       100.0           1.000           90.00
    14      1     14      1       100.0           1.000           90.00
    15      1     15      1       100.0           1.000           90.00
    16      1     16      1       100.0           1.000           90.00
    17      1     17      1       100.0           1.000           90.00
    18      1     18      1       100.0           1.000           90.00

   18 RIVER REACHES

BOUND. NO. LAYER   ROW   COL     STAGE      CONDUCTANCE
----------------------------------------------------------
     1      1      1     18       350.0          0.1000E-01
     2      1      2     18       350.0          0.1000E-01
     3      1      3     18       350.0          0.1000E-01
     4      1      4     18       350.0          0.1000E-01
     5      1      5     18       350.0          0.1000E-01
     6      1      6     18       350.0          0.1000E-01
     7      1      7     18       350.0          0.1000E-01
     8      1      8     18       350.0          0.1000E-01
     9      1      9     18       350.0          0.1000E-01
    10      1     10     18       350.0          0.1000E-01
    11      1     11     18       350.0          0.1000E-01
    12      1     12     18       350.0          0.1000E-01
    13      1     13     18       350.0          0.1000E-01
    14      1     14     18       350.0          0.1000E-01
    15      1     15     18       350.0          0.1000E-01
    16      1     16     18       350.0          0.1000E-01
    17      1     17     18       350.0          0.1000E-01
    18      1     18     18       350.0          0.1000E-01
    19      3      1     18       350.0          0.1000E-01
    20      3      2     18       350.0          0.1000E-01
    21      3      3     18       350.0          0.1000E-01
    22      3      4     18       350.0          0.1000E-01
    23      3      5     18       350.0          0.1000E-01
    24      3      6     18       350.0          0.1000E-01
    25      3      7     18       350.0          0.1000E-01
    26      3      8     18       350.0          0.1000E-01
    27      3      9     18       350.0          0.1000E-01
    28      3     10     18       350.0          0.1000E-01
    29      3     11     18       350.0          0.1000E-01
    30      3     12     18       350.0          0.1000E-01
    31      3     13     18       350.0          0.1000E-01
    32      3     14     18       350.0          0.1000E-01
    33      3     15     18       350.0          0.1000E-01
    34      3     16     18       350.0          0.1000E-01
    35      3     17     18       350.0          0.1000E-01
    36      3     18     18       350.0          0.1000E-01

   36 GHB CELLS


RECH array defined by the following parameters:
 Parameter:  RCH1
 Parameter:  RCH2


                          RECHARGE

SOLVING FOR HEAD

HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 1
CELL-BY-CELL FLOW TERM FLAG = 0
```

```
 OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:
   HEAD    DRAWDOWN  HEAD  DRAWDOWN
 PRINTOUT  PRINTOUT  SAVE    SAVE
 ----------------------------------
     1         0       0       0
1
              HEAD IN LAYER  1 AT END OF TIME STEP  1 IN STRESS PERIOD  1
  -----------------------------------------------------------------------

...

1
              HEAD IN LAYER  2 AT END OF TIME STEP  1 IN STRESS PERIOD  1
  -----------------------------------------------------------------------

...

1
              HEAD IN LAYER  3 AT END OF TIME STEP  1 IN STRESS PERIOD  1
  -----------------------------------------------------------------------

...

1
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  1
  -----------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                      IN:
           ---                                      ---
             STORAGE =      651601.0000               STORAGE =           7.4757
       CONSTANT HEAD =           0.0000         CONSTANT HEAD =           0.0000
               WELLS =           0.0000                 WELLS =           0.0000
       RIVER LEAKAGE =           0.0000         RIVER LEAKAGE =           0.0000
     HEAD DEP BOUNDS =     5328314.5000       HEAD DEP BOUNDS =          61.1312
            RECHARGE =      353006.0625              RECHARGE =           4.0500

            TOTAL IN =     6332921.5000              TOTAL IN =          72.6569

          OUT:                                     OUT:
          ----                                     ----
             STORAGE =     5698661.5000               STORAGE =          65.3801
       CONSTANT HEAD =           0.0000         CONSTANT HEAD =           0.0000
               WELLS =      435810.0000                 WELLS =           5.0000
       RIVER LEAKAGE =      198362.3906         RIVER LEAKAGE =           2.2758
     HEAD DEP BOUNDS =           0.0000       HEAD DEP BOUNDS =           0.0000
            RECHARGE =           0.0000              RECHARGE =           0.0000

           TOTAL OUT =     6332834.0000             TOTAL OUT =          72.6559

            IN - OUT =          87.5000              IN - OUT =       1.0147E-03

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00




          TIME SUMMARY AT END OF TIME STEP  1 IN STRESS PERIOD  1
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH  87162.      1452.7      24.212      1.0088     2.76200E-03
 STRESS PERIOD TIME  87162.      1452.7      24.212      1.0088     2.76200E-03
         TOTAL TIME  87162.      1452.7      24.212      1.0088     2.76200E-03
1
1
                            STRESS PERIOD NO.   2, LENGTH =   261486.0
                            ----------------------------------------------

                              NUMBER OF TIME STEPS =     1

                               MULTIPLIER FOR DELT =     1.200

                            INITIAL TIME STEP SIZE =   261486.0

 REUSING NON-PARAMETER WELLS FROM LAST STRESS PERIOD
```

```
     5 WELLS

 REUSING NON-PARAMETER RIVER REACHES FROM LAST STRESS PERIOD

    18 RIVER REACHES

 REUSING NON-PARAMETER GHB CELLS FROM LAST STRESS PERIOD

    36 GHB CELLS



 RECH array defined by the following parameters:
  Parameter:  RCH1
  Parameter:  RCH2


                           RECHARGE

 SOLVING FOR HEAD

 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 1
 CELL-BY-CELL FLOW TERM FLAG = 0
 REUSING PREVIOUS VALUES OF IOFLG
1
              HEAD IN LAYER  1 AT END OF TIME STEP  1 IN STRESS PERIOD  2
  -----------------------------------------------------------------------

...

1
              HEAD IN LAYER  2 AT END OF TIME STEP  1 IN STRESS PERIOD  2
  -----------------------------------------------------------------------

...

1
              HEAD IN LAYER  3 AT END OF TIME STEP  1 IN STRESS PERIOD  2
  -----------------------------------------------------------------------

...

1
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  2
  -----------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                      IN:
           ---                                      ---
             STORAGE =     2154857.7500             STORAGE =          5.7489
       CONSTANT HEAD =           0.0000       CONSTANT HEAD =          0.0000
               WELLS =           0.0000               WELLS =          0.0000
       RIVER LEAKAGE =           0.0000       RIVER LEAKAGE =          0.0000
     HEAD DEP BOUNDS =    20593000.0000     HEAD DEP BOUNDS =         58.3767
            RECHARGE =     1412024.2500            RECHARGE =          4.0500

            TOTAL IN =    24159882.0000            TOTAL IN =         68.1756

          OUT:                                     OUT:
          ----                                     ----
             STORAGE =    21999544.0000             STORAGE =         62.3394
       CONSTANT HEAD =           0.0000       CONSTANT HEAD =          0.0000
               WELLS =     1743240.0000               WELLS =          5.0000
       RIVER LEAKAGE =      416905.6562       RIVER LEAKAGE =          0.8358
     HEAD DEP BOUNDS =           0.0000     HEAD DEP BOUNDS =          0.0000
            RECHARGE =           0.0000            RECHARGE =          0.0000

           TOTAL OUT =    24159690.0000           TOTAL OUT =         68.1752

            IN - OUT =         192.0000            IN - OUT =      4.1199E-04

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =          0.00




          TIME SUMMARY AT END OF TIME STEP  1 IN STRESS PERIOD  2
```

```
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    ------------------------------------------------------------
   TIME STEP LENGTH 2.61486E+05  4358.1      72.635      3.0265     8.28599E-03
 STRESS PERIOD TIME 2.61486E+05  4358.1      72.635      3.0265     8.28599E-03
         TOTAL TIME 3.48648E+05  5810.8      96.847      4.0353     1.10480E-02
1
1
                            STRESS PERIOD NO.   3, LENGTH =   522972.0
                            ----------------------------------------------

                              NUMBER OF TIME STEPS =     1

                               MULTIPLIER FOR DELT =     1.200

                            INITIAL TIME STEP SIZE =   522972.0

 REUSING NON-PARAMETER WELLS FROM LAST STRESS PERIOD

     5 WELLS

 REUSING NON-PARAMETER RIVER REACHES FROM LAST STRESS PERIOD

    18 RIVER REACHES

 REUSING NON-PARAMETER GHB CELLS FROM LAST STRESS PERIOD

    36 GHB CELLS


 RECH array defined by the following parameters:
  Parameter:  RCH1
  Parameter:  RCH2


                           RECHARGE

 SOLVING FOR HEAD

 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 1
 CELL-BY-CELL FLOW TERM FLAG = 0

 OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:
   HEAD    DRAWDOWN  HEAD  DRAWDOWN
 PRINTOUT  PRINTOUT  SAVE    SAVE
 ----------------------------------
     0         0       0       0
1
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  3
  -----------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                      IN:
           ---                                      ---
             STORAGE =      4792874.5000              STORAGE =            5.0443
       CONSTANT HEAD =            0.0000        CONSTANT HEAD =            0.0000
               WELLS =            0.0000                WELLS =            0.0000
       RIVER LEAKAGE =            0.0000        RIVER LEAKAGE =            0.0000
     HEAD DEP BOUNDS =     48794636.0000      HEAD DEP BOUNDS =           53.9257
            RECHARGE =      3530060.7500             RECHARGE =            4.0500

            TOTAL IN =     57117572.0000             TOTAL IN =           63.0200

          OUT:                                     OUT:
          ----                                     ----
             STORAGE =     52126352.0000              STORAGE =           57.6069
       CONSTANT HEAD =            0.0000        CONSTANT HEAD =            0.0000
               WELLS =      4358100.0000                WELLS =            5.0000
       RIVER LEAKAGE =       632880.8750        RIVER LEAKAGE =            0.4130
     HEAD DEP BOUNDS =            0.0000      HEAD DEP BOUNDS =            0.0000
            RECHARGE =            0.0000             RECHARGE =            0.0000

           TOTAL OUT =     57117332.0000            TOTAL OUT =           63.0199

            IN - OUT =          240.0000             IN - OUT =        8.3923E-05

 PERCENT DISCREPANCY =            0.00    PERCENT DISCREPANCY =            0.00
```

```
          TIME SUMMARY AT END OF TIME STEP  1 IN STRESS PERIOD  3
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 5.22972E+05  8716.2      145.27      6.0529     1.65720E-02
 STRESS PERIOD TIME 5.22972E+05  8716.2      145.27      6.0529     1.65720E-02
         TOTAL TIME 8.71620E+05  14527.      242.12      10.088     2.76200E-02
1
1
                            STRESS PERIOD NO.   4, LENGTH =  0.2356744E+08
                            ----------------------------------------------

                              NUMBER OF TIME STEPS =     9

                               MULTIPLIER FOR DELT =     1.200

                            INITIAL TIME STEP SIZE =   1133110.

 REUSING NON-PARAMETER WELLS FROM LAST STRESS PERIOD

     5 WELLS

 REUSING NON-PARAMETER RIVER REACHES FROM LAST STRESS PERIOD

    18 RIVER REACHES

 REUSING NON-PARAMETER GHB CELLS FROM LAST STRESS PERIOD

    36 GHB CELLS



 RECH array defined by the following parameters:
  Parameter:  RCH1
  Parameter:  RCH2


                           RECHARGE

 SOLVING FOR HEAD

 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 1
 CELL-BY-CELL FLOW TERM FLAG = 0
 REUSING PREVIOUS VALUES OF IOFLG
1
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  4
  ------------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                      IN:
           ---                                      ---
             STORAGE =    10166688.0000               STORAGE =           4.7425
       CONSTANT HEAD =          0.0000          CONSTANT HEAD =           0.0000
               WELLS =          0.0000                  WELLS =           0.0000
       RIVER LEAKAGE =          0.0000          RIVER LEAKAGE =           0.0000
     HEAD DEP BOUNDS =   102304648.0000       HEAD DEP BOUNDS =          47.2240
            RECHARGE =     8119154.5000              RECHARGE =           4.0500

            TOTAL IN =   120590488.0000              TOTAL IN =          56.0166

          OUT:                                     OUT:
          ----                                     ----
             STORAGE =   109484688.0000               STORAGE =          50.6203
       CONSTANT HEAD =          0.0000          CONSTANT HEAD =           0.0000
               WELLS =    10023648.0000                 WELLS =           5.0000
       RIVER LEAKAGE =     1082042.8750         RIVER LEAKAGE =           0.3964
     HEAD DEP BOUNDS =          0.0000        HEAD DEP BOUNDS =           0.0000
            RECHARGE =          0.0000               RECHARGE =           0.0000

           TOTAL OUT =   120590376.0000             TOTAL OUT =          56.0167

            IN - OUT =        112.0000               IN - OUT =      -1.1063E-04

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00
```

```
          TIME SUMMARY AT END OF TIME STEP  1 IN STRESS PERIOD  4
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 1.13311E+06  18885.      314.75      13.115     3.59061E-02
 STRESS PERIOD TIME 1.13311E+06  18885.      314.75      13.115     3.59061E-02
         TOTAL TIME 2.00473E+06  33412.      556.87      23.203     6.35260E-02
1

 SOLVING FOR HEAD

 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 1
 CELL-BY-CELL FLOW TERM FLAG = 0
 REUSING PREVIOUS VALUES OF IOFLG
1
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  2 IN STRESS PERIOD  4
  -----------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                      IN:
           ---                                      ---
             STORAGE =    16386104.0000               STORAGE =          4.5740
       CONSTANT HEAD =           0.0000         CONSTANT HEAD =          0.0000
               WELLS =           0.0000                 WELLS =          0.0000
       RIVER LEAKAGE =           0.0000         RIVER LEAKAGE =          0.0000
     HEAD DEP BOUNDS =   158912464.0000       HEAD DEP BOUNDS =         41.6316
            RECHARGE =    13626067.0000              RECHARGE =          4.0500

            TOTAL IN =   188924624.0000              TOTAL IN =         50.2556

          OUT:                                     OUT:
          ----                                     ----
             STORAGE =   170418144.0000               STORAGE =         44.8129
       CONSTANT HEAD =           0.0000         CONSTANT HEAD =          0.0000
               WELLS =    16822306.0000                 WELLS =          5.0000
       RIVER LEAKAGE =     1684351.8750         RIVER LEAKAGE =          0.4430
     HEAD DEP BOUNDS =           0.0000       HEAD DEP BOUNDS =          0.0000
            RECHARGE =           0.0000              RECHARGE =          0.0000

           TOTAL OUT =   188924800.0000             TOTAL OUT =         50.2558

            IN - OUT =        -176.0000              IN - OUT =     -2.0981E-04

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =          0.00




          TIME SUMMARY AT END OF TIME STEP  2 IN STRESS PERIOD  4
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 1.35973E+06  22662.      377.70      15.738     4.30873E-02
 STRESS PERIOD TIME 2.49284E+06  41547.      692.46      28.852     7.89934E-02
         TOTAL TIME 3.36446E+06  56074.      934.57      38.941     0.10661
1

 SOLVING FOR HEAD

 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 1
 CELL-BY-CELL FLOW TERM FLAG = 0

 OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:
   HEAD    DRAWDOWN  HEAD  DRAWDOWN
 PRINTOUT  PRINTOUT  SAVE    SAVE
 ----------------------------------
    0         0       0       0
1
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  3 IN STRESS PERIOD  4
  -----------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                      IN:
```

```
           ---                                        ---
             STORAGE =    23453994.0000                 STORAGE =           4.3317
       CONSTANT HEAD =           0.0000           CONSTANT HEAD =           0.0000
               WELLS =           0.0000                   WELLS =           0.0000
       RIVER LEAKAGE =           0.0000           RIVER LEAKAGE =           0.0000
     HEAD DEP BOUNDS =   219173856.0000         HEAD DEP BOUNDS =          36.9322
            RECHARGE =    20234362.0000                RECHARGE =           4.0500

            TOTAL IN =   262862224.0000                TOTAL IN =          45.3138

          OUT:                                     OUT:
          ----                                     ----
             STORAGE =   235403488.0000                 STORAGE =          39.8273
       CONSTANT HEAD =           0.0000           CONSTANT HEAD =           0.0000
               WELLS =    24980696.0000                   WELLS =           5.0000
       RIVER LEAKAGE =     2478269.2500           RIVER LEAKAGE =           0.4866
     HEAD DEP BOUNDS =           0.0000         HEAD DEP BOUNDS =           0.0000
            RECHARGE =           0.0000                RECHARGE =           0.0000

           TOTAL OUT =   262862464.0000               TOTAL OUT =          45.3139

            IN - OUT =        -240.0000                IN - OUT =      -4.5776E-05

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00




          TIME SUMMARY AT END OF TIME STEP  3 IN STRESS PERIOD  4
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 1.63168E+06  27195.      453.24      18.885     5.17048E-02
 STRESS PERIOD TIME 4.12452E+06  68742.      1145.7      47.737     0.13070
         TOTAL TIME 4.99614E+06  83269.      1387.8      57.826     0.15832
1

 SOLVING FOR HEAD

 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 0
 CELL-BY-CELL FLOW TERM FLAG = 0
 REUSING PREVIOUS VALUES OF IOFLG

 SOLVING FOR HEAD

 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 0
 CELL-BY-CELL FLOW TERM FLAG = 0
 REUSING PREVIOUS VALUES OF IOFLG

 SOLVING FOR HEAD

 CELL CONVERSIONS FOR ITER.= 10  LAYER=  1  STEP=  6  PERIOD=  4   (ROW,COL)
    DRY(  9, 10)

 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 0
 CELL-BY-CELL FLOW TERM FLAG = 0

 OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:
   HEAD    DRAWDOWN  HEAD  DRAWDOWN
 PRINTOUT  PRINTOUT  SAVE    SAVE
 ----------------------------------
     0         0       0       0

 SOLVING FOR HEAD

 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 0
 CELL-BY-CELL FLOW TERM FLAG = 0
 REUSING PREVIOUS VALUES OF IOFLG

 SOLVING FOR HEAD

 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 0
 CELL-BY-CELL FLOW TERM FLAG = 0
 REUSING PREVIOUS VALUES OF IOFLG

 SOLVING FOR HEAD

 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 0
 CELL-BY-CELL FLOW TERM FLAG = 0
```

```
 OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:
   HEAD    DRAWDOWN  HEAD  DRAWDOWN
 PRINTOUT  PRINTOUT  SAVE    SAVE
 ----------------------------------
     0         0       0       0
1
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  9 IN STRESS PERIOD  4
  ------------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                      IN:
           ---                                      ---
             STORAGE =     63072188.0000              STORAGE =            1.0275
       CONSTANT HEAD =            0.0000        CONSTANT HEAD =            0.0000
               WELLS =            0.0000                WELLS =            0.0000
       RIVER LEAKAGE =            0.0000        RIVER LEAKAGE =            0.0000
     HEAD DEP BOUNDS =    691365760.0000      HEAD DEP BOUNDS =           19.5218
            RECHARGE =     98751168.0000             RECHARGE =            4.0350

            TOTAL IN =    853189120.0000             TOTAL IN =           24.5843

          OUT:                                     OUT:
          ----                                     ----
             STORAGE =    731379584.0000              STORAGE =           19.8770
       CONSTANT HEAD =            0.0000        CONSTANT HEAD =            0.0000
               WELLS =    107060016.0000                WELLS =            4.0000
       RIVER LEAKAGE =     14750643.0000        RIVER LEAKAGE =            0.7073
     HEAD DEP BOUNDS =            0.0000      HEAD DEP BOUNDS =            0.0000
            RECHARGE =            0.0000             RECHARGE =            0.0000

           TOTAL OUT =    853190272.0000            TOTAL OUT =           24.5843

            IN - OUT =        -1152.0000             IN - OUT =       -1.7166E-05

 PERCENT DISCREPANCY =            0.00    PERCENT DISCREPANCY =            0.00




          TIME SUMMARY AT END OF TIME STEP  9 IN STRESS PERIOD  4
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 4.87217E+06  81203.      1353.4      56.391     0.15439
 STRESS PERIOD TIME 2.35674E+07 3.92791E+05  6546.5      272.77     0.74681
         TOTAL TIME 2.44391E+07 4.07318E+05  6788.6      282.86     0.77443
1

 DATA AT HEAD LOCATIONS

       OBSERVATION      MEAS.       CALC.                                WEIGHTED
  OBS#    NAME          HEAD        HEAD      RESIDUAL  WEIGHT**.5   RESIDUAL

     1 H1_8_8_1         152.270     152.270  -0.458E-04    1.00      -0.458E-04
     2 H1_8_8_2         152.282     152.282   0.427E-03    1.00       0.427E-03
     3 H1_8_8_3         152.216     152.216  -0.183E-03    1.00      -0.183E-03
     4 H1_8_8_4         140.927     140.925   0.163E-02    1.00       0.163E-02
     5 H2_8_8_1         152.266     152.266  -0.916E-04    1.00      -0.916E-04
     6 H2_8_8_2         152.264     152.264  -0.427E-03    1.00      -0.427E-03
     7 H2_8_8_3         152.172     152.172  -0.168E-03    1.00      -0.168E-03
     8 H2_8_8_4         140.111     140.111  -0.397E-03    1.00      -0.397E-03
     9 H3_8_8_1         152.262     152.262  -0.122E-03    1.00      -0.122E-03
    10 H3_8_8_2         152.247     152.247  -0.305E-03    1.00      -0.305E-03
    11 H3_8_8_3         152.128     152.128  -0.305E-04    1.00      -0.305E-04
    12 H3_8_8_4         139.296     139.295   0.133E-02    1.00       0.133E-02
    13 H1_2_2_1         110.016     110.016  -0.328E-03    1.00      -0.328E-03
    14 H1_2_2_2         110.128     110.128  -0.237E-03    1.00      -0.237E-03
    15 H1_2_2_3         110.342     110.342   0.130E-03    1.00       0.130E-03
    16 H1_2_2_4         117.746     117.746  -0.298E-03    1.00      -0.298E-03
    17 H2_2_2_1         110.002     110.002  -0.183E-03    1.00      -0.183E-03
    18 H2_2_2_2         110.075     110.075  -0.336E-03    1.00      -0.336E-03
    19 H2_2_2_3         110.230     110.230   0.763E-04    1.00       0.763E-04
    20 H2_2_2_4         117.178     117.178  -0.145E-03    1.00      -0.145E-03
    21 H3_2_2_1         109.987     109.987   0.145E-03    1.00       0.145E-03
    22 H3_2_2_2         110.021     110.021  -0.275E-03    1.00      -0.275E-03
    23 H3_2_2_3         110.115     110.115  -0.397E-03    1.00      -0.397E-03
    24 H3_2_2_4         116.597     116.597  -0.153E-04    1.00      -0.153E-04
    25 H1_16_16_1       176.152     176.152  -0.443E-03    1.00      -0.443E-03
```

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   26 H1_16_16_2       176.244     176.244   0.610E-04    1.00       0.610E-04
   27 H1_16_16_3       176.720     176.720   0.488E-03    1.00       0.488E-03
   28 H1_16_16_4       240.060     240.060  -0.275E-03    1.00      -0.275E-03
   29 H2_16_16_1       176.140     176.140  -0.244E-03    1.00      -0.244E-03
   30 H2_16_16_2       176.209     176.209   0.427E-03    1.00       0.427E-03
   31 H2_16_16_3       176.673     176.673  -0.122E-03    1.00      -0.122E-03
   32 H2_16_16_4       240.181     240.181   0.397E-03    1.00       0.397E-03
   33 H3_16_16_1       176.129     176.129  -0.458E-04    1.00      -0.458E-04
   34 H3_16_16_2       176.173     176.173  -0.244E-03    1.00      -0.244E-03
   35 H3_16_16_3       176.627     176.627   0.153E-03    1.00       0.153E-03
   36 H3_16_16_4       240.301     240.301  -0.122E-03    1.00      -0.122E-03
   37 H1_16_2_1        110.016     110.016  -0.328E-03    1.00      -0.328E-03
   38 H1_16_2_2        110.128     110.128  -0.237E-03    1.00      -0.237E-03
   39 H1_16_2_3        110.342     110.342   0.130E-03    1.00       0.130E-03
   40 H1_16_2_4        117.742     117.742  -0.443E-03    1.00      -0.443E-03
   41 H2_16_2_1        110.002     110.002  -0.183E-03    1.00      -0.183E-03
   42 H2_16_2_2        110.075     110.075  -0.336E-03    1.00      -0.336E-03
   43 H2_16_2_3        110.230     110.230   0.763E-04    1.00       0.763E-04
   44 H2_16_2_4        117.174     117.174  -0.496E-03    1.00      -0.496E-03
   45 H3_16_2_1        109.987     109.987   0.145E-03    1.00       0.145E-03
   46 H3_16_2_2        110.021     110.021  -0.275E-03    1.00      -0.275E-03
   47 H3_16_2_3        110.115     110.115  -0.397E-03    1.00      -0.397E-03
   48 H3_16_2_4        116.594     116.594   0.404E-03    1.00       0.404E-03

STATISTICS FOR HEAD RESIDUALS :
MAXIMUM WEIGHTED RESIDUAL  : 0.163E-02 OBS#      4
MINIMUM WEIGHTED RESIDUAL  :-0.496E-03 OBS#     44
AVERAGE WEIGHTED RESIDUAL  :-0.448E-04
# RESIDUALS >= 0. :     15
# RESIDUALS < 0.  :     33
NUMBER OF RUNS  :   28  IN   48 OBSERVATIONS

SUM OF SQUARED WEIGHTED RESIDUALS (HEADS ONLY)  0.80469E-05

DATA FOR FLOWS REPRESENTED USING THE GENERAL-HEAD BOUNDARY PACKAGE

      OBSERVATION      MEAS.      CALC.                          WEIGHTED
 OBS#    NAME          FLOW       FLOW     RESIDUAL  WEIGHT**.5  RESIDUAL

   49 GHB1            30.6       30.6      0.379E-01  0.654      0.248E-01
   50 GHB2            29.2       29.2      0.299E-01  0.685      0.205E-01
   51 GHB3            26.9       26.9     -0.125E-01  0.743     -0.932E-02
   52 GHB4            9.62       9.62      0.127E-02   2.08      0.265E-02

STATISTICS FOR GENERAL-HEAD BOUNDARY FLOW RESIDUALS :
MAXIMUM WEIGHTED RESIDUAL  : 0.248E-01 OBS#     49
MINIMUM WEIGHTED RESIDUAL  :-0.932E-02 OBS#     51
AVERAGE WEIGHTED RESIDUAL  : 0.965E-02
# RESIDUALS >= 0. :      3
# RESIDUALS < 0.  :      1
NUMBER OF RUNS  :    3  IN    4 OBSERVATIONS

SUM OF SQUARED WEIGHTED RESIDUALS
  (GENERAL-HEAD BOUNDARY FLOWS ONLY)  0.11273E-02

SUM OF SQUARED WEIGHTED RESIDUALS (ALL DEPENDENT VARIABLES)  0.11353E-02

STATISTICS FOR ALL RESIDUALS :
AVERAGE WEIGHTED RESIDUAL  : 0.701E-03
# RESIDUALS >= 0. :     18
# RESIDUALS < 0.  :     34
NUMBER OF RUNS  :   30  IN   52 OBSERVATIONS


THE NUMBER OF RUNS EQUALS THE EXPECTED NUMBER OF RUNS
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Test Case 2 Variant 4 Sample Files

Input File

```
# HUF file for Test Case 2 Variant 4
#
  0  -999.  5  12   00       Item 1:  IHUFCB HDRY NHUF NPHUF IOHUF
  0    0    0                Item 2:  LTHUF
  0    0    0                Item 3:  LAYWT
HGU1                                              Item 6:  HGUNAM
 INTERNAL       1.0 (9f10.2)                20    Item 7:  TOP
      0.00    466.66    970.89    979.17    979.48    980.07   1025.00   1123.69   1184.28
   1185.76   1186.51   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
      0.00    460.53    968.83    979.02    979.21    979.77   1015.11   1103.04   1170.61
   1186.49   1187.26   1188.65   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
      0.00    432.95    961.24    973.60    978.55    957.74    987.47   1088.84   1179.69
   1186.78   1187.39   1190.05   1191.79   9999.00   9999.00   9999.00   9999.00   9999.00
      0.00    291.69    752.49    967.22    971.47    964.35    990.43   1082.56   1176.54
   1177.24   1159.66   1192.36   1193.54   1194.92   9999.00   9999.00   9999.00   9999.00
      0.00    220.86    552.04    799.15    897.53    929.42    956.07    983.73   1077.55
   1147.71   1154.33   1194.15   1195.09   1196.29   1197.29   9999.00   9999.00   9999.00
      0.00    188.80    463.00    692.59    852.09    892.57    932.76    906.94   1007.63
   1147.73   1201.15   1195.77   1196.37   1197.88   1198.28   1198.34   9999.00   9999.00
     27.65    189.71    420.51    653.17    857.06    922.11   1014.73    951.16   1023.76
   1183.96   1259.68   1242.39   1215.40   1200.60   1200.03   1198.83   1197.33   9999.00
     50.33    209.99    431.34    642.47    850.77    944.38   1014.46    953.31   1036.80
   1233.05   1337.05   1346.38   1256.78   1205.05   1203.72   1200.92   1197.30   1100.00
     67.18    233.93    444.97    634.74    835.28    925.80    971.05    931.50   1049.61
   1275.58   1407.16   1449.87   1356.59   1209.95   1209.11   1204.70   1176.94   1100.00
     77.44    262.59    462.38    635.42    812.44    951.31    990.28    999.73   1107.81
   1286.30   1395.35   1453.25   1424.78   1276.80   1214.27   1202.18   1159.09   1100.00
    207.65    336.39    484.48    640.95    809.63    926.59    996.19   1045.80   1129.56
   1312.27   1441.08   1456.96   1447.99   1315.52   1217.30   1204.81   1157.15   1100.00
   9999.00   9999.00   9999.00   9999.00    871.62    949.88   1018.16   1062.88   1036.73
   1312.10   1459.70   1459.79   1479.20   1375.99   1284.80   1218.50   1164.71   1100.00
   9999.00   9999.00   9999.00   9999.00   9999.00   1000.38   1063.05   1123.83   1184.97
   1336.58   1482.97   1513.53   1515.39   1419.18   1314.91   1228.81   1181.96   1153.66
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   1117.51   1183.17   1225.02
   1283.48   1375.39   1404.99   1388.08   1333.35   1276.05   1215.86   1193.01   1177.67
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   1239.21   1241.07
   1242.52   1282.86   1303.60   1286.91   1219.00   1240.73   1206.68   1193.28   1188.76
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   1241.55
   1242.06   1255.55   1262.52   1249.10   1206.20   1216.15   1197.47   1193.35   1192.28
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   1242.22   1246.68   1247.25   1238.52   1221.48   1209.43   1195.85   1194.18   1193.66
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00   1244.51   1242.16   1234.80   1222.75   1208.12   1195.45   1194.60   1194.10
 CONSTANT   300.0                                 Item 8:  THCK
HGU2                                              Item 6:  HGUNAM
 INTERNAL       1.0 (9f10.2)                20    Item 7:  TOP
   -300.00    166.66    670.89    679.17    679.48    680.07    725.00    823.69    884.28
    885.76    886.51      0.00      0.00      0.00      0.00      0.00      0.00      0.00
   -300.00    160.53    668.83    679.02    679.21    679.77    715.11    803.04    870.61
    886.49    887.26    888.65      0.00      0.00      0.00      0.00      0.00      0.00
   -300.00    132.95    661.24    673.60    678.55    657.74    687.47    788.84    879.69
    886.78    887.39    890.05    891.79      0.00      0.00      0.00      0.00      0.00
   -300.00     -8.31    452.49    667.22    671.47    664.35    690.43    782.56    876.54
    877.24    859.66    892.36    893.54    894.92      0.00      0.00      0.00      0.00
   -300.00    -79.14    252.04    499.15    597.53    629.42    656.07    683.73    777.55
    847.71    854.33    894.15    895.09    896.29    897.29      0.00      0.00      0.00
   -300.00   -111.20    163.00    392.59    552.09    592.57    632.76    606.94    707.63
    847.73    901.15    895.77    896.37    897.88    898.28    898.34      0.00      0.00
   -272.35   -110.29    120.51    353.17    557.06    622.11    714.73    651.16    723.76
    883.96    959.68    942.39    915.40    900.60    900.03    898.83    897.33      0.00
   -249.67    -90.01    131.34    342.47    550.77    644.38    714.46    653.31    736.80
    933.05   1037.05   1046.38    956.78    905.05    903.72    900.92    897.30    800.00
   -232.82    -66.07    144.97    334.74    535.28    625.80    671.05    631.50    749.61
    975.58   1107.16   1149.87   1056.59    909.95    909.11    904.70    876.94    800.00
   -222.56    -37.41    162.38    335.42    512.44    651.31    690.28    699.73    807.81
    986.30   1095.35   1153.25   1124.78    976.80    914.27    902.18    859.09    800.00
    -92.35     36.39    184.48    340.95    509.63    626.59    696.19    745.80    829.56
   1012.27   1141.08   1156.96   1147.99   1015.52    917.30    904.81    857.15    800.00
      0.00      0.00      0.00      0.00    571.62    649.88    718.16    762.88    736.73
   1012.10   1159.70   1159.79   1179.20   1075.99    984.80    918.50    864.71    800.00
      0.00      0.00      0.00      0.00      0.00    700.38    763.05    823.83    884.97
   1036.58   1182.97   1213.53   1215.39   1119.18   1014.91    928.81    881.96    853.66
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      0.00      0.00      0.00      0.00      0.00      0.00    817.51    883.17    925.02
    983.48   1075.39   1104.99   1088.08   1033.35    976.05    915.86    893.01    877.67
      0.00      0.00      0.00      0.00      0.00      0.00      0.00    939.21    941.07
    942.52    982.86   1003.60    986.91    919.00    940.73    906.68    893.28    888.76
      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00    941.55
    942.06    955.55    962.52    949.10    906.20    916.15    897.47    893.35    892.28
      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
    942.22    946.68    947.25    938.52    921.48    909.43    895.85    894.18    893.66
      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
      0.00    944.51    942.16    934.80    922.75    908.12    895.45    894.60    894.10
 CONSTANT  200.0                                  Item 8:  THCK
HGU3                                              Item 6:  HGUNAM
 INTERNAL       1.0 (9f10.2)                20    Item 7:  TOP
   -500.00    -33.34    470.89    479.17    479.48    480.07    525.00    623.69    684.28
    685.76    686.51   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   -500.00    -39.47    468.83    479.02    479.21    479.77    515.11    603.04    670.61
    686.49    687.26    688.65   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   -500.00    -67.05    461.24    473.60    478.55    457.74    487.47    588.84    679.69
    686.78    687.39    690.05    691.79   9999.00   9999.00   9999.00   9999.00   9999.00
   -500.00   -208.31    252.49    467.22    471.47    464.35    490.43    582.56    676.54
    677.24    659.66    692.36    693.54    694.92   9999.00   9999.00   9999.00   9999.00
   -500.00   -279.14     52.04    299.15    397.53    429.42    456.07    483.73    577.55
    647.71    654.33    694.15    695.09    696.29    697.29   9999.00   9999.00   9999.00
   -500.00   -311.20    -37.00    192.59    352.09    392.57    432.76    406.94    507.63
    647.73    701.15    695.77    696.37    697.88    698.28    698.34   9999.00   9999.00
   -472.35   -310.29    -79.49    153.17    357.06    422.11    514.73    451.16    523.76
    683.96    759.68    742.39    715.40    700.60    700.03    698.83    697.33   9999.00
   -449.67   -290.01    -68.66    142.47    350.77    444.38    514.46    453.31    536.80
    733.05    837.05    846.38    756.78    705.05    703.72    700.92    697.30    600.00
   -432.82   -266.07    -55.03    134.74    335.28    425.80    471.05    431.50    549.61
    775.58    907.16    949.87    856.59    709.95    709.11    704.70    676.94    600.00
   -422.56   -237.41    -37.62    135.42    312.44    451.31    490.28    499.73    607.81
    786.30    895.35    953.25    924.78    776.80    714.27    702.18    659.09    600.00
   -292.35   -163.61    -15.52    140.95    309.63    426.59    496.19    545.80    629.56
    812.27    941.08    956.96    947.99    815.52    717.30    704.81    657.15    600.00
   9999.00   9999.00   9999.00   9999.00    371.62    449.88    518.16    562.88    536.73
    812.10    959.70    959.79    979.20    875.99    784.80    718.50    664.71    600.00
   9999.00   9999.00   9999.00   9999.00   9999.00    500.38    563.05    623.83    684.97
    836.58    982.97   1013.53   1015.39    919.18    814.91    728.81    681.96    653.66
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00    617.51    683.17    725.02
    783.48    875.39    904.99    888.08    833.35    776.05    715.86    693.01    677.67
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00    739.21    741.07
    742.52    782.86    803.60    786.91    719.00    740.73    706.68    693.28    688.76
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00    741.55
    742.06    755.55    762.52    749.10    706.20    716.15    697.47    693.35    692.28
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
    742.22    746.68    747.25    738.52    721.48    709.43    695.85    694.18    693.66
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00    744.51    742.16    734.80    722.75    708.12    695.45    694.60    694.10
 CONSTANT  550.0                                  Item 8:  THCK
HGU4                                              Item 6:  HGUNAM
 INTERNAL       1.0 (9f10.2)                20    Item 7:  TOP
  -1050.00   -583.34    -79.11    -70.83    -70.52    -69.93    -25.00     73.69    134.28
    135.76    136.51      0.00      0.00      0.00      0.00      0.00      0.00      0.00
  -1050.00   -589.47    -81.17    -70.98    -70.79    -70.23    -34.89     53.04    120.61
    136.49    137.26    138.65      0.00      0.00      0.00      0.00      0.00      0.00
  -1050.00   -617.05    -88.76    -76.40    -71.45    -92.26    -62.53     38.84    129.69
    136.78    137.39    140.05    141.79      0.00      0.00      0.00      0.00      0.00
  -1050.00   -758.31   -297.51    -82.78    -78.53    -85.65    -59.57     32.56    126.54
    127.24    109.66    142.36    143.54    144.92      0.00      0.00      0.00      0.00
  -1050.00   -829.14   -497.96   -250.85   -152.47   -120.58    -93.93    -66.27     27.55
     97.71    104.33    144.15    145.09    146.29    147.29      0.00      0.00      0.00
  -1050.00   -861.20   -587.00   -357.41   -197.91   -157.43   -117.24   -143.06    -42.37
     97.73    151.15    145.77    146.37    147.88    148.28    148.34      0.00      0.00
  -1022.35   -860.29   -629.49   -396.83   -192.94   -127.89    -35.27    -98.84    -26.24
    133.96    209.68    192.39    165.40    150.60    150.03    148.83    147.33      0.00
   -999.67   -840.01   -618.66   -407.53   -199.23   -105.62    -35.54    -96.69    -13.20
    183.05    287.05    296.38    206.78    155.05    153.72    150.92    147.30     50.00
   -982.82   -816.07   -605.03   -415.26   -214.72   -124.20    -78.95   -118.50     -0.39
    225.58    357.16    399.87    306.59    159.95    159.11    154.70    126.94     50.00
   -972.56   -787.41   -587.62   -414.58   -237.56    -98.69    -59.72    -50.27     57.81
    236.30    345.35    403.25    374.78    226.80    164.27    152.18    109.09     50.00
   -842.35   -713.61   -565.52   -409.05   -240.37   -123.41    -53.81     -4.20     79.56
    262.27    391.08    406.96    397.99    265.52    167.30    154.81    107.15     50.00
      0.00      0.00      0.00      0.00   -178.38   -100.12    -31.84     12.88    -13.27
    262.10    409.70    409.79    429.20    325.99    234.80    168.50    114.71     50.00
      0.00      0.00      0.00      0.00      0.00    -49.62     13.05     73.83    134.97
    286.58    432.97    463.53    465.39    369.18    264.91    178.81    131.96    103.66
      0.00      0.00      0.00      0.00      0.00      0.00     67.51    133.17    175.02
    233.48    325.39    354.99    338.08    283.35    226.05    165.86    143.01    127.67
      0.00      0.00      0.00      0.00      0.00      0.00      0.00    189.21    191.07
```

```
    192.52    232.86    253.60    236.91    169.00    190.73    156.68    143.28    138.76
      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00    191.55
    192.06    205.55    212.52    199.10    156.20    166.15    147.47    143.35    142.28
      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
    192.22    196.68    197.25    188.52    171.48    159.43    145.85    144.18    143.66
      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
      0.00    194.51    192.16    184.80    172.75    158.12    145.45    144.60    144.10
 CONSTANT  200.0
HGU5                                              Item 7:  HGUNAM
 INTERNAL       1.0 (9f10.2)                20    Item 8:  TOP
  -1250.00   -783.34   -279.11   -270.83   -270.52   -269.93   -225.00   -126.31    -65.72
    -64.24    -63.49   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
  -1250.00   -789.47   -281.17   -270.98   -270.79   -270.23   -234.89   -146.96    -79.39
    -63.51    -62.74    -61.35   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
  -1250.00   -817.05   -288.76   -276.40   -271.45   -292.26   -262.53   -161.16    -70.31
    -63.22    -62.61    -59.95    -58.21   9999.00   9999.00   9999.00   9999.00   9999.00
  -1250.00   -958.31   -497.51   -282.78   -278.53   -285.65   -259.57   -167.44    -73.46
    -72.76    -90.34    -57.64    -56.46    -55.08   9999.00   9999.00   9999.00   9999.00
  -1250.00  -1029.14   -697.96   -450.85   -352.47   -320.58   -293.93   -266.27   -172.45
   -102.29    -95.67    -55.85    -54.91    -53.71    -52.71   9999.00   9999.00   9999.00
  -1250.00  -1061.20   -787.00   -557.41   -397.91   -357.43   -317.24   -343.06   -242.37
   -102.27    -48.85    -54.23    -53.63    -52.12    -51.72    -51.66   9999.00   9999.00
  -1222.35  -1060.29   -829.49   -596.83   -392.94   -327.89   -235.27   -298.84   -226.24
    -66.04      9.68     -7.61    -34.60    -49.40    -49.97    -51.17    -52.67   9999.00
  -1199.67  -1040.01   -818.66   -607.53   -399.23   -305.62   -235.54   -296.69   -213.20
    -16.95     87.05     96.38      6.78    -44.95    -46.28    -49.08    -52.70   -150.00
  -1182.82  -1016.07   -805.03   -615.26   -414.72   -324.20   -278.95   -318.50   -200.39
     25.58    157.16    199.87    106.59    -40.05    -40.89    -45.30    -73.06   -150.00
  -1172.56   -987.41   -787.62   -614.58   -437.56   -298.69   -259.72   -250.27   -142.19
     36.30    145.35    203.25    174.78     26.80    -35.73    -47.82    -90.91   -150.00
  -1042.35   -913.61   -765.52   -609.05   -440.37   -323.41   -253.81   -204.20   -120.44
     62.27    191.08    206.96    197.99     65.52    -32.70    -45.19    -92.85   -150.00
   9999.00   9999.00   9999.00   9999.00   -378.38   -300.12   -231.84   -187.12   -213.27
     62.10    209.70    209.79    229.20    125.99     34.80    -31.50    -85.29   -150.00
   9999.00   9999.00   9999.00   9999.00   9999.00   -249.62   -186.95   -126.17    -65.03
     86.58    232.97    263.53    265.39    169.18     64.91    -21.19    -68.04    -96.34
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   -132.49    -66.83    -24.98
     33.48    125.39    154.99    138.08     83.35     26.05    -34.14    -56.99    -72.33
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00    -10.79     -8.93
     -7.48     32.86     53.60     36.91    -31.00     -9.27    -43.32    -56.72    -61.24
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00     -8.45
     -7.94      5.55     12.52     -0.90    -43.80    -33.85    -52.53    -56.65    -57.72
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
     -7.78     -3.32     -2.75    -11.48    -28.52    -40.57    -54.15    -55.82    -56.34
   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00   9999.00
   9999.00     -5.49     -7.84    -15.20    -27.25    -41.88    -54.55    -55.40    -55.90
 CONSTANT  1500.0                                 Item 8:  THCK
ALL  1.0    0                                     Item 9:  HGUNAM   HGUHANI   HGUVANI
HK1        HK      1.0   5    Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU1    NONE   ZLAY1  1       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU2    NONE   ZLAY1  1       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU3    NONE   ZLAY2  1       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU4    NONE   ZLAY2  1       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU5    NONE   ZLAY3  1       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HK2        HK   1.0E-2   5    Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU1    NONE   ZLAY1  2       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU2    NONE   ZLAY1  2       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU3    NONE   ZLAY2  2       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU4    NONE   ZLAY2  2       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU5    NONE   ZLAY3  2       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HK3        HK   1.0E-4   5    Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU1    NONE   ZLAY1  3       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU2    NONE   ZLAY1  3       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU3    NONE   ZLAY2  3       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU4    NONE   ZLAY2  3       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU5    NONE   ZLAY3  3       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HK4        HK   1.0E-6   5    Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU1    NONE   ZLAY1  4       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU2    NONE   ZLAY1  4       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU3    NONE   ZLAY2  4       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU4    NONE   ZLAY2  4       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU5    NONE   ZLAY3  4       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
VKA12_1    VK   0.25     4    Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU1    NONE   ZLAY1  1       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU2    NONE   ZLAY1  1       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU3    NONE   ZLAY2  1       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU4    NONE   ZLAY2  1       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
VKA12_2    VK   2.5E-3   4    Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU1    NONE   ZLAY1  2       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU2    NONE   ZLAY1  2       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU3    NONE   ZLAY2  2       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
```

```
HGU4    NONE   ZLAY2  2       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
VKA12_3    VK   2.5E-5   4    Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU1    NONE   ZLAY1  3       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU2    NONE   ZLAY1  3       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU3    NONE   ZLAY2  3       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU4    NONE   ZLAY2  3       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
VKA12_4    VK   2.5E-7   4    Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU1    NONE   ZLAY1  4       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU2    NONE   ZLAY1  4       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU3    NONE   ZLAY2  4       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
HGU4    NONE   ZLAY2  4       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
VKA3_1     VK   1.0      1    Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU5    NONE   ZLAY3  1       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
VKA3_2     VK   1.0E-2   1    Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU5    NONE   ZLAY3  2       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
VKA3_3     VK   1.0E-4   1    Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU5    NONE   ZLAY3  3       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
VKA3_4     VK   1.0E-6   1    Item 10:  PARNAM   PARTYP   Parval   NCLU
HGU5    NONE   ZLAY3  4       Item 11:  HGUNAM   Mltarr   Zonarr   IZ
PRINT  HGU2  2  ALL           Item 12:  HGUNAM   PRINTCODE   PRINTFLAGS
```

GLOBAL Output File

An example of the excerpted GLOBAL output file for Test Case 2, Variant 4 is shown below. The HUF Package output appears in bold, and three dots (…) indicates omitted output.

```
                                    MODFLOW-2000
        U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
                              VERSION 1.0.2 08/21/2000


   This model run produced both GLOBAL and LIST files.  This is the GLOBAL file.

   GLOBAL LISTING FILE: tc2var4.glo
                           UNIT   1

   OPENING tc2var4.lst
   FILE TYPE:LIST   UNIT   2

   OPENING tc2var4.huf
   FILE TYPE:HUF   UNIT  11

   OPENING tc2var4.sen
   FILE TYPE:SEN   UNIT  38
  #Common files

   OPENING ..\common\tc2.bas
   FILE TYPE:BAS6   UNIT   8

   OPENING ..\common\tc2.dis
   FILE TYPE:DIS   UNIT   9

   OPENING ..\common\tc2.wel
   FILE TYPE:WEL   UNIT  12

   OPENING ..\common\tc2.drn
   FILE TYPE:DRN   UNIT  13

   OPENING ..\common\tc2.evt
   FILE TYPE:EVT   UNIT  15

   OPENING ..\common\tc2.ghb
   FILE TYPE:GHB   UNIT  17

   OPENING ..\common\tc2.rch
   FILE TYPE:RCH   UNIT  18

   OPENING ..\common\tc2.oc
   FILE TYPE:OC   UNIT  22

   OPENING ..\common\tc2.pcg
   FILE TYPE:PCG   UNIT  23

   OPENING ..\common\tc2.obs
   FILE TYPE:OBS   UNIT  37

   OPENING ..\common\tc2.zon
   FILE TYPE:ZONE   UNIT  39
```

```
OPENING ..\common\tc2.hob
FILE TYPE:HOB   UNIT  40

OPENING ..\common\tc2.odr
FILE TYPE:DROB   UNIT  41

OPENING ..\common\tc2.ogb
FILE TYPE:GBOB   UNIT  42

OPENING ..\common\tc2.pes
FILE TYPE:PES   UNIT  44

OPENING ..\common\tc2.b
FILE TYPE:DATA   UNIT  48

OPENING ..\common\tc2.bin
FILE TYPE:DATA(BINARY)   UNIT  49

DISCRETIZATION INPUT DATA READ FROM UNIT  9
# DIS file for test case ymptc
#
   3 LAYERS        18 ROWS        18 COLUMNS
  1 STRESS PERIOD(S) IN SIMULATION
MODEL TIME UNIT IS DAYS
MODEL LENGTH UNIT IS METERS

THE OBSERVATION PROCESS IS ACTIVE
THE SENSITIVITY PROCESS IS ACTIVE
THE PARAMETER-ESTIMATION PROCESS IS ACTIVE

MODE: PARAMETER ESTIMATION


ZONE OPTION, INPUT READ FROM UNIT 39
    4 ZONE ARRAYS
 Confining bed flag for each layer:
  0   0   0

      8784  ELEMENTS OF GX ARRAY USED OUT OF       8784
       972  ELEMENTS OF GZ ARRAY USED OUT OF        972
      2268  ELEMENTS OF IG ARRAY USED OUT OF       2268

                    DELR =   1500.00

                    DELC =   1500.00



          TOP ELEVATION OF LAYER 1
READING ON UNIT   9 WITH FORMAT: (18F10.2)



            MODEL LAYER BOTTOM EL. FOR LAYER   1
READING ON UNIT   9 WITH FORMAT: (18F10.2)



            MODEL LAYER BOTTOM EL. FOR LAYER   2
READING ON UNIT   9 WITH FORMAT: (18F10.2)



            MODEL LAYER BOTTOM EL. FOR LAYER   3
READING ON UNIT   9 WITH FORMAT: (18F10.2)

STRESS PERIOD     LENGTH       TIME STEPS     MULTIPLIER FOR DELT    SS FLAG
----------------------------------------------------------------------------
       1        86400.00          1                  1.000         SS

STEADY-STATE SIMULATION




            ZONE ARRAY: ZLAY1
READING ON UNIT  39 WITH FORMAT: (I1,17I2)
```

```
            ZONE ARRAY: ZLAY2
READING ON UNIT  39 WITH FORMAT: (I1,17I2)



            ZONE ARRAY: ZLAY3
READING ON UNIT  39 WITH FORMAT: (I1,17I2)



            ZONE ARRAY: RCHETM
READING ON UNIT  39 WITH FORMAT: (I1,17I2)

HUF1 -- HYDROGEOLOGIC UNIT FLOW PACKAGE, ’ VERSION 0.13-ERA, 9/26/00
INPUT READ FROM UNIT 11

# HUF file for Test Case 2 Variant 4
#
HEAD AT CELLS THAT CONVERT TO DRY=  -999.00
Hydrogeologic Unit Package Active with  12 parameters
   12 Named Parameters
STEADY-STATE SIMULATION

  INTERPRETATION OF LAYER FLAGS:
LAYER    LTHUF     LAYER TYPE     LAYWT WETTABILITY
---------------------------------------------------------------------------
   1         0      CONFINED         0  NON-WETTABLE
   2         0      CONFINED         0  NON-WETTABLE
   3         0      CONFINED         0  NON-WETTABLE

      7776 ELEMENTS IN X ARRAY ARE USED BY HUF
        25 ELEMENTS IN IX ARRAY ARE USED BY HUF

PCG2 -- CONJUGATE GRADIENT SOLUTION PACKAGE, VERSION 2.4, 12/29/98
MAXIMUM OF    250 CALLS OF SOLUTION ROUTINE
MAXIMUM OF      8 INTERNAL ITERATIONS PER CALL TO SOLUTION ROUTINE
MATRIX PRECONDITIONING TYPE :    1
      6916 ELEMENTS IN X ARRAY ARE USED BY PCG
     14000 ELEMENTS IN IX ARRAY ARE USED BY PCG
      1944 ELEMENTS IN Z ARRAY ARE USED BY PCG

SEN1BAS6 -- SENSITIVITY PROCESS, VERSION 1.0, 10/15/98
INPUT READ FROM UNIT  38

NUMBER OF PARAMETER VALUES TO BE READ FROM SEN FILE:   15
ISENALL............................................:    0
SENSITIVITIES WILL BE STORED IN MEMORY
FOR UP TO  15 PARAMETERS

      1725 ELEMENTS IN X ARRAY ARE USED FOR SENSITIVITIES
       972 ELEMENTS IN Z ARRAY ARE USED FOR SENSITIVITIES
        30 ELEMENTS IN IX ARRAY ARE USED FOR SENSITIVITIES

PES1BAS6 -- PARAMETER-ESTIMATION PROCESS, VERSION 1.0, 07/22/99
INPUT READ FROM UNIT  44
# PES file for test case tc2
#

MAXIMUM NUMBER OF PARAMETER-ESTIMATION ITERATIONS (MAX-ITER)  =    30
MAXIMUM PARAMETER CORRECTION (MAX-CHANGE) ------------------- =  2.0000
CLOSURE CRITERION (TOL) ------------------------------------- = 0.10000E-01
SUM OF SQUARES CLOSURE CRITERION (SOSC) --------------------- =  0.0000

FLAG TO GENERATE INPUT NEEDED BY BEALE-2000 (IBEFLG) -------- =     0
FLAG TO GENERATE INPUT NEEDED BY YCINT-2000 (IYCFLG) -------- =     0
OMIT PRINTING TO SCREEN (IF = 1) (IOSTAR) ------------------- =     0
ADJUST GAUSS-NEWTON MATRIX WITH NEWTON UPDATES (IF = 1)(NOPT) =     0
NUMBER OF FLETCHER-REEVES ITERATIONS (NFIT) ----------------- =     0
CRITERION FOR ADDING MATRIX R (SOSR) ------------------------ =  0.0000
INITIAL VALUE OF MARQUARDT PARAMETER (RMAR) ----------------- = 0.10000E-02
MARQUARDT PARAMETER MULTIPLIER (RMARM) ---------------------- =  1.5000
APPLY MAX-CHANGE IN REGRESSION SPACE (IF = 1) (IAP) --------- =     0

FORMAT CODE FOR COVARIANCE AND CORRELATION MATRICES (IPRCOV)  =     8
PRINT PARAMETER-ESTIMATION STATISTICS
    EACH ITERATION (IF > 0)  (IPRINT) ----------------------- =     0
PRINT EIGENVALUES AND EIGENVECTORS OF
    COVARIANCE MATRIX (IF > 0)  (LPRINT) -------------------- =     0
```

```
SEARCH DIRECTION ADJUSTMENT PARAMETER (CSA) ----------------- = 0.80000E-01
MODIFY CONVERGENCE CRITERIA (IF > 0) (FCONV) ---------------- =  0.0000
CALCULATE SENSITIVITIES USING FINAL
    PARAMETER ESTIMATES (IF > 0) (LASTX) -------------------- =     0

NUMBER OF USUALLY POS. PARAMETERS THAT MAY BE NEGATIVE (NPNG) =     0
NUMBER OF PARAMETERS WITH CORRELATED PRIOR INFORMATION (IFPR) =     0
NUMBER OF PRIOR-INFORMATION EQUATIONS (MPR) ----------------- =     0

   832 ELEMENTS IN X ARRAY ARE USED FOR PARAMETER ESTIMATION
   730 ELEMENTS IN Z ARRAY ARE USED FOR PARAMETER ESTIMATION
    32 ELEMENTS IN IX ARRAY ARE USED FOR PARAMETER ESTIMATION

OBS1BAS6 -- OBSERVATION PROCESS, VERSION 1.0, 4/27/99
INPUT READ FROM UNIT  37
OBSERVATION GRAPH-DATA OUTPUT FILES WILL NOT BE PRINTED
DIMENSIONLESS SCALED OBSERVATION SENSITIVITIES WILL BE PRINTED

HEAD OBSERVATIONS -- INPUT READ FROM UNIT  40

NUMBER OF HEADS....................................:   42
  NUMBER OF MULTILAYER HEADS.......................:    2
  MAXIMUM NUMBER OF LAYERS FOR MULTILAYER HEADS....:    3

OBS1DRN6 -- OBSERVATION PROCESS (DRAIN FLOW OBSERVATIONS)
VERSION 1.0, 10/15/98
INPUT READ FROM UNIT  41

NUMBER OF FLOW-OBSERVATION DRAIN-CELL GROUPS.......:    5
  NUMBER OF CELLS IN DRAIN-CELL GROUPS.............:    5
  NUMBER OF DRAIN-CELL FLOWS.......................:    5

OBS1GHB6 -- OBSERVATION PROCESS (GENERAL HEAD BOUNDARY FLOW OBSERVATIONS)
VERSION 1.0, 10/15/98
INPUT READ FROM UNIT  42

NUMBER OF FLOW-OBSERVATION GENERAL-HEAD-CELL GROUPS:    5
  NUMBER OF CELLS IN GENERAL-HEAD-CELL GROUPS......:    5
  NUMBER OF GENERAL-HEAD-CELL FLOWS................:    5

   3377 ELEMENTS IN X ARRAY ARE USED FOR OBSERVATIONS
    132 ELEMENTS IN Z ARRAY ARE USED FOR OBSERVATIONS
    509 ELEMENTS IN IX ARRAY ARE USED FOR OBSERVATIONS

COMMON ERROR VARIANCE FOR ALL OBSERVATIONS SET TO:       1.000

     20626  ELEMENTS OF X ARRAY USED OUT OF      20626
      3778  ELEMENTS OF Z ARRAY USED OUT OF       3778
     14596  ELEMENTS OF IX ARRAY USED OUT OF      14596
     14580  ELEMENTS OF XHS ARRAY USED OUT OF      14580

INFORMATION ON PARAMETERS LISTED IN SEN FILE
                                            LOWER         UPPER       ALTERNATE
                       VALUE IN SEN   REASONABLE    REASONABLE     SCALING
   NAME     ISENS  LN   INPUT FILE      LIMIT         LIMIT        FACTOR
----------  -----  --  ------------  ------------  ------------  ------------
HK1           1     0    1.5000       -1.4000      -0.80000       0.10000E-02
HK2           1     0   0.15000E-01   0.20000E-08   0.20000E-06   0.10000E-04
HK3           1     0   0.15000E-03   0.10000E-08   0.10000E-06   0.10000E-06
HK4           1     0   0.12000E-05   0.12000E-03   0.12000E-01   0.10000E-08
VKA12_1       1     0   0.33300       0.13000E-03   0.13000E-01   0.13000E-01
VKA12_2       1     0   0.38500E-02   0.13000E-03   0.13000E-01   0.13000E-01
VKA12_3       1     0   0.42900E-04   0.13000E-03   0.13000E-01   0.13000E-01
VKA12_4       1     0   0.28600E-06   0.13000E-03   0.13000E-01   0.13000E-01
VKA3_1        1     0    1.6700       0.30000E-04   0.30000E-02   0.30000E-02
VKA3_3        1     0   0.12500E-03   0.30000E-04   0.30000E-02   0.30000E-02
VKA3_4        1     0   0.16000E-05   0.30000E-04   0.30000E-02   0.30000E-02
DRAIN         1     0    1.5000       0.10000E-07   0.10000E-05   0.10000E-05
GHB           1     0    1.5000       0.20000E-04   0.20000E-02   0.20000E-02
RCH           1     0   0.35000E-03   0.40000E-05   0.40000E-03   0.40000E-03
ETM           1     0   0.45000E-03   0.40000E-05   0.40000E-03   0.40000E-03
-----------------------------------------------------------------------------
FOR THE PARAMETERS LISTED IN THE TABLE ABOVE, PARAMETER VALUES IN INDIVIDUAL
PACKAGE INPUT FILES ARE REPLACED BY THE VALUES FROM THE SEN INPUT FILE.  THE
ALTERNATE SCALING FACTOR IS USED TO SCALE SENSITIVITIES IF IT IS LARGER THAN
THE PARAMETER VALUE IN ABSOLUTE VALUE AND THE PARAMETER IS NOT LOG-TRANSFORMED.

HEAD OBSERVATION VARIANCES ARE MULTIPLIED BY:       1.000

OBSERVED HEAD DATA -- TIME OFFSETS ARE MULTIPLIED BY:   1.0000
```

```
...


                                    SOLUTION BY THE CONJUGATE-GRADIENT METHOD
                                   -------------------------------------------
                    MAXIMUM NUMBER OF CALLS TO PCG ROUTINE =      250
                        MAXIMUM ITERATIONS PER CALL TO PCG =        8
                               MATRIX PRECONDITIONING TYPE =        1
        RELAXATION FACTOR (ONLY USED WITH PRECOND. TYPE 1) =    0.10000E+01
 PARAMETER OF POLYMOMIAL PRECOND. = 2 (2) OR IS CALCULATED :        2
                         HEAD CHANGE CRITERION FOR CLOSURE =    0.10000E-03
                     RESIDUAL CHANGE CRITERION FOR CLOSURE =    0.80000E+02
            PCG HEAD AND RESIDUAL CHANGE PRINTOUT INTERVAL =      999
     PRINTING FROM SOLVER IS LIMITED(1) OR SUPPRESSED (>1) =        1
                                         DAMPING PARAMETER =    0.10000E+01

 CONVERGENCE CRITERIA FOR SENSITIVITIES
 PARAMETER      HCLOSE        RCLOSE
 ----------  ------------  ------------
 HK1          0.66667E-06   0.53333
 HK2          0.66667E-04    53.333
 HK3          0.66667E-02    5333.3
 HK4          0.83333       0.66667E+06
 VKA12_1      0.30030E-05    2.4024
 VKA12_2      0.25974E-03    207.79
 VKA12_3      0.23310E-01    18648.
 VKA12_4       3.4965       0.27972E+07
 VKA3_1       0.59880E-06   0.47904
 VKA3_3       0.80000E-02    6400.0
 VKA3_4       0.62500       0.50000E+06
 DRAIN        0.66667E-06   0.53333
 GHB          0.66667E-06   0.53333
 RCH          0.28571E-02    2285.7
 ETM          0.22222E-02    1777.8
 --------------------------------------

 WETTING CAPABILITY IS NOT ACTIVE IN ANY LAYER


 HUF1 -- HYDROGEOLOGIC UNIT FLOW PACKAGE
 ---------------------------------------------------------------------------



            TOP ELEVATN: HGU1
 READING ON UNIT  11 WITH FORMAT: (9F10.2)

...
    THICKNESS: HGU1       =   300.000



            TOP ELEVATN: HGU2
 READING ON UNIT  11 WITH FORMAT: (9F10.2)

...
    THICKNESS: HGU2       =   200.000



            TOP ELEVATN: HGU3
 READING ON UNIT  11 WITH FORMAT: (9F10.2)

...
    THICKNESS: HGU3       =   550.000



            TOP ELEVATN: HGU4
 READING ON UNIT  11 WITH FORMAT: (9F10.2)

...
    THICKNESS: HGU4       =   200.000



            TOP ELEVATN: HGU5
 READING ON UNIT  11 WITH FORMAT: (9F10.2)

...
```

```
    THICKNESS: HGU5       =   1500.00


   INTERPRETATION OF UNIT FLAGS:
     UNIT      HANI           VK/VANI
 -----------------------------------------------------------------------
 HGU1       1.000000        VERTICAL K
 HGU2       1.000000        VERTICAL K
 HGU3       1.000000        VERTICAL K
 HGU4       1.000000        VERTICAL K
 HGU5       1.000000        VERTICAL K

 PARAMETER NAME:HK1          TYPE:HK   UNITS:   5
 The parameter value from the package file is:   1.0000
 This parameter value has been replaced by the value from the
 Sensitivity Process file:   1.5000
UNIT HGU1      CORRESPONDS TO UNIT NO.     1
                LAYER:  1   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    1
UNIT HGU2      CORRESPONDS TO UNIT NO.     2
                LAYER:  2   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    1
UNIT HGU3      CORRESPONDS TO UNIT NO.     3
                LAYER:  3   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    1
UNIT HGU4      CORRESPONDS TO UNIT NO.     4
                LAYER:  4   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    1
UNIT HGU5      CORRESPONDS TO UNIT NO.     5
                LAYER:  5   MULTIPLIER:NONE   ZONE:ZLAY3
                ZONE VALUES:    1

 PARAMETER NAME:HK2          TYPE:HK   UNITS:   5
 The parameter value from the package file is:  1.00000E-02
 This parameter value has been replaced by the value from the
 Sensitivity Process file:  1.50000E-02
UNIT HGU1      CORRESPONDS TO UNIT NO.     1
                LAYER:  1   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    2
UNIT HGU2      CORRESPONDS TO UNIT NO.     2
                LAYER:  2   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    2
UNIT HGU3      CORRESPONDS TO UNIT NO.     3
                LAYER:  3   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    2
UNIT HGU4      CORRESPONDS TO UNIT NO.     4
                LAYER:  4   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    2
UNIT HGU5      CORRESPONDS TO UNIT NO.     5
                LAYER:  5   MULTIPLIER:NONE   ZONE:ZLAY3
                ZONE VALUES:    2

 PARAMETER NAME:HK3          TYPE:HK   UNITS:   5
 The parameter value from the package file is:  1.00000E-04
 This parameter value has been replaced by the value from the
 Sensitivity Process file:  1.50000E-04
UNIT HGU1      CORRESPONDS TO UNIT NO.     1
                LAYER:  1   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    3
UNIT HGU2      CORRESPONDS TO UNIT NO.     2
                LAYER:  2   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    3
UNIT HGU3      CORRESPONDS TO UNIT NO.     3
                LAYER:  3   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    3
UNIT HGU4      CORRESPONDS TO UNIT NO.     4
                LAYER:  4   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    3
UNIT HGU5      CORRESPONDS TO UNIT NO.     5
                LAYER:  5   MULTIPLIER:NONE   ZONE:ZLAY3
                ZONE VALUES:    3

 PARAMETER NAME:HK4          TYPE:HK   UNITS:   5
 The parameter value from the package file is:  1.00000E-06
 This parameter value has been replaced by the value from the
 Sensitivity Process file:  1.20000E-06
UNIT HGU1      CORRESPONDS TO UNIT NO.     1
                LAYER:  1   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    4
UNIT HGU2      CORRESPONDS TO UNIT NO.     2
                LAYER:  2   MULTIPLIER:NONE   ZONE:ZLAY1
```

```
                ZONE VALUES:    4
UNIT HGU3      CORRESPONDS TO UNIT NO.     3
                LAYER:  3   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    4
UNIT HGU4      CORRESPONDS TO UNIT NO.     4
                LAYER:  4   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    4
UNIT HGU5      CORRESPONDS TO UNIT NO.     5
                LAYER:  5   MULTIPLIER:NONE   ZONE:ZLAY3
                ZONE VALUES:    4

 PARAMETER NAME:VKA12_1      TYPE:VK   UNITS:   4
 The parameter value from the package file is:  0.25000
 This parameter value has been replaced by the value from the
 Sensitivity Process file:  0.33300
UNIT HGU1      CORRESPONDS TO UNIT NO.     1
                LAYER:  1   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    1
UNIT HGU2      CORRESPONDS TO UNIT NO.     2
                LAYER:  2   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    1
UNIT HGU3      CORRESPONDS TO UNIT NO.     3
                LAYER:  3   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    1
UNIT HGU4      CORRESPONDS TO UNIT NO.     4
                LAYER:  4   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    1

 PARAMETER NAME:VKA12_2      TYPE:VK   UNITS:   4
 The parameter value from the package file is:  2.50000E-03
 This parameter value has been replaced by the value from the
 Sensitivity Process file:  3.85000E-03
UNIT HGU1      CORRESPONDS TO UNIT NO.     1
                LAYER:  1   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    2
UNIT HGU2      CORRESPONDS TO UNIT NO.     2
                LAYER:  2   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    2
UNIT HGU3      CORRESPONDS TO UNIT NO.     3
                LAYER:  3   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    2
UNIT HGU4      CORRESPONDS TO UNIT NO.     4
                LAYER:  4   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    2

 PARAMETER NAME:VKA12_3      TYPE:VK   UNITS:   4
 The parameter value from the package file is:  2.50000E-05
 This parameter value has been replaced by the value from the
 Sensitivity Process file:  4.29000E-05
UNIT HGU1      CORRESPONDS TO UNIT NO.     1
                LAYER:  1   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    3
UNIT HGU2      CORRESPONDS TO UNIT NO.     2
                LAYER:  2   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    3
UNIT HGU3      CORRESPONDS TO UNIT NO.     3
                LAYER:  3   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    3
UNIT HGU4      CORRESPONDS TO UNIT NO.     4
                LAYER:  4   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    3

 PARAMETER NAME:VKA12_4      TYPE:VK   UNITS:   4
 The parameter value from the package file is:  2.50000E-07
 This parameter value has been replaced by the value from the
 Sensitivity Process file:  2.86000E-07
UNIT HGU1      CORRESPONDS TO UNIT NO.     1
                LAYER:  1   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    4
UNIT HGU2      CORRESPONDS TO UNIT NO.     2
                LAYER:  2   MULTIPLIER:NONE   ZONE:ZLAY1
                ZONE VALUES:    4
UNIT HGU3      CORRESPONDS TO UNIT NO.     3
                LAYER:  3   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    4
UNIT HGU4      CORRESPONDS TO UNIT NO.     4
                LAYER:  4   MULTIPLIER:NONE   ZONE:ZLAY2
                ZONE VALUES:    4

 PARAMETER NAME:VKA3_1       TYPE:VK   UNITS:   1
 The parameter value from the package file is:   1.0000
```

```
 This parameter value has been replaced by the value from the
 Sensitivity Process file:   1.6700
UNIT HGU5      CORRESPONDS TO UNIT NO.     5
                LAYER:  5   MULTIPLIER:NONE   ZONE:ZLAY3
                ZONE VALUES:    1

 PARAMETER NAME:VKA3_2       TYPE:VK   UNITS:   1
 The parameter value from the package file is:  1.00000E-02
UNIT HGU5      CORRESPONDS TO UNIT NO.     5
                LAYER:  5   MULTIPLIER:NONE   ZONE:ZLAY3
                ZONE VALUES:    2

 PARAMETER NAME:VKA3_3       TYPE:VK   UNITS:   1
 The parameter value from the package file is:  1.00000E-04
 This parameter value has been replaced by the value from the
 Sensitivity Process file:  1.25000E-04
UNIT HGU5      CORRESPONDS TO UNIT NO.     5
                LAYER:  5   MULTIPLIER:NONE   ZONE:ZLAY3
                ZONE VALUES:    3

 PARAMETER NAME:VKA3_4       TYPE:VK   UNITS:   1
 The parameter value from the package file is:  1.00000E-06
 This parameter value has been replaced by the value from the
 Sensitivity Process file:  1.60000E-06
UNIT HGU5      CORRESPONDS TO UNIT NO.     5
                LAYER:  5   MULTIPLIER:NONE   ZONE:ZLAY3
                ZONE VALUES:    4
 ITRSS           0

Reading PRINTCODE information
UNIT HGU2      CORRESPONDS TO UNIT NO.     2


PRINTCODE FLAGS ARE SET AS FOLLOWS
   UNIT       HK   HANI   VK    SS    SY
------------------------------------------
HGU1           0     0     0     0     0
HGU2          20    20    20     0     0
HGU3           0     0     0     0     0
HGU4           0     0     0     0     0
HGU5           0     0     0     0     0


     0 Well parameters


     1 Drain parameters

 PARAMETER NAME:DRAIN        TYPE:DRN
 Parameter value from package file is:    1.0000
 This value has been changed to:          1.5000    , as read from
 the Sensitivity Process file
   NUMBER OF ENTRIES:      5

 DRAIN NO.  LAYER   ROW   COL     DRAIN EL.  STRESS FACTOR
 ------------------------------------------------------------
      1      1      7      6       400.0          1.000
      2      1     10     11       550.0          1.000
      3      1     14     14       1200.          1.000
      4      1     15     14       1200.          1.000
      5      1     16     14       1200.          1.000


     1 Evapotranspiration parameters

 PARAMETER NAME:ETM          TYPE:EVT    CLUSTERS:   1
 Parameter value from package file is:   4.00000E-04
 This value has been changed to:         4.50000E-04, as read from
 the Sensitivity Process file
               MULTIPLIER ARRAY: NONE    ZONE ARRAY: RCHETM
               ZONE VALUES:    2


     1 GHB parameters

 PARAMETER NAME:GHB          TYPE:GHB
 Parameter value from package file is:    1.0000
 This value has been changed to:          1.5000    , as read from
 the Sensitivity Process file
   NUMBER OF ENTRIES:      5
```

```
 BOUND. NO. LAYER   ROW   COL     STAGE    STRESS FACTOR
 ----------------------------------------------------------
      1      1      3      6       350.0          1.000
      2      1      3     11       500.0          1.000
      3      1      4     11       500.0          1.000
      4      1      5     11       500.0          1.000
      5      1     12      9       1000.          1.000


     1 Recharge parameters

 PARAMETER NAME:RCH          TYPE:RCH    CLUSTERS:   1
 Parameter value from package file is:   3.10000E-04
 This value has been changed to:         3.50000E-04, as read from
 the Sensitivity Process file
               MULTIPLIER ARRAY: NONE    ZONE ARRAY: RCHETM
               ZONE VALUES:    1

  16 PARAMETERS HAVE BEEN DEFINED IN ALL PACKAGES.
 (SPACE IS ALLOCATED FOR  500 PARAMETERS.)

OBSERVATION SENSITIVITY TABLE(S) FOR PARAMETER-ESTIMATION ITERATION     1

 FOR THE SCALING OF THE SENSITIVITIES BELOW, B IS REPLACED BY
 BSCAL (THE ALTERNATE SCALING FACTOR) FOR PARAMETER(S):
     VKA12_2     VKA12_3     VKA12_4     VKA3_3      VKA3_4      RCH

 DIMENSIONLESS SCALED SENSITIVITIES (SCALED BY B*(WT**.5))

...


 STARTING VALUES OF REGRESSION PARAMETERS :

   HK1          HK2          HK3          HK4          VKA12_1      VKA12_2
   VKA12_3      VKA12_4      VKA3_1       VKA3_3       VKA3_4       DRAIN
   GHB          RCH          ETM

    1.500       1.5000E-02   1.5000E-04   1.2000E-06   0.3330       3.8500E-03
   4.2900E-05   2.8600E-07    1.670       1.2500E-04   1.6000E-06    1.500
    1.500       3.5000E-04   4.5000E-04

 SUMS OF SQUARED, WEIGHTED RESIDUALS:
   ALL DEPENDENT VARIABLES:   3288.2
   DEP. VARIABLES PLUS PARAMETERS:   3288.2

 -----------------------------------------------------------------------
 PARAMETER VALUES AND STATISTICS FOR ALL PARAMETER-ESTIMATION ITERATIONS
 -----------------------------------------------------------------------

     MODIFIED GAUSS-NEWTON CONVERGES IF THE ABSOLUTE VALUE OF THE MAXIMUM
 FRACTIONAL PARAMETER CHANGE (MAX CALC. CHANGE) IS LESS THAN TOL OR IF THE
 SUM OF SQUARED, WEIGHTED RESIDUALS CHANGES LESS THAN SOSC OVER TWO
 PARAMETER-ESTIMATION ITERATIONS.

 MODIFIED GAUSS-NEWTON PROCEDURE FOR PARAMETER-ESTIMATION ITERATION NO. =     1

 VALUES FROM SOLVING THE NORMAL EQUATION :
   MARQUARDT PARAMETER ------------------- =  0.0000
   MAX. FRAC. PAR. CHANGE (TOL= 0.100E-01) = -.84183
        OCCURRED FOR PARAMETER  "VKA3_4    " TYPE U

 CALCULATION OF DAMPING PARAMETER
   MAX-CHANGE SPECIFIED:    2.00 USED:    2.00
   OSCILL. CONTROL FACTOR (1, NO EFFECT)-- =  1.0000
   DAMPING PARAMETER (RANGE 0 TO 1) ------ =  1.0000
        CONTROLLED BY PARAMETER "VKA3_4    " TYPE U

 UPDATED ESTIMATES OF REGRESSION PARAMETERS :

   HK1          HK2          HK3          HK4          VKA12_1      VKA12_2
   VKA12_3      VKA12_4      VKA3_1       VKA3_3       VKA3_4       DRAIN
   GHB          RCH          ETM

   0.9807       9.1555E-03   8.5516E-05   6.2954E-07   0.1294       2.1816E-03
   1.5859E-05   4.3503E-07   0.4923       1.5541E-04   2.5308E-07   0.9163
   0.9555       3.2754E-04   4.2061E-04

 SUMS OF SQUARED, WEIGHTED RESIDUALS:
   ALL DEPENDENT VARIABLES:   1496.9
   DEP. VARIABLES PLUS PARAMETERS:   1496.9
```

```
MODIFIED GAUSS-NEWTON PROCEDURE FOR PARAMETER-ESTIMATION ITERATION NO. =     2

VALUES FROM SOLVING THE NORMAL EQUATION :
  MARQUARDT PARAMETER ------------------- =  0.0000
  MAX. FRAC. PAR. CHANGE (TOL= 0.100E-01) =  1.2835
       OCCURRED FOR PARAMETER  "VKA3_4    " TYPE U

CALCULATION OF DAMPING PARAMETER
  MAX-CHANGE SPECIFIED:    2.00 USED:    2.00
  OSCILL. CONTROL FACTOR (1, NO EFFECT)-- = 0.32795
  DAMPING PARAMETER (RANGE 0 TO 1) ------ = 0.32795
       CONTROLLED BY PARAMETER "VKA3_4    " TYPE U

UPDATED ESTIMATES OF REGRESSION PARAMETERS :

  HK1         HK2         HK3         HK4         VKA12_1     VKA12_2
  VKA12_3     VKA12_4     VKA3_1      VKA3_3      VKA3_4      DRAIN
  GHB         RCH         ETM

  0.9920      9.3795E-03  8.8347E-05  7.4045E-07  0.1364      2.2569E-03
  1.7898E-05  3.9770E-07  0.6774      1.5910E-04  3.5960E-07  0.9390
  0.9730      3.2119E-04  4.1316E-04

SUMS OF SQUARED, WEIGHTED RESIDUALS:
  ALL DEPENDENT VARIABLES:   697.47
  DEP. VARIABLES PLUS PARAMETERS:   697.47

MODIFIED GAUSS-NEWTON PROCEDURE FOR PARAMETER-ESTIMATION ITERATION NO. =     3

VALUES FROM SOLVING THE NORMAL EQUATION :
  MARQUARDT PARAMETER ------------------- =  0.0000
  MAX. FRAC. PAR. CHANGE (TOL= 0.100E-01) =  1.1402
       OCCURRED FOR PARAMETER  "VKA3_4    " TYPE U

CALCULATION OF DAMPING PARAMETER
  MAX-CHANGE SPECIFIED:    2.00 USED:    2.00
  OSCILL. CONTROL FACTOR (1, NO EFFECT)-- =  1.0000
  DAMPING PARAMETER (RANGE 0 TO 1) ------ =  1.0000
       CONTROLLED BY PARAMETER "VKA3_4    " TYPE U

UPDATED ESTIMATES OF REGRESSION PARAMETERS :

  HK1         HK2         HK3         HK4         VKA12_1     VKA12_2
  VKA12_3     VKA12_4     VKA3_1      VKA3_3      VKA3_4      DRAIN
  GHB         RCH         ETM

   1.010      9.9074E-03  9.6262E-05  1.1291E-06  0.1709      2.4462E-03
  2.3227E-05  2.8983E-07   1.247      1.1821E-04  7.6964E-07  0.9918
   1.007      3.0878E-04  3.9877E-04

SUMS OF SQUARED, WEIGHTED RESIDUALS:
  ALL DEPENDENT VARIABLES:   4.6752
  DEP. VARIABLES PLUS PARAMETERS:   4.6752

MODIFIED GAUSS-NEWTON PROCEDURE FOR PARAMETER-ESTIMATION ITERATION NO. =     4

VALUES FROM SOLVING THE NORMAL EQUATION :
  MARQUARDT PARAMETER ------------------- =  0.0000
  MAX. FRAC. PAR. CHANGE (TOL= 0.100E-01) = 0.33212
       OCCURRED FOR PARAMETER  "VKA3_4    " TYPE U

CALCULATION OF DAMPING PARAMETER
  MAX-CHANGE SPECIFIED:    2.00 USED:    2.00
  OSCILL. CONTROL FACTOR (1, NO EFFECT)-- =  1.0000
  DAMPING PARAMETER (RANGE 0 TO 1) ------ =  1.0000
       CONTROLLED BY PARAMETER "VKA3_4    " TYPE U

UPDATED ESTIMATES OF REGRESSION PARAMETERS :

  HK1         HK2         HK3         HK4         VKA12_1     VKA12_2
  VKA12_3     VKA12_4     VKA3_1      VKA3_3      VKA3_4      DRAIN
  GHB         RCH         ETM

   1.003      9.9937E-03  9.9292E-05  1.1065E-06  0.2147      2.4934E-03
  2.4865E-05  2.5633E-07   1.262      1.0332E-04  1.0253E-06  0.9993
   1.003      3.0977E-04  4.0005E-04

SUMS OF SQUARED, WEIGHTED RESIDUALS:
  ALL DEPENDENT VARIABLES:  0.67760E-01
  DEP. VARIABLES PLUS PARAMETERS:  0.67760E-01
```

```
MODIFIED GAUSS-NEWTON PROCEDURE FOR PARAMETER-ESTIMATION ITERATION NO. =     5

VALUES FROM SOLVING THE NORMAL EQUATION :
  MARQUARDT PARAMETER ------------------- =  0.0000
  MAX. FRAC. PAR. CHANGE (TOL= 0.100E-01) = -.26155
       OCCURRED FOR PARAMETER  "VKA3_1    " TYPE U

CALCULATION OF DAMPING PARAMETER
  MAX-CHANGE SPECIFIED:    2.00 USED:    2.00
  OSCILL. CONTROL FACTOR (1, NO EFFECT)-- =  1.0000
  DAMPING PARAMETER (RANGE 0 TO 1) ------ =  1.0000
       CONTROLLED BY PARAMETER "VKA3_1    " TYPE U

UPDATED ESTIMATES OF REGRESSION PARAMETERS :

  HK1          HK2          HK3          HK4          VKA12_1      VKA12_2
  VKA12_3      VKA12_4      VKA3_1       VKA3_3       VKA3_4       DRAIN
  GHB          RCH          ETM

  0.9999       9.9958E-03   9.9922E-05   1.0050E-06   0.2443       2.4986E-03
  2.4986E-05   2.5024E-07   0.9316       1.0006E-04   1.0081E-06   0.9994
  0.9998       3.0986E-04   3.9984E-04

SUMS OF SQUARED, WEIGHTED RESIDUALS:
  ALL DEPENDENT VARIABLES:  0.70503E-02
  DEP. VARIABLES PLUS PARAMETERS:  0.70503E-02

MODIFIED GAUSS-NEWTON PROCEDURE FOR PARAMETER-ESTIMATION ITERATION NO. =     6

VALUES FROM SOLVING THE NORMAL EQUATION :
  MARQUARDT PARAMETER ------------------- =  0.0000
  MAX. FRAC. PAR. CHANGE (TOL= 0.100E-01) = 0.66359E-01
       OCCURRED FOR PARAMETER  "VKA3_1    " TYPE U

CALCULATION OF DAMPING PARAMETER
  MAX-CHANGE SPECIFIED:    2.00 USED:    2.00
  OSCILL. CONTROL FACTOR (1, NO EFFECT)-- = 0.84405
  DAMPING PARAMETER (RANGE 0 TO 1) ------ = 0.84405
       CONTROLLED BY PARAMETER "VKA3_1    " TYPE U

UPDATED ESTIMATES OF REGRESSION PARAMETERS :

  HK1          HK2          HK3          HK4          VKA12_1      VKA12_2
  VKA12_3      VKA12_4      VKA3_1       VKA3_3       VKA3_4       DRAIN
  GHB          RCH          ETM

  0.9997       9.9959E-03   9.9945E-05   1.0018E-06   0.2489       2.4987E-03
  2.4989E-05   2.5003E-07   0.9838       9.9976E-05   1.0021E-06   0.9994
  0.9997       3.0987E-04   3.9983E-04

SUMS OF SQUARED, WEIGHTED RESIDUALS:
  ALL DEPENDENT VARIABLES:  0.32119E-03
  DEP. VARIABLES PLUS PARAMETERS:  0.32119E-03

MODIFIED GAUSS-NEWTON PROCEDURE FOR PARAMETER-ESTIMATION ITERATION NO. =     7

VALUES FROM SOLVING THE NORMAL EQUATION :
  MARQUARDT PARAMETER ------------------- =  0.0000
  MAX. FRAC. PAR. CHANGE (TOL= 0.100E-01) = 0.14268E-01
       OCCURRED FOR PARAMETER  "VKA3_1    " TYPE U

CALCULATION OF DAMPING PARAMETER
  MAX-CHANGE SPECIFIED:    2.00 USED:    2.00
  OSCILL. CONTROL FACTOR (1, NO EFFECT)-- =  1.0000
  DAMPING PARAMETER (RANGE 0 TO 1) ------ =  1.0000
       CONTROLLED BY PARAMETER "VKA3_1    " TYPE U

UPDATED ESTIMATES OF REGRESSION PARAMETERS :

  HK1          HK2          HK3          HK4          VKA12_1      VKA12_2
  VKA12_3      VKA12_4      VKA3_1       VKA3_3       VKA3_4       DRAIN
  GHB          RCH          ETM

  0.9996       9.9959E-03   9.9949E-05   1.0012E-06   0.2499       2.4988E-03
  2.4990E-05   2.4997E-07   0.9978       9.9960E-05   1.0010E-06   0.9994
  0.9996       3.0987E-04   3.9983E-04

SUMS OF SQUARED, WEIGHTED RESIDUALS:
  ALL DEPENDENT VARIABLES:  0.70775E-04
  DEP. VARIABLES PLUS PARAMETERS:  0.70775E-04
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 MODIFIED GAUSS-NEWTON PROCEDURE FOR PARAMETER-ESTIMATION ITERATION NO. =     8

 VALUES FROM SOLVING THE NORMAL EQUATION :
   MARQUARDT PARAMETER ------------------- =  0.0000
   MAX. FRAC. PAR. CHANGE (TOL= 0.100E-01) = 0.25789E-03
        OCCURRED FOR PARAMETER  "VKA3_1    " TYPE U

 CALCULATION OF DAMPING PARAMETER
   MAX-CHANGE SPECIFIED:    2.00 USED:    2.00
   OSCILL. CONTROL FACTOR (1, NO EFFECT)-- =  1.0000
   DAMPING PARAMETER (RANGE 0 TO 1) ------ =  1.0000
        CONTROLLED BY PARAMETER "VKA3_1    " TYPE U

 UPDATED ESTIMATES OF REGRESSION PARAMETERS :

   HK1          HK2          HK3          HK4          VKA12_1      VKA12_2
   VKA12_3      VKA12_4      VKA3_1       VKA3_3       VKA3_4       DRAIN
   GHB          RCH          ETM

   0.9996       9.9959E-03   9.9950E-05   1.0012E-06   0.2499       2.4988E-03
   2.4990E-05   2.4996E-07   0.9981       9.9959E-05   1.0010E-06   0.9994
   0.9996       3.0987E-04   3.9983E-04

 *** PARAMETER ESTIMATION CONVERGED BY SATISFYING THE TOL CRITERION ***


OBSERVATION SENSITIVITY TABLE(S) FOR PARAMETER-ESTIMATION ITERATION     8

 FOR THE SCALING OF THE SENSITIVITIES BELOW, B IS REPLACED BY
 BSCAL (THE ALTERNATE SCALING FACTOR) FOR PARAMETER(S):
     VKA12_2     VKA12_3     VKA12_4     VKA3_3      VKA3_4      RCH
  ETM

 DIMENSIONLESS SCALED SENSITIVITIES (SCALED BY B*(WT**.5))

         PARAMETER:   HK1         HK2         HK3         HK4         VKA12_1
 OBS #  OBSERVATION
     1  W2L             4.22        22.8       -11.2      -0.915E-01   0.297E-01
     2  WL2             4.15        17.3       -9.22      -0.777E-01   0.253E-01
     3  WL2             4.38       -8.84       -1.59      -0.186E-01   0.330E-02
     4  WL4             1.48        6.94       -5.78      -0.110       0.262E-01
     5  WL4             4.28        24.8       -11.0      -0.898E-01   0.397E-01
     6  WL4             4.31       -6.51       -2.26      -0.198E-01   0.931E-02
     7  WL4             3.25       -8.75       -1.43      -0.172E-01   0.275E-02
     8  WL5             5.38        16.0       -10.1       -2.13       0.197
     9  WL6             1.63        1.96       -1.99      -0.979E-02   0.727E-01
    10  WL6             12.0        15.8      -0.344      -0.267E-02   0.793
    11  WL6             12.1        12.8       0.147       0.182E-02   0.732
    12  WL6             2.51       -9.25       -1.58      -0.177E-01  -0.596E-06
    13  WL6             2.19       -8.74       -1.31      -0.161E-01   0.257E-02
    14  WL6             2.10       -8.76       -1.25      -0.155E-01   0.234E-02
    15  WL8             2.47       -5.16        4.90       0.146       0.126
    16  WL8             8.15        2.81        3.59       0.112       0.450
    17  WL8             14.0       -1.64      -0.144      -0.113E-03    1.22
    18  WL8             4.53       -21.3       -1.45      -0.305E-01   0.159
    19  WL8            0.999       -17.8       -1.55      -0.187E-01  -0.137E-01
    20  WL8             1.58       -8.90       -1.22      -0.151E-01   0.368E-02
    21  WL9             5.51       -3.00        6.72       0.237       0.282
    22  WL10            7.96       -1.51        6.51       0.275       0.396
    23  WL10            12.7        2.45       -2.55       -2.09       0.594
    24  WL10            8.50       -10.6       0.425      -0.229E-01   0.387
    25  WL10           0.231       -39.0       -2.77      -0.278E-01  -0.451E-01
    26  WL10          -0.586       -19.6       -1.40      -0.173E-01  -0.967E-01
    27  WL10           0.185       -5.43      -0.642      -0.796E-02  -0.382E-01
    28  WL11            4.06       -7.29        7.11       0.236       0.200
    29  WL12            5.76       -9.22       0.640       0.723E-01   0.261
    30  WL12           0.592       -35.1       -1.03      -0.707E-01   0.147E-01
    31  WL12           -1.01       -56.7       -2.44      -0.243E-01  -0.748E-01
    32  WL12          -0.687       -13.6      -0.863      -0.107E-01  -0.995E-01
    33  WL13          -0.989       -56.4       -3.77      -0.300E-01  -0.534E-01
    34  WL13          -0.797       -28.0       -1.09      -0.129E-01  -0.972E-01
    35  WL14            1.90       -24.4       -1.39       0.424E-01   0.746E-01
    36  WL14          -0.446       -45.5       -1.65      -0.344E-01  -0.370E-01
    37  WL14          -0.434       -12.1      -0.443      -0.627E-02  -0.642E-01
    38  WL15          -0.107       -5.29        2.22       0.976E-03  -0.137E-01
    39  WL16           0.434       -23.2       -1.06       0.468E-01   0.438E-03
    40  WL16          -0.508       -12.6      -0.416      -0.610E-02  -0.632E-01
    41  WL18           0.190       -18.1       -1.18       0.436E-01  -0.154E-01
    42  WL18          -0.489       -12.3      -0.334      -0.557E-02  -0.621E-01
    43  DRN1          -0.397      -0.365       0.954E-02   0.518E-04  -0.291E-01
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   44  DRN1          -0.455E-02   0.768       0.546E-01   0.547E-03   0.889E-03
   45  DRN1           0.854E-01    3.51       0.168       0.163E-02   0.945E-02
   46  DRN1           0.939E-01    4.64       -1.95      -0.856E-03   0.120E-01
   47  DRN1           0.580E-01    7.82       -1.82      -0.128E-01   0.157E-01
   48  GHB1          -0.112      -0.714       0.287       0.238E-02  -0.833E-03
   49  GHB2          -0.102       0.213       0.372E-01   0.441E-03  -0.760E-04
   50  GHB3          -0.901E-01   0.655E-01   0.369E-01   0.432E-03  -0.780E-04
   51  GHB4          -0.732E-01   0.191E-01   0.355E-01   0.419E-03  -0.587E-04
   52  GHB5          -0.351        1.93       -2.05       0.113E-03  -0.152E-01

       COMPOSITE SCALED SENSITIVITIES ((SUM OF THE SQUARED VALUES)/ND)**.5
                       4.65        18.8        3.74       0.420       0.272

DIMENSIONLESS SCALED SENSITIVITIES (SCALED BY B*(WT**.5))

        PARAMETER:   VKA12_2     VKA12_3     VKA12_4     VKA3_1      VKA3_3
OBS #  OBSERVATION
    1  W2L            -43.8       -402.        2.22      -0.184E-01   0.106
    2  WL2            -46.3       -336.       -16.6      -0.217E-01   0.354E-01
    3  WL2            -58.4       -96.6       -104.      -0.380E-01  -0.236
    4  WL4            -11.9       0.117E+04    5.68       0.190E-02   0.391E-01
    5  WL4            -42.1       -384.        6.30      -0.137E-01   0.112
    6  WL4            -57.2       -114.       -269.      -0.350E-01  -0.226
    7  WL4            -58.9       -91.3       -102.      -0.385E-01  -0.235
    8  WL5            -23.8       0.169E+04    332.       0.594E-01  -0.188
    9  WL6            -4.15       0.105E+04    4.03       0.254E-01   0.238
   10  WL6             26.1        10.7        36.1       0.279      -0.497E-01
   11  WL6             30.1        7.12        50.3       0.255       0.284E-01
   12  WL6            -57.9       -118.       -268.      -0.368E-01  -0.289
   13  WL6            -59.4       -85.8       -95.1      -0.391E-01  -0.232
   14  WL6            -59.6       -81.0       -89.7      -0.393E-01  -0.229
   15  WL8            -1.04        626.        3.94       0.509E-01    3.10
   16  WL8            0.987       -952.        1.55       0.175       -6.13
   17  WL8             2.72        2.28        32.1       0.318      -0.502E-01
   18  WL8            -39.0       -284.      -0.928E+04   0.410E-01   0.165
   19  WL8            -62.1       -135.       -130.      -0.382E-01  -0.428
   20  WL8            -58.9       -78.4       -86.9      -0.389E-01  -0.230
   21  WL9           -0.400      -0.105E+04    10.8       0.117       0.201E-01
   22  WL10           0.837E-01  -0.170E+04    17.1       0.171       -8.07
   23  WL10          -0.249        903.        34.2       0.270        13.1
   24  WL10           -13.1       -439.       -505.       0.167        1.70
   25  WL10           -57.3       -296.       -272.      -0.302E-01  -0.907
   26  WL10           -66.9       -104.       -103.      -0.375E-01  -0.282
   27  WL10           -29.3       -42.0       -45.3      -0.199E-01  -0.222
   28  WL11          -0.953        63.9        11.9       0.863E-01    16.6
   29  WL12           -11.5        443.       -36.7       0.119       0.635
   30  WL12           -41.1       -148.       -167.       0.216E-02    1.28
   31  WL12           -64.5       -313.       -182.      -0.322E-01  -0.968
   32  WL12           -39.5       -52.4       -61.1      -0.238E-01  -0.432
   33  WL13           -60.1       -388.       -214.      -0.306E-01   -1.05
   34  WL13           -56.3       -87.5       -75.1      -0.246E-01  -0.435
   35  WL14           -28.6        390.       -83.7       0.350E-01   0.569
   36  WL14           -47.9       -428.       -146.      -0.165E-01   -3.69
   37  WL14           -22.1       -30.1       -39.3      -0.137E-01  -0.253
   38  WL15           -8.33        182.       -15.5      -0.353E-02  -0.628
   39  WL16           -28.2        221.       -74.5       0.449E-02   -2.91
   40  WL16           -23.4       -23.7       -40.6      -0.140E-01  -0.245
   41  WL18           -24.3        353.       -57.7       0.357E-04    1.15
   42  WL18           -22.3       -26.3       -39.6      -0.136E-01  -0.234
   43  DRN1          -0.673      -0.189      -0.982      -0.928E-02   0.217E-02
   44  DRN1            1.13        5.83        5.36       0.594E-03   0.179E-01
   45  DRN1            5.67        18.3        9.68       0.263E-02   0.656E-01
   46  DRN1            7.30       -159.        13.6       0.309E-02   0.551
   47  DRN1            11.4       -490.        24.4       0.304E-02   0.208
   48  GHB1            1.16        10.0      -0.128       0.469E-03  -0.297E-02
   49  GHB2            1.42        2.30        2.51       0.925E-03   0.571E-02
   50  GHB3            1.41        2.30        2.94       0.919E-03   0.572E-02
   51  GHB4            1.41        2.39        3.90       0.909E-03   0.598E-02
   52  GHB5            2.31       -309.        9.97      -0.678E-02  -0.160

       COMPOSITE SCALED SENSITIVITIES ((SUM OF THE SQUARED VALUES)/ND)**.5
                       35.9        513.       0.129E+04   0.950E-01    3.37

DIMENSIONLESS SCALED SENSITIVITIES (SCALED BY B*(WT**.5))

        PARAMETER:   VKA3_4      DRAIN       GHB         RCH         ETM
OBS #  OBSERVATION
    1  W2L            -33.6       -1.77       -25.3        30.7       -2.57
    2  WL2            -27.3       -1.86       -22.7        32.4       -2.50
    3  WL2            -6.98       -2.27       -8.66        40.7       -2.14
    4  WL4            -166.      -0.539       -7.03        8.53       -1.30
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    5  WL4            -32.1       -1.74       -26.9        29.7       -2.87
    6  WL4            -7.16       -2.24       -9.76        40.0       -2.34
    7  WL4            -6.62       -2.28       -7.94        41.0       -2.14
    8  WL5            0.558E+04   -1.48       -14.2        17.6       -7.51
    9  WL6            -59.3      -0.376       -2.65        3.52       -2.49
   10  WL6           -0.468       -2.45      -0.699        3.20       -32.7
   11  WL6             2.86       -1.02      -0.606        3.30       -32.6
   12  WL6            -7.48       -2.90       -9.63        45.7       -2.16
   13  WL6            -6.34       -2.27       -7.01        41.1       -2.14
   14  WL6            -6.14       -2.23       -6.57        40.6       -2.13
   15  WL8             55.3      -0.375      -0.934        2.09       -3.89
   16  WL8            -8.72       -1.23       -1.84        4.54       -13.7
   17  WL8            0.716E-01  -0.926      -0.554        3.39       -15.2
   18  WL8            -6.35       -5.76       -5.26        59.5       -7.71
   19  WL8            -10.0       -3.70       -6.41        56.9       -2.17
   20  WL8            -5.96       -2.22       -6.29        40.8       -2.09
   21  WL9             134.      -0.737       -1.12        3.70       -8.68
   22  WL10            200.      -0.970       -1.00        5.14       -12.1
   23  WL10           0.685E+04   -1.12      -0.748        5.17       -17.7
   24  WL10            42.3       -4.39       -2.66        33.1       -13.5
   25  WL10           -14.3       -17.7       -5.70        104.       -2.00
   26  WL10           -6.44       -3.18       -6.19        61.2       -2.07
   27  WL10           -3.02       -1.22       -3.21        22.8       -1.07
   28  WL11            175.      -0.540      -0.676        3.18       -6.07
   29  WL12            74.3       -2.36       -3.61        23.9       -8.40
   30  WL12            24.3       -6.94       -5.57        78.0       -3.00
   31  WL12           -11.5       -7.39       -5.72        116.       -1.96
   32  WL12           -4.14       -2.04       -3.91        39.9       -1.31
   33  WL13           -17.2       -9.09       -5.80        119.       -2.05
   34  WL13           -6.01       -3.23       -4.11        65.2       -1.39
   35  WL14            59.4       -4.42       -3.94        54.0       -4.17
   36  WL14           -75.2       -6.80       -4.70        93.9       -2.11
   37  WL14           -1.77       -1.71       -2.30        29.2      -0.783
   38  WL15            2.57       -3.85      -0.736        12.3      -0.291
   39  WL16            79.1       -4.09       -3.10        50.3       -2.21
   40  WL16           -1.27       -1.81       -2.36        30.4      -0.807
   41  WL18            79.1       -3.19       -2.66        40.1       -1.70
   42  WL18          -0.359       -1.74       -2.31        29.4      -0.793
   43  DRN1           0.271E-01   -3.17       0.178E-01  -0.987E-01   0.814
   44  DRN1           0.282       -2.98       0.112       -2.04       0.393E-01
   45  DRN1            1.08       -2.53       0.450       -8.28       0.153
   46  DRN1           -2.25       0.457E-01   0.645       -10.8       0.255
   47  DRN1           -23.0        1.03        1.17       -17.7       0.593
   48  GHB1           0.846       0.470E-01   -2.54      -0.811       0.695E-01
   49  GHB2           0.166       0.550E-01   -3.13      -0.988       0.519E-01
   50  GHB3           0.165       0.556E-01   -2.98      -0.991       0.520E-01
   51  GHB4           0.167       0.588E-01   -2.94       -1.01       0.518E-01
   52  GHB5           -9.27       0.420      -0.287       -4.50       0.602

       COMPOSITE SCALED SENSITIVITIES ((SUM OF THE SQUARED VALUES)/ND)**.5
                      0.123E+04    3.93        7.61        43.4        8.36

 PARAMETER    COMPOSITE SCALED SENSITIVITY
 ----------   ----------------------------
 HK1            4.64572E+00
 HK2            1.88031E+01
 HK3            3.74500E+00
 HK4            4.20112E-01
 VKA12_1        2.71863E-01
 VKA12_2        3.59047E+01
 VKA12_3        5.13260E+02
 VKA12_4        1.29274E+03
 VKA3_1         9.49773E-02
 VKA3_3         3.37216E+00
 VKA3_4         1.22659E+03
 DRAIN          3.93459E+00
 GHB            7.61336E+00
 RCH            4.33604E+01
 ETM            8.36342E+00

FINAL PARAMETER VALUES AND STATISTICS:

PARAMETER NAME(S) AND VALUE(S):

  HK1          HK2          HK3          HK4          VKA12_1      VKA12_2
  VKA12_3      VKA12_4      VKA3_1       VKA3_3       VKA3_4       DRAIN
  GHB          RCH          ETM

  0.9996       9.9959E-03   9.9950E-05   1.0012E-06   0.2499       2.4988E-03
  2.4990E-05   2.4996E-07   0.9981       9.9959E-05   1.0010E-06   0.9994
  0.9996       3.0987E-04   3.9983E-04
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SUMS OF SQUARED WEIGHTED RESIDUALS:
  OBSERVATIONS   PRIOR INFO.    TOTAL
   0.706E-04      0.00         0.706E-04

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SELECTED STATISTICS FROM MODIFIED GAUSS-NEWTON ITERATIONS

       MAX. PARAMETER CALC. CHANGE   MAX. CHANGE     DAMPING
ITER.     PARNAM     MAX. CHANGE       ALLOWED      PARAMETER
-----  ----------  -------------   -------------  ------------
   1    VKA3_4      -0.841826         2.00000        1.0000
   2    VKA3_4        1.28345         2.00000       0.32795
   3    VKA3_4        1.14025         2.00000        1.0000
   4    VKA3_4       0.332119         2.00000        1.0000
   5    VKA3_1      -0.261548         2.00000        1.0000
   6    VKA3_1       0.663591E-01     2.00000       0.84405
   7    VKA3_1       0.142675E-01     2.00000        1.0000
   8    VKA3_1       0.257887E-03     2.00000        1.0000

SUMS OF SQUARED WEIGHTED RESIDUALS FOR EACH ITERATION

        SUMS OF SQUARED WEIGHTED RESIDUALS
ITER.  OBSERVATIONS  PRIOR INFO.      TOTAL
    1    3288.2        0.0000        3288.2
    2    1496.9        0.0000        1496.9
    3    697.47        0.0000        697.47
    4    4.6752        0.0000        4.6752
    5   0.67760E-01    0.0000       0.67760E-01
    6   0.70503E-02    0.0000       0.70503E-02
    7   0.32119E-03    0.0000       0.32119E-03
    8   0.70775E-04    0.0000       0.70775E-04
FINAL   0.70643E-04    0.0000       0.70643E-04

*** PARAMETER ESTIMATION CONVERGED BY SATISFYING THE TOL CRITERION ***

-----------------------------------------------------------------------

         COVARIANCE MATRIX FOR THE PARAMETERS
         ------------------------------------

            HK1          HK2          HK3          HK4          VKA12_1
            VKA12_2      VKA12_3      VKA12_4      VKA3_1       VKA3_3
            VKA3_4       DRAIN        GHB          RCH          ETM
...........................................................................
HK1         1.03696E-07  1.02094E-10  1.06613E-12 -1.91894E-13 -1.35507E-07
            9.97668E-11  4.11943E-13  1.78167E-13 -1.58327E-06 -1.92891E-12
           -2.41057E-13  1.67224E-08  2.06771E-08  4.86439E-12  9.76711E-12
HK2         1.02094E-10  2.03120E-12  1.88059E-14  5.17223E-16  1.59427E-10
            4.31163E-13  3.77560E-15 -7.74737E-17  2.28515E-09  3.82222E-14
            5.60387E-16  1.42097E-10  1.90330E-10  5.77090E-14  7.65767E-14
HK3         1.06613E-12  1.88059E-14  4.65769E-16 -5.34395E-17  1.80080E-12
            5.70361E-15  2.83309E-17  1.22041E-18  1.60811E-11  6.41508E-16
           -4.73536E-17  1.46667E-12  7.31866E-13  5.68597E-16  7.86773E-16
HK4        -1.91894E-13  5.17223E-16 -5.34395E-17  2.52602E-17  2.45374E-12
            1.53744E-16  1.51911E-17 -1.70751E-18 -3.35257E-11 -4.07653E-16
            2.50390E-17  3.38873E-15  1.65449E-13  1.20316E-17 -3.51991E-17
VKA12_1    -1.35507E-07  1.59427E-10  1.80080E-12  2.45374E-12  1.43296E-06
            1.32235E-10  2.93182E-13 -3.36752E-13 -1.50771E-05 -1.48068E-11
            2.98492E-12  1.00497E-08 -8.24051E-09  5.32192E-12 -1.10176E-11
VKA12_2     9.97668E-11  4.31163E-13  5.70361E-15  1.53744E-16  1.32235E-10
            2.56580E-13  1.03581E-15  9.87578E-17 -4.39940E-09  1.25173E-15
            2.52799E-16  4.88268E-11  3.59922E-11  1.58871E-14  1.94025E-14
VKA12_3     4.11943E-13  3.77560E-15  2.83309E-17  1.51911E-17  2.93182E-13
            1.03581E-15  6.30185E-17 -1.62152E-18 -4.04200E-12 -7.38609E-16
            1.33232E-17  2.54873E-13  3.24808E-13  1.12636E-16  1.54886E-16
VKA12_4     1.78167E-13 -7.74737E-17  1.22041E-18 -1.70751E-18 -3.36752E-13
            9.87578E-17 -1.62152E-18  4.49197E-18 -1.97796E-12  4.67777E-17
           -1.84357E-18 -3.84993E-15  1.60693E-14  1.37836E-18  6.99979E-18
VKA3_1     -1.58327E-06  2.28515E-09  1.60811E-11 -3.35257E-11 -1.50771E-05
           -4.39940E-09 -4.04200E-12 -1.97796E-12  3.33630E-04  5.20934E-10
           -4.04983E-11 -1.56115E-07  1.17661E-07 -2.16065E-11  2.64854E-10
VKA3_3     -1.92891E-12  3.82222E-14  6.41508E-16 -4.07653E-16 -1.48068E-11
            1.25173E-15 -7.38609E-16  4.67777E-17  5.20934E-10  5.24233E-14
           -4.31975E-16  2.77248E-12  3.75402E-12  1.00751E-15  1.45134E-15
VKA3_4     -2.41057E-13  5.60387E-16 -4.73536E-17  2.50390E-17  2.98492E-12
            2.52799E-16  1.33232E-17 -1.84357E-18 -4.04983E-11 -4.31975E-16
            2.55340E-17  1.07736E-14  1.44004E-13  1.44377E-17 -4.14456E-17
DRAIN       1.67224E-08  1.42097E-10  1.46667E-12  3.38873E-15  1.00497E-08
            4.88268E-11  2.54873E-13 -3.84993E-15 -1.56115E-07  2.77248E-12
```

```
            1.07736E-14  2.51984E-08  1.36041E-08  4.91344E-12  5.94491E-12
GHB         2.06771E-08  1.90330E-10  7.31866E-13  1.65449E-13 -8.24051E-09
            3.59922E-11  3.24808E-13  1.60693E-14  1.17661E-07  3.75402E-12
            1.44004E-13  1.36041E-08  2.49382E-08  5.41178E-12  7.41861E-12
RCH         4.86439E-12  5.77090E-14  5.68597E-16  1.20316E-17  5.32192E-12
            1.58871E-14  1.12636E-16  1.37836E-18 -2.16065E-11  1.00751E-15
            1.44377E-17  4.91344E-12  5.41178E-12  1.74363E-15  2.30081E-15
ETM         9.76711E-12  7.65767E-14  7.86773E-16 -3.51991E-17 -1.10176E-11
            1.94025E-14  1.54886E-16  6.99979E-18  2.64854E-10  1.45134E-15
           -4.14456E-17  5.94491E-12  7.41861E-12  2.30081E-15  4.04871E-15


PARAMETER SUMMARY


PHYSICAL PARAMETER VALUES --- NONE OF THE PARAMETERS IS LOG TRANSFORMED

PARAMETER:        HK1        HK2        HK3        HK4        VKA12_1
* = LOG TRNS:


UPPER 95% C.I.     1.00E+00   1.00E-02   1.00E-04   1.01E-06   2.52E-01
FINAL VALUES       1.00E+00   1.00E-02   9.99E-05   1.00E-06   2.50E-01
LOWER 95% C.I.     9.99E-01   9.99E-03   9.99E-05   9.91E-07   2.47E-01

STD. DEV.          3.22E-04   1.43E-06   2.16E-08   5.03E-09   1.20E-03

COEF. OF VAR. (STD. DEV. / FINAL VALUE); "--" IF FINAL VALUE = 0.0
                   3.22E-04   1.43E-04   2.16E-04   5.02E-03   4.79E-03

    REASONABLE
   UPPER LIMIT    -8.00E-01   2.00E-07   1.00E-07   1.20E-02   1.30E-02
    REASONABLE
   LOWER LIMIT    -1.40E+00   2.00E-09   1.00E-09   1.20E-04   1.30E-04

ESTIMATE ABOVE (1)
BELOW(-1)LIMITS        1          1          1         -1          1
ENTIRE CONF. INT.
ABOVE(1)BELOW(-1)      1          1          1         -1          1


PHYSICAL PARAMETER VALUES --- NONE OF THE PARAMETERS IS LOG TRANSFORMED

PARAMETER:        VKA12_2    VKA12_3    VKA12_4    VKA3_1     VKA3_3
* = LOG TRNS:


UPPER 95% C.I.     2.50E-03   2.50E-05   2.54E-07   1.04E+00   1.00E-04
FINAL VALUES       2.50E-03   2.50E-05   2.50E-07   9.98E-01   1.00E-04
LOWER 95% C.I.     2.50E-03   2.50E-05   2.46E-07   9.61E-01   9.95E-05

STD. DEV.          5.07E-07   7.94E-09   2.12E-09   1.83E-02   2.29E-07

COEF. OF VAR. (STD. DEV. / FINAL VALUE); "--" IF FINAL VALUE = 0.0
                   2.03E-04   3.18E-04   8.48E-03   1.83E-02   2.29E-03

    REASONABLE
   UPPER LIMIT     1.30E-02   1.30E-02   1.30E-02   3.00E-03   3.00E-03
    REASONABLE
   LOWER LIMIT     1.30E-04   1.30E-04   1.30E-04   3.00E-05   3.00E-05

ESTIMATE ABOVE (1)
BELOW(-1)LIMITS        0         -1         -1          1          0
ENTIRE CONF. INT.
ABOVE(1)BELOW(-1)      0         -1         -1          1          0


PHYSICAL PARAMETER VALUES --- NONE OF THE PARAMETERS IS LOG TRANSFORMED

PARAMETER:        VKA3_4     DRAIN      GHB        RCH        ETM
* = LOG TRNS:
```

```
UPPER 95% C.I.     1.01E-06   1.00E+00   1.00E+00   3.10E-04   4.00E-04
FINAL VALUES       1.00E-06   9.99E-01   1.00E+00   3.10E-04   4.00E-04
LOWER 95% C.I.     9.91E-07   9.99E-01   9.99E-01   3.10E-04   4.00E-04

STD. DEV.          5.05E-09   1.59E-04   1.58E-04   4.18E-08   6.36E-08

COEF. OF VAR. (STD. DEV. / FINAL VALUE); "--" IF FINAL VALUE = 0.0
                   5.05E-03   1.59E-04   1.58E-04   1.35E-04   1.59E-04

    REASONABLE
   UPPER LIMIT     3.00E-03   1.00E-06   2.00E-03   4.00E-04   4.00E-04
    REASONABLE
   LOWER LIMIT     3.00E-05   1.00E-08   2.00E-05   4.00E-06   4.00E-06

ESTIMATE ABOVE (1)
BELOW(-1)LIMITS       -1          1          1          0          0
ENTIRE CONF. INT.
ABOVE(1)BELOW(-1)     -1          1          1          0          0

SOME PARAMETER VALUES ARE OUTSIDE THEIR USER-SPECIFIED REASONABLE
RANGES TO A STATISTICALLY SIGNIFICANT EXTENT, BASED ON LINEAR THEORY.
THIS IMPLIES THAT THERE ARE PROBLEMS WITH THE OBSERVATIONS, THE MODEL
DOES NOT ADEQUATELY REPRESENT THE PHYSICAL SYSTEM, THE DATA ARE NOT
CONSISTENT WITH THEIR SIMULATED EQUIVALENTS, OR THE SPECIFIED MINIMUM
AND/OR MAXIMUM ARE NOT REASONABLE.  CHECK YOUR DATA, CONCEPTUAL MODEL,
AND MODEL DESIGN.


         -------------------------------------
         CORRELATION MATRIX FOR THE PARAMETERS
         -------------------------------------

            HK1          HK2          HK3          HK4          VKA12_1
            VKA12_2      VKA12_3      VKA12_4      VKA3_1       VKA3_3
            VKA3_4       DRAIN        GHB          RCH          ETM
...........................................................................
HK1          1.0000      0.22246      0.15341     -0.11857     -0.35153
            0.61164      0.16115      0.26105     -0.26918     -2.61619E-02
           -0.14814      0.32714      0.40661      0.36176      0.47668
HK2         0.22246       1.0000      0.61141      7.22077E-02  9.34480E-02
            0.59725      0.33372     -2.56484E-02  8.77822E-02  0.11713
            7.78131E-02  0.62809      0.84567      0.96971      0.84443
HK3         0.15341      0.61141       1.0000     -0.49267      6.97049E-02
            0.52174      0.16536      2.66809E-02  4.07941E-02  0.12982
           -0.43422      0.42811      0.21474      0.63095      0.57293
HK4        -0.11857      7.22077E-02 -0.49267       1.0000      0.40784
            6.03904E-02  0.38075     -0.16030     -0.36520     -0.35425
            0.98591      4.24749E-03  0.20845      5.73295E-02 -0.11007
VKA12_1    -0.35153      9.34480E-02  6.97049E-02  0.40784       1.0000
            0.21808      3.08522E-02 -0.13273     -0.68956     -5.40236E-02
            0.49347      5.28870E-02 -4.35918E-02  0.10647     -0.14465
VKA12_2     0.61164      0.59725      0.52174      6.03904E-02  0.21808
             1.0000      0.25759      9.19902E-02 -0.47550      1.07929E-02
            9.87652E-02  0.60724      0.44995      0.75111      0.60199
VKA12_3     0.16115      0.33372      0.16536      0.38075      3.08522E-02
            0.25759       1.0000     -9.63761E-02 -2.78760E-02 -0.40637
            0.33214      0.20226      0.25910      0.33979      0.30663
VKA12_4     0.26105     -2.56484E-02  2.66809E-02 -0.16030     -0.13273
            9.19902E-02 -9.63761E-02   1.0000     -5.10936E-02  9.63958E-02
           -0.17214     -1.14432E-02  4.80117E-02  1.55747E-02  5.19048E-02
VKA3_1     -0.26918      8.77822E-02  4.07941E-02 -0.36520     -0.68956
           -0.47550     -2.78760E-02 -5.10936E-02   1.0000      0.12456
           -0.43878     -5.38426E-02  4.07915E-02 -2.83287E-02  0.22788
VKA3_3     -2.61619E-02  0.11713      0.12982     -0.35425     -5.40236E-02
            1.07929E-02 -0.40637      9.63958E-02  0.12456       1.0000
           -0.37337      7.62817E-02  0.10382      0.10538      9.96203E-02
VKA3_4     -0.14814      7.78131E-02 -0.43422      0.98591      0.49347
            9.87652E-02  0.33214     -0.17214     -0.43878     -0.37337
             1.0000      1.34312E-02  0.18046      6.84246E-02 -0.12890
DRAIN       0.32714      0.62809      0.42811      4.24749E-03  5.28870E-02
            0.60724      0.20226     -1.14432E-02 -5.38426E-02  7.62817E-02
            1.34312E-02   1.0000      0.54269      0.74126      0.58857
GHB         0.40661      0.84567      0.21474      0.20845     -4.35918E-02
            0.44995      0.25910      4.80117E-02  4.07915E-02  0.10382
            0.18046      0.54269       1.0000      0.82069      0.73830
RCH         0.36176      0.96971      0.63095      5.73295E-02  0.10647
            0.75111      0.33979      1.55747E-02 -2.83287E-02  0.10538
            6.84246E-02  0.74126      0.82069       1.0000      0.86595
ETM         0.47668      0.84443      0.57293     -0.11007     -0.14465
            0.60199      0.30663      5.19048E-02  0.22788      9.96203E-02
```

```
           -0.12890      0.58857      0.73830      0.86595       1.0000

THE CORRELATION OF THE FOLLOWING PARAMETER PAIRS >= .95
    PARAMETER   PARAMETER   CORRELATION
    HK2         RCH             0.97
    HK4         VKA3_4          0.99

THE CORRELATION OF THE FOLLOWING PARAMETER PAIRS IS BETWEEN .90 AND .95
    PARAMETER   PARAMETER   CORRELATION

THE CORRELATION OF THE FOLLOWING PARAMETER PAIRS IS BETWEEN .85 AND .90
    PARAMETER   PARAMETER   CORRELATION
    RCH         ETM             0.87

CORRELATIONS GREATER THAN 0.95 COULD INDICATE THAT THERE IS NOT ENOUGH
INFORMATION IN THE OBSERVATIONS AND PRIOR USED IN THE REGRESSION TO ESTIMATE
PARAMETER VALUES INDIVIDUALLY.
TO CHECK THIS, START THE REGRESSION FROM SETS OF INITIAL PARAMETER VALUES
THAT DIFFER BY MORE THAT TWO STANDARD DEVIATIONS FROM THE ESTIMATED
VALUES.  IF THE RESULTING ESTIMATES ARE WELL WITHIN ONE STANDARD DEVIATION
OF THE PREVIOUSLY ESTIMATED VALUE, THE ESTIMATES ARE PROBABLY
DETERMINED INDEPENDENTLY WITH THE OBSERVATIONS AND PRIOR USED IN
THE REGRESSION.  OTHERWISE, YOU MAY ONLY BE ESTIMATING THE RATIO
OR SUM OF THE HIGHLY CORRELATED PARAMETERS.
THE INITIAL PARAMETER VALUES ARE IN THE SEN FILE.


 LEAST-SQUARES OBJ FUNC (DEP.VAR. ONLY)- = 0.70643E-04
 LEAST-SQUARES OBJ FUNC (W/PARAMETERS)-- = 0.70643E-04
 CALCULATED ERROR VARIANCE-------------- = 0.19093E-05
 STANDARD ERROR OF THE REGRESSION------- = 0.13818E-02
 CORRELATION COEFFICIENT---------------- =  1.0000
      W/PARAMETERS---------------------- =  1.0000
 ITERATIONS----------------------------- =       8

 MAX LIKE OBJ FUNC =  311.04
 AIC STATISTIC---- =  341.04
 BIC STATISTIC---- =  370.31

ORDERED DEPENDENT-VARIABLE WEIGHTED RESIDUALS
NUMBER OF RESIDUALS INCLUDED:        52
   -0.291E-02 -0.260E-02 -0.135E-02 -0.132E-02 -0.117E-02 -0.512E-03 -0.313E-03
   -0.269E-03 -0.244E-03 -0.232E-03 -0.146E-03 -0.146E-03 -0.146E-03 -0.122E-03
   -0.116E-03 -0.977E-04 -0.732E-04 -0.732E-04 -0.732E-04 -0.610E-04 -0.488E-04
     0.00       0.00       0.00      0.122E-04  0.244E-04  0.244E-04  0.244E-04
    0.244E-04  0.732E-04  0.732E-04  0.854E-04  0.916E-04  0.977E-04  0.122E-03
    0.122E-03  0.122E-03  0.146E-03  0.146E-03  0.159E-03  0.195E-03  0.250E-03
    0.256E-03  0.262E-03  0.269E-03  0.366E-03  0.415E-03  0.483E-03  0.488E-03
    0.707E-03  0.795E-03  0.689E-02

SMALLEST AND LARGEST DEPENDENT-VARIABLE WEIGHTED RESIDUALS

    SMALLEST WEIGHTED RESIDUALS                LARGEST WEIGHTED RESIDUALS
       OBSERVATION     WEIGHTED                   OBSERVATION     WEIGHTED
 OBS#     NAME         RESIDUAL             OBS#     NAME         RESIDUAL
   50  GHB3          -0.29115E-02             45  DRN1           0.68890E-02
   48  GHB1          -0.25987E-02             52  GHB5           0.79482E-03
   46  DRN1          -0.13482E-02             49  GHB2           0.70749E-03
   25  WL10          -0.13184E-02             31  WL12           0.48828E-03
   43  DRN1          -0.11661E-02             51  GHB4           0.48281E-03

CORRELATION BETWEEN ORDERED WEIGHTED RESIDUALS AND
NORMAL ORDER STATISTICS (EQ.38 OF TEXT) =    0.512

--------------------------------------------------------------------------
COMMENTS ON THE INTERPRETATION OF THE CORRELATION BETWEEN
WEIGHTED RESIDUALS AND NORMAL ORDER STATISTICS:

The critical value for correlation at the 5% significance level is 0.956

IF the reported CORRELATION is GREATER than the 5% critical value, ACCEPT
the hypothesis that the weighted residuals are INDEPENDENT AND NORMALLY
DISTRIBUTED at the 5% significance level.  The probability that this
conclusion is wrong is less than 5%.

IF the reported correlation IS LESS THAN the 5% critical value REJECT the,
hypothesis that the weighted residuals are INDEPENDENT AND NORMALLY
DISTRIBUTED at the 5% significance level.

The analysis can also be done using the 10% significance level.
The associated critical value is 0.964
```

```
 --------------------------------------------------------------------------

 *** PARAMETER ESTIMATION CONVERGED BY SATISFYING THE TOL CRITERION ***
```

LIST Output File

An example of the excerpted LIST output file for Test Case 2, Variant 4 is shown below. The HUF Package output appears in bold, and three dots (…) indicates omitted output.

```
                                  MODFLOW-2000
      U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
                            VERSION 1.0.2 08/21/2000


 This model run produced both GLOBAL and LIST files.  This is the LIST file.


 THIS FILE CONTAINS OUTPUT UNIQUE TO FINAL PARAMETER VALUES
   --REGRESSION HAS CONVERGED
 SENSITIVITIES ARE CALCULATED USING PREVIOUS SET OF PARAMETER VALUES

 CURRENT VALUES OF PARAMETERS LISTED IN THE SEN FILE:

 PARAMETER   PARAMETER   PARAMETER    FOOT-
    NAME        TYPE       VALUE      NOTE
 ----------  ---------  ------------  -----
 HK1            HK      0.99961         *
 HK2            HK      9.99594E-03     *
 HK3            HK      9.99499E-05     *
 HK4            HK      1.00120E-06     *
 VKA12_1        VK      0.24987         *
 VKA12_2        VK      2.49876E-03     *
 VKA12_3        VK      2.49898E-05     *
 VKA12_4        VK      2.49959E-07     *
 VKA3_1         VK      0.99809         *
 VKA3_3         VK      9.99589E-05     *
 VKA3_4         VK      1.00102E-06     *
 DRAIN          DRN     0.99942         *
 GHB            GHB     0.99965         *
 RCH            RCH     3.09867E-04     *
 ETM            EVT     3.99829E-04     *
 ------------------------------------------
 * INDICATES VALUE ADJUSTABLE BY PARAMETER-
   ESTIMATION PROCESS


 REWOUND tc2var4.lst
 FILE TYPE:LIST   UNIT   2

 REWOUND ..\common\tc2.bas
 FILE TYPE:BAS6   UNIT   8

 REWOUND ..\common\tc2.dis
 FILE TYPE:DIS   UNIT   9

 REWOUND ..\common\tc2.wel
 FILE TYPE:WEL   UNIT  12

 REWOUND ..\common\tc2.drn
 FILE TYPE:DRN   UNIT  13

 REWOUND ..\common\tc2.evt
 FILE TYPE:EVT   UNIT  15

 REWOUND ..\common\tc2.ghb
 FILE TYPE:GHB   UNIT  17

 REWOUND ..\common\tc2.rch
 FILE TYPE:RCH   UNIT  18

 REWOUND ..\common\tc2.oc
 FILE TYPE:OC   UNIT  22

 REWOUND ..\common\tc2.obs
 FILE TYPE:OBS   UNIT  37

 REWOUND ..\common\tc2.zon
```

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 FILE TYPE:ZONE   UNIT  39

 REWOUND ..\common\tc2.hob
 FILE TYPE:HOB   UNIT  40

 REWOUND ..\common\tc2.odr
 FILE TYPE:DROB   UNIT  41

 REWOUND ..\common\tc2.ogb
 FILE TYPE:GBOB   UNIT  42

 REWOUND ..\common\tc2.b
 FILE TYPE:DATA   UNIT  48

 REWOUND ..\common\tc2.bin
 FILE TYPE:DATA(BINARY)   UNIT  49

 # MODFLOW-2000 SIMULATION OF DEATH VALLEY TEST CASE 1
 # test case ymptc
 THE FREE FORMAT OPTION HAS BEEN SELECTED
    3 LAYERS        18 ROWS        18 COLUMNS
   1 STRESS PERIOD(S) IN SIMULATION

 BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT  8
         15 ELEMENTS IN IR ARRAY ARE USED BY BAS

 WEL6 -- WELL PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 12
 No named parameters
 MAXIMUM OF    3 ACTIVE WELLS AT ONE TIME
         12 ELEMENTS IN RX ARRAY ARE USED BY WEL

 DRN6 -- DRAIN PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 13
     1 Named Parameters         5 List entries
 MAXIMUM OF    5 ACTIVE DRAINs AT ONE TIME
         50 ELEMENTS IN RX ARRAY ARE USED BY DRN

 EVT6 -- EVAPOTRANSPIRATION PACKAGE, VERSION 6, 1/11/2000
         INPUT READ FROM UNIT 15
     1 Named Parameters
 OPTION 1 -- EVAPOTRANSPIRATION FROM TOP LAYER
        972 ELEMENTS IN RX ARRAY ARE USED BY EVT
        324 ELEMENTS IN IR ARRAY ARE USED BY EVT

 GHB6 -- GHB PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 17
     1 Named Parameters         5 List entries
 MAXIMUM OF    5 ACTIVE GHB CELLS AT ONE TIME
         50 ELEMENTS IN RX ARRAY ARE USED BY GHB

 RCH6 -- RECHARGE PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 18
     1 Named Parameters
 OPTION 1 -- RECHARGE TO TOP LAYER
        324 ELEMENTS IN RX ARRAY ARE USED BY RCH
        324 ELEMENTS IN IR ARRAY ARE USED BY RCH

       1408  ELEMENTS OF RX ARRAY USED OUT OF       1408
        663  ELEMENTS OF IR ARRAY USED OUT OF        663
1
 # MODFLOW-2000 SIMULATION OF DEATH VALLEY TEST CASE 1
 # test case ymptc



                     BOUNDARY ARRAY FOR LAYER   1
 READING ON UNIT   8 WITH FORMAT: (18I3)



                     BOUNDARY ARRAY FOR LAYER   2
 READING ON UNIT   8 WITH FORMAT: (18I3)



                     BOUNDARY ARRAY FOR LAYER   3
 READING ON UNIT   8 WITH FORMAT: (18I3)

 AQUIFER HEAD WILL BE SET TO  9999.0     AT ALL NO-FLOW NODES (IBOUND=0).



                       INITIAL HEAD FOR LAYER   1
 READING ON UNIT   8 WITH FORMAT: (18F10.2)
```

```
                      INITIAL HEAD FOR LAYER   2
 READING ON UNIT   8 WITH FORMAT: (18F10.2)



                      INITIAL HEAD FOR LAYER   3
 READING ON UNIT   8 WITH FORMAT: (18F10.2)

 OUTPUT CONTROL IS SPECIFIED EVERY TIME STEP
 HEAD PRINT FORMAT CODE IS  20    DRAWDOWN PRINT FORMAT CODE IS   0
 HEADS WILL BE SAVED ON UNIT  49    DRAWDOWNS WILL BE SAVED ON UNIT   0


   HYD. COND. ALONG ROWS FOR UNIT HGU2


              HYD. COND. ALONG ROWS

           1           2           3           4           5           6
           7           8           9          10          11          12
          13          14          15          16          17          18
 .........................................................................
  1   9.9959E-03  9.9950E-05  9.9959E-03  0.9996      0.9996      0.9996
      9.9959E-03  9.9959E-03  0.9996      0.9996      0.9996       0.000
       0.000       0.000       0.000       0.000       0.000       0.000
  2   9.9959E-03  9.9950E-05  9.9959E-03  0.9996      0.9996      0.9996
      9.9959E-03  9.9959E-03  9.9959E-03  0.9996      0.9996      0.9996
       0.000       0.000       0.000       0.000       0.000       0.000
  3   9.9959E-03  9.9950E-05  9.9959E-03  9.9959E-03  0.9996      9.9959E-03
      9.9959E-03  9.9950E-05  9.9959E-03  0.9996      0.9996      0.9996
      0.9996       0.000       0.000       0.000       0.000       0.000
  4   9.9959E-03  9.9950E-05  9.9950E-05  9.9959E-03  9.9959E-03  9.9959E-03
      9.9950E-05  9.9950E-05  9.9959E-03  9.9959E-03  9.9959E-03  0.9996
      0.9996      0.9996       0.000       0.000       0.000       0.000
  5   9.9959E-03  9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05
      9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9959E-03  0.9996
      0.9996      0.9996      0.9996       0.000       0.000       0.000
  6   9.9959E-03  9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9959E-03
      9.9959E-03  9.9959E-03  9.9950E-05  9.9950E-05  9.9959E-03  0.9996
      0.9996      0.9996      0.9996      0.9996       0.000       0.000
  7   9.9959E-03  9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9959E-03
      0.9996      9.9959E-03  9.9950E-05  9.9950E-05  9.9959E-03  9.9959E-03
      9.9959E-03  0.9996      0.9996      0.9996      0.9996       0.000
  8   9.9959E-03  9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9959E-03
      0.9996      9.9959E-03  9.9950E-05  9.9950E-05  9.9959E-03  9.9959E-03
      9.9959E-03  0.9996      0.9996      0.9996      0.9996      9.9959E-03
  9   9.9959E-03  9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9959E-03
      9.9959E-03  9.9959E-03  9.9950E-05  9.9950E-05  9.9959E-03  0.9996
      9.9959E-03  0.9996      0.9996      0.9996      9.9959E-03  9.9959E-03
 10   9.9959E-03  9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05
      9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9959E-03  0.9996
      9.9959E-03  9.9959E-03  0.9996      9.9959E-03  9.9959E-03  9.9959E-03
 11   9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05
      9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9959E-03  0.9996
      9.9959E-03  9.9959E-03  0.9996      9.9959E-03  9.9959E-03  9.9959E-03
 12    0.000       0.000       0.000       0.000      9.9950E-05  9.9950E-05
      9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9959E-03  0.9996
      9.9959E-03  9.9959E-03  9.9959E-03  9.9959E-03  9.9959E-03  9.9959E-03
 13    0.000       0.000       0.000       0.000       0.000      9.9950E-05
      9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9959E-03  9.9959E-03
      9.9959E-03  9.9959E-03  9.9959E-03  9.9959E-03  9.9959E-03  0.9996
 14    0.000       0.000       0.000       0.000       0.000       0.000
      9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05  9.9950E-05
      9.9950E-05  9.9959E-03  9.9959E-03  9.9959E-03  0.9996      9.9959E-03
 15    0.000       0.000       0.000       0.000       0.000       0.000
       0.000      9.9959E-03  9.9959E-03  9.9959E-03  9.9950E-05  9.9950E-05
      9.9950E-05  9.9950E-05  9.9959E-03  9.9959E-03  0.9996      9.9959E-03
 16    0.000       0.000       0.000       0.000       0.000       0.000
       0.000       0.000      0.9996      9.9959E-03  9.9950E-05  9.9950E-05
      9.9950E-05  9.9950E-05  9.9950E-05  9.9959E-03  0.9996      9.9959E-03
 17    0.000       0.000       0.000       0.000       0.000       0.000
       0.000       0.000       0.000      9.9959E-03  9.9950E-05  9.9950E-05
      9.9950E-05  9.9950E-05  9.9950E-05  9.9959E-03  9.9959E-03  9.9959E-03
 18    0.000       0.000       0.000       0.000       0.000       0.000
       0.000       0.000       0.000       0.000      9.9950E-05  9.9950E-05
      9.9950E-05  9.9950E-05  9.9950E-05  9.9959E-03  9.9959E-03  9.9959E-03
```

```
 HORIZ. ANI. (COL./ROW) FOR UNIT HGU2

  HORIZ. ANI. (COL./ROW) =   1.00000


    VERTICAL HYD. COND. FOR UNIT HGU2


               VERTICAL HYD. COND.

           1           2           3           4           5           6
           7           8           9          10          11          12
          13          14          15          16          17          18
........................................................................
  1   2.4988E-03  2.4990E-05  2.4988E-03  0.2499      0.2499      0.2499
      2.4988E-03  2.4988E-03  0.2499      0.2499      0.2499       0.000
       0.000       0.000       0.000       0.000       0.000       0.000
  2   2.4988E-03  2.4990E-05  2.4988E-03  0.2499      0.2499      0.2499
      2.4988E-03  2.4988E-03  2.4988E-03  0.2499      0.2499      0.2499
       0.000       0.000       0.000       0.000       0.000       0.000
  3   2.4988E-03  2.4990E-05  2.4988E-03  2.4988E-03  0.2499      2.4988E-03
      2.4988E-03  2.4990E-05  2.4988E-03  0.2499      0.2499      0.2499
      0.2499       0.000       0.000       0.000       0.000       0.000
  4   2.4988E-03  2.4990E-05  2.4990E-05  2.4988E-03  2.4988E-03  2.4988E-03
      2.4990E-05  2.4990E-05  2.4988E-03  2.4988E-03  2.4988E-03  0.2499
      0.2499      0.2499       0.000       0.000       0.000       0.000
  5   2.4988E-03  2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05
      2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4988E-03  0.2499
      0.2499      0.2499      0.2499       0.000       0.000       0.000
  6   2.4988E-03  2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4988E-03
      2.4988E-03  2.4988E-03  2.4990E-05  2.4990E-05  2.4988E-03  0.2499
      0.2499      0.2499      0.2499      0.2499       0.000       0.000
  7   2.4988E-03  2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4988E-03
      0.2499      2.4988E-03  2.4990E-05  2.4990E-05  2.4988E-03  2.4988E-03
      2.4988E-03  0.2499      0.2499      0.2499      0.2499       0.000
  8   2.4988E-03  2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4988E-03
      0.2499      2.4988E-03  2.4990E-05  2.4990E-05  2.4988E-03  2.4988E-03
      2.4988E-03  0.2499      0.2499      0.2499      0.2499      2.4988E-03
  9   2.4988E-03  2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4988E-03
      2.4988E-03  2.4988E-03  2.4990E-05  2.4990E-05  2.4988E-03  0.2499
      2.4988E-03  0.2499      0.2499      0.2499      2.4988E-03  2.4988E-03
 10   2.4988E-03  2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05
      2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4988E-03  0.2499
      2.4988E-03  2.4988E-03  0.2499      2.4988E-03  2.4988E-03  2.4988E-03
 11   2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05
      2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4988E-03  0.2499
      2.4988E-03  2.4988E-03  0.2499      2.4988E-03  2.4988E-03  2.4988E-03
 12    0.000       0.000       0.000       0.000      2.4990E-05  2.4990E-05
      2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4988E-03  0.2499
      2.4988E-03  2.4988E-03  2.4988E-03  2.4988E-03  2.4988E-03  2.4988E-03
 13    0.000       0.000       0.000       0.000       0.000      2.4990E-05
      2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4988E-03  2.4988E-03
      2.4988E-03  2.4988E-03  2.4988E-03  2.4988E-03  2.4988E-03  0.2499
 14    0.000       0.000       0.000       0.000       0.000       0.000
      2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05  2.4990E-05
      2.4990E-05  2.4988E-03  2.4988E-03  2.4988E-03  0.2499      2.4988E-03
 15    0.000       0.000       0.000       0.000       0.000       0.000
       0.000      2.4988E-03  2.4988E-03  2.4988E-03  2.4990E-05  2.4990E-05
      2.4990E-05  2.4990E-05  2.4988E-03  2.4988E-03  0.2499      2.4988E-03
 16    0.000       0.000       0.000       0.000       0.000       0.000
       0.000       0.000      0.2499      2.4988E-03  2.4990E-05  2.4990E-05
      2.4990E-05  2.4990E-05  2.4990E-05  2.4988E-03  0.2499      2.4988E-03
 17    0.000       0.000       0.000       0.000       0.000       0.000
       0.000       0.000       0.000      2.4988E-03  2.4990E-05  2.4990E-05
      2.4990E-05  2.4990E-05  2.4990E-05  2.4988E-03  2.4988E-03  2.4988E-03
 18    0.000       0.000       0.000       0.000       0.000       0.000
       0.000       0.000       0.000       0.000      2.4990E-05  2.4990E-05
      2.4990E-05  2.4990E-05  2.4990E-05  2.4988E-03  2.4988E-03  2.4988E-03
1
                           STRESS PERIOD NO.   1, LENGTH =   86400.00
                           ----------------------------------------------

                             NUMBER OF TIME STEPS =     1

                              MULTIPLIER FOR DELT =     1.000

                           INITIAL TIME STEP SIZE =   86400.00

WELL NO.  LAYER   ROW   COL   STRESS RATE
--------------------------------------------
     1      1      9      7      -100.0
```

```
      2      1      8     16      -200.0
      3      1     11     13      -150.0

    3 WELLS

 Parameter:  DRAIN
 DRAIN NO.  LAYER   ROW   COL     DRAIN EL.  CONDUCTANCE
 ----------------------------------------------------------
      1      1      7      6       400.0          0.9994
      2      1     10     11       550.0          0.9994
      3      1     14     14       1200.          0.9994
      4      1     15     14       1200.          0.9994
      5      1     16     14       1200.          0.9994

    5 DRAINS

              ET SURFACE =   1000.00


 EVTR array defined by the following parameters:
  Parameter:  ETM


           EVAPOTRANSPIRATION RATE

...

        EXTINCTION DEPTH =   950.000

 Parameter:  GHB
 BOUND. NO. LAYER   ROW   COL     STAGE      CONDUCTANCE
 ----------------------------------------------------------
      1      1      3      6       350.0          0.9996
      2      1      3     11       500.0          0.9996
      3      1      4     11       500.0          0.9996
      4      1      5     11       500.0          0.9996
      5      1     12      9       1000.          0.9996

    5 GHB CELLS



 RECH array defined by the following parameters:
  Parameter:  RCH


                          RECHARGE

...

 SOLVING FOR HEAD


   31 CALLS TO PCG ROUTINE FOR TIME STEP   1 IN STRESS PERIOD  1
  237 TOTAL ITERATIONS

 MAXIMUM HEAD CHANGE FOR LAST ITER1 ITERATIONS
 (1 INDICATES THE FIRST INNER ITERATION):

   HEAD CHANGE    HEAD CHANGE    HEAD CHANGE    HEAD CHANGE    HEAD CHANGE
  LAYER,ROW,COL  LAYER,ROW,COL  LAYER,ROW,COL  LAYER,ROW,COL  LAYER,ROW,COL
 ---------------------------------------------------------------------------
  0  0.4549E-03  0  0.2154E-03  0  0.1476E-02  1 -0.1075E-02  0 -0.3808E-03
   (  3,  2,  7)  (  3,  2,  7)  (  3,  2,  7)  (  3,  2,  7)  (  3,  2,  7)
  0 -0.4910E-03  0 -0.7622E-04  1  0.5274E-04
   (  3,  2,  7)  (  3,  8, 14)  (  3,  2,  7)

 MAXIMUM RESIDUAL FOR LAST ITER1 ITERATIONS
 (1 INDICATES THE FIRST INNER ITERATION):

   RESIDUAL       RESIDUAL       RESIDUAL       RESIDUAL       RESIDUAL
  LAYER,ROW,COL  LAYER,ROW,COL  LAYER,ROW,COL  LAYER,ROW,COL  LAYER,ROW,COL
 ---------------------------------------------------------------------------
  0  0.5231E-01  0  0.5100E-01  0 -0.4193E-01  1  0.4077E-01  0  0.4023E-01
   (  3,  8, 17)  (  3,  8, 17)  (  3,  7,  8)  (  3,  8, 17)  (  3,  8, 17)
  0  0.3917E-01  0  0.3853E-01  1  0.3845E-01
   (  3,  8, 17)  (  3,  8, 17)  (  3,  8, 17)
```

```
 HEAD/DRAWDOWN PRINTOUT FLAG = 1     TOTAL BUDGET PRINTOUT FLAG = 1
 CELL-BY-CELL FLOW TERM FLAG = 0

 OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:
   HEAD    DRAWDOWN  HEAD  DRAWDOWN
 PRINTOUT  PRINTOUT  SAVE    SAVE
 ----------------------------------
     1         0       1       0
1
              HEAD IN LAYER  1 AT END OF TIME STEP  1 IN STRESS PERIOD  1
  -----------------------------------------------------------------------

...

1
              HEAD IN LAYER  2 AT END OF TIME STEP  1 IN STRESS PERIOD  1
  -----------------------------------------------------------------------

...

1
              HEAD IN LAYER  3 AT END OF TIME STEP  1 IN STRESS PERIOD  1
  -----------------------------------------------------------------------

...

 HEAD WILL BE SAVED ON UNIT  49 AT END OF TIME STEP  1, STRESS PERIOD  1
1
  VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD  1
  -----------------------------------------------------------------------------

     CUMULATIVE VOLUMES      L**3       RATES FOR THIS TIME STEP      L**3/T
     ------------------                 ------------------------

           IN:                                      IN:
           ---                                      ---
             STORAGE =            0.0000              STORAGE =            0.0000
       CONSTANT HEAD =    500247744.0000        CONSTANT HEAD =         5789.9043
               WELLS =            0.0000                WELLS =            0.0000
              DRAINS =            0.0000               DRAINS =            0.0000
                  ET =            0.0000                   ET =            0.0000
     HEAD DEP BOUNDS =            0.0000      HEAD DEP BOUNDS =            0.0000
            RECHARGE =   1144523264.0000             RECHARGE =        13246.7969

            TOTAL IN =   1644771072.0000             TOTAL IN =        19036.7012

          OUT:                                     OUT:
          ----                                     ----
             STORAGE =            0.0000              STORAGE =            0.0000
       CONSTANT HEAD =    367566688.0000        CONSTANT HEAD =         4254.2441
               WELLS =     38880000.0000                WELLS =          450.0000
              DRAINS =    131773312.0000               DRAINS =         1525.1541
                  ET =    878034688.0000                   ET =        10162.4385
     HEAD DEP BOUNDS =    228519264.0000      HEAD DEP BOUNDS =         2644.8989
            RECHARGE =            0.0000             RECHARGE =            0.0000

           TOTAL OUT =   1644774016.0000            TOTAL OUT =        19036.7344

            IN - OUT =        -2944.0000             IN - OUT =       -3.3203E-02

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00




          TIME SUMMARY AT END OF TIME STEP  1 IN STRESS PERIOD  1
                    SECONDS     MINUTES      HOURS       DAYS        YEARS
                    -----------------------------------------------------------
   TIME STEP LENGTH 7.46496E+09 1.24416E+08 2.07360E+06  86400.      236.55
 STRESS PERIOD TIME 7.46496E+09 1.24416E+08 2.07360E+06  86400.      236.55
         TOTAL TIME 7.46496E+09 1.24416E+08 2.07360E+06  86400.      236.55
1

 DATA AT HEAD LOCATIONS

       OBSERVATION      MEAS.       CALC.                             WEIGHTED
  OBS#    NAME          HEAD        HEAD      RESIDUAL  WEIGHT**.5   RESIDUAL

     1 W2L              979.029     979.029   0.427E-03   0.200       0.854E-04
```

```
    2 WL2             1015.113    1015.112   0.488E-03   0.200       0.977E-04
    3 WL2             1186.494    1186.494     0.00       0.200        0.00
    4 WL4              291.694     291.695  -0.580E-03   0.200      -0.116E-03
    5 WL4              964.356     964.355   0.128E-02   0.200       0.256E-03
    6 WL4             1176.542    1176.543  -0.732E-03   0.200      -0.146E-03
    7 WL4             1192.363    1192.363     0.00       0.200        0.00
    8 WL5              760.721     760.720   0.134E-02   0.200       0.269E-03
    9 WL6              188.804     188.805  -0.732E-03   0.200      -0.146E-03
   10 WL6              892.570     892.571  -0.122E-02   0.200      -0.244E-03
   11 WL6              906.942     906.941   0.732E-03   0.200       0.146E-03
   12 WL6             1201.148    1201.148   0.122E-03   0.200       0.244E-04
   13 WL6             1197.885    1197.885  -0.244E-03   0.200      -0.488E-04
   14 WL6             1198.344    1198.344  -0.366E-03   0.200      -0.732E-04
   15 WL8              209.993     209.992   0.125E-02   0.200       0.250E-03
   16 WL8              642.477     642.476   0.793E-03   0.200       0.159E-03
   17 WL8             1014.458    1014.458   0.610E-04   0.200       0.122E-04
   18 WL8             1233.051    1233.051   0.122E-03   0.200       0.244E-04
   19 WL8             1256.783    1256.784  -0.610E-03   0.200      -0.122E-03
   20 WL8             1200.920    1200.921  -0.732E-03   0.200      -0.146E-03
   21 WL9              444.975     444.975   0.458E-03   0.200       0.916E-04
   22 WL10             635.429     635.429  -0.305E-03   0.200      -0.610E-04
   23 WL10             941.034     941.035  -0.116E-02   0.200      -0.232E-03
   24 WL10            1107.806    1107.807  -0.488E-03   0.200      -0.977E-04
   25 WL10            1395.352    1395.359  -0.659E-02   0.200      -0.132E-02
   26 WL10            1276.801    1276.800   0.610E-03   0.200       0.122E-03
   27 WL10            1159.089    1159.089  -0.366E-03   0.200      -0.732E-04
   28 WL11             336.394     336.393   0.131E-02   0.200       0.262E-03
   29 WL12            1062.879    1062.879   0.366E-03   0.200       0.732E-04
   30 WL12            1312.104    1312.103   0.977E-03   0.200       0.195E-03
   31 WL12            1479.198    1479.196   0.244E-02   0.200       0.488E-03
   32 WL12            1218.503    1218.503   0.122E-03   0.200       0.244E-04
   33 WL13            1482.972    1482.970   0.183E-02   0.200       0.366E-03
   34 WL13            1314.911    1314.910   0.610E-03   0.200       0.122E-03
   35 WL14            1225.021    1225.021   0.122E-03   0.200       0.244E-04
   36 WL14            1404.986    1404.984   0.208E-02   0.200       0.415E-03
   37 WL14            1193.007    1193.006   0.610E-03   0.200       0.122E-03
   38 WL15            1219.002    1219.003  -0.134E-02   0.200      -0.269E-03
   39 WL16            1262.521    1262.521     0.00       0.200        0.00
   40 WL16            1197.466    1197.466   0.366E-03   0.200       0.732E-04
   41 WL18            1234.803    1234.803  -0.366E-03   0.200      -0.732E-04
   42 WL18            1194.097    1194.096   0.732E-03   0.200       0.146E-03

STATISTICS FOR HEAD RESIDUALS :
MAXIMUM WEIGHTED RESIDUAL  : 0.488E-03 OBS#     31
MINIMUM WEIGHTED RESIDUAL  :-0.132E-02 OBS#     25
AVERAGE WEIGHTED RESIDUAL  : 0.163E-04
# RESIDUALS >= 0. :     27
# RESIDUALS < 0.  :     15
NUMBER OF RUNS  :   16  IN   42 OBSERVATIONS

SUM OF SQUARED WEIGHTED RESIDUALS (HEADS ONLY)  0.30516E-05

DATA FOR FLOWS REPRESENTED USING THE DRAIN PACKAGE

      OBSERVATION      MEAS.      CALC.                            WEIGHTED
 OBS#    NAME          FLOW       FLOW     RESIDUAL  WEIGHT**.5  RESIDUAL

   43 DRN1           -522.      -522.     -0.183      0.639E-02 -0.117E-02
   44 DRN1           -845.      -845.     -0.130      0.394E-02 -0.512E-03
   45 DRN1           -133.      -133.      0.275      0.251E-01  0.689E-02
   46 DRN1           -19.0      -19.0     -0.768E-02  0.175     -0.135E-02
   47 DRN1           -6.20      -6.20     -0.581E-03  0.538     -0.313E-03

STATISTICS FOR DRAIN FLOW RESIDUALS :
MAXIMUM WEIGHTED RESIDUAL  : 0.689E-02 OBS#     45
MINIMUM WEIGHTED RESIDUAL  :-0.135E-02 OBS#     46
AVERAGE WEIGHTED RESIDUAL  : 0.710E-03
# RESIDUALS >= 0. :      1
# RESIDUALS < 0.  :      4
NUMBER OF RUNS  :    3  IN    5 OBSERVATIONS

SUM OF SQUARED WEIGHTED RESIDUALS (DRAIN FLOWS ONLY)  0.50996E-04

DATA FOR FLOWS REPRESENTED USING THE GENERAL-HEAD BOUNDARY PACKAGE

      OBSERVATION      MEAS.      CALC.                            WEIGHTED
 OBS#    NAME          FLOW       FLOW     RESIDUAL  WEIGHT**.5  RESIDUAL

   48 GHB1           -608.      -608.     -0.474      0.548E-02 -0.260E-02
   49 GHB2           -687.      -687.      0.146      0.485E-02  0.707E-03
   50 GHB3           -660.      -659.     -0.576      0.505E-02 -0.291E-02
```

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   51 GHB4           -654.      -654.      0.947E-01  0.510E-02  0.483E-03
   52 GHB5           -36.7      -36.7      0.875E-02  0.908E-01  0.795E-03

STATISTICS FOR GENERAL-HEAD BOUNDARY FLOW RESIDUALS :
MAXIMUM WEIGHTED RESIDUAL  : 0.795E-03 OBS#     52
MINIMUM WEIGHTED RESIDUAL  :-0.291E-02 OBS#     50
AVERAGE WEIGHTED RESIDUAL  :-0.705E-03
# RESIDUALS >= 0. :      3
# RESIDUALS < 0.  :      2
NUMBER OF RUNS  :    4  IN    5 OBSERVATIONS

SUM OF SQUARED WEIGHTED RESIDUALS
  (GENERAL-HEAD BOUNDARY FLOWS ONLY)  0.16595E-04

SUM OF SQUARED WEIGHTED RESIDUALS (ALL DEPENDENT VARIABLES)  0.70643E-04

STATISTICS FOR ALL RESIDUALS :
AVERAGE WEIGHTED RESIDUAL  : 0.136E-04
# RESIDUALS >= 0. :     31
# RESIDUALS < 0.  :     21
NUMBER OF RUNS  :   22  IN   52 OBSERVATIONS


INTERPRETTING THE CALCULATED RUNS STATISTIC VALUE OF     -1.03
NOTE: THE FOLLOWING APPLIES ONLY IF
       # RESIDUALS >= 0 . IS GREATER THAN 10 AND
       # RESIDUALS < 0.   IS GREATER THAN 10
THE NEGATIVE VALUE MAY INDICATE TOO FEW RUNS:
   IF THE VALUE IS LESS THAN -1.28, THERE IS LESS THAN A 10 PERCENT
      CHANCE THE VALUES ARE RANDOM,
   IF THE VALUE IS LESS THAN -1.645, THERE IS LESS THAN A 5 PERCENT
      CHANCE THE VALUES ARE RANDOM,
   IF THE VALUE IS LESS THAN -1.96, THERE IS LESS THAN A 2.5 PERCENT
      CHANCE THE VALUES ARE RANDOM.
```

APPENDIX B: SENSITIVITY PROCESS – DERIVATION OF SENSITIVITY EQUATIONS FOR THE HYDROGEOLOGIC-UNIT FLOW PACKAGE

The governing equation for the calculation of sensitivities of heads at steady state with no unconfined cells is equation 23 from Hill and others (2000):

$$\underline{A}(0)\frac{\partial \underline{h}(0)}{\partial b_l} = -\frac{\partial \underline{A}(0)}{\partial b_l}\underline{h}(0) - \frac{\partial \underline{f}(0)}{\partial b_l}, \qquad \text{(B-1)}$$

where

$\underline{h}(0)$ is a vector of hydraulic heads [L],

$\underline{A}(0)$ equals $\underline{K} + \underline{P}(0)$ [L^2/T],

$\underline{K}$ is a matrix of horizontal and vertical conductances [L^2/T],

$\underline{P}(0)$ is a diagonal matrix of conductances at head-dependent boundaries [L^2/T],

$\underline{f}(n)$ is the forcing function [L^3/T].

Underlined capital letters indicate matrices and underlined lower-case letters indicate vectors. MODFLOW-2000 calculates sensitivities by assembling the right-hand side of the equation and then solving to obtain the sensitivities. For the LPF Package, the first term on the right-hand side is non zero, and subroutine SENLPF1FM assembles the contributions. For the parameters used in the HUF Package, subroutine SENLPF1FM is replaced by SENHUF1FM.

Evaluating the derivative of matrix A, as needed in equation B-1, is accomplished by (1) taking the derivative of each term within the matrix, (2) multiplying by the correct hydraulic head, and (3) adding the result to the proper element of the vector that stores the right-hand side (RHS in MODFLOW-2000). A is a sparse, symmetric matrix, as discussed by McDonald and Harbaugh (1988), and the non-zero terms occur on the diagonal and three off diagonals on each side of the diagonal. Elements termed CC, which stands for conductance between columns, occur on the off-diagonals immediately adjacent to the diagonal. Elements termed CR, which stands for conductance between rows, occur further away from the diagonal. Elements termed CV, which stands for conductance in the vertical direction, occur farthest from the diagonal. The diagonal for each row of the matrix is a sum of the conductance term in that row and additional terms related to head-dependent boundaries. Calculation of the derivatives of the CC, CR, and CV terms and their multiplication by hydraulic head are discussed in this section.

The derivatives of the CC, CR, and CV terms are calculated sequentially for each row and column in the grid. When calculated, the proper multiplication by hydraulic head is accomplished – these include once for each of the off-diagonal locations where the conductance occurs, and once for each of the two diagonal terms involved. The conductances apply between finite-difference cells, and here the conductance between the present cell and the next cell going in a positive direction always is considered.

For cells where the saturated thickness varies, the governing equation of sensitivities is equation 26 from Hill and others (2000):

$$\underline{A}(0)\left[\frac{\partial \underline{h}(0)}{\partial b_l}\right]^r = -\frac{\partial \underline{A}(0)}{\partial b_l}\underline{h}(0) - \frac{\partial \underline{f}(0)}{\partial b_l} - \frac{\partial \underline{A}(0)}{\partial \underline{h}(0)}\left[\frac{\partial \underline{h}(0)}{\partial b_l}\right]^{r-1}\underline{h}(0). \qquad \text{(B-2)}$$

The last term on the right-hand side is assembled in subroutine SENHUF1UN and the first term is assembled in subroutine SENHUF1FM.

For transient simulations, the governing flow equation is given as:

$$\underline{A}(m)\underline{h}(m) = \underline{B}(m-1)\left(\underline{h}(m-1) - \underline{TP}\right) + \underline{B}(m)\underline{TP} - \underline{f}(m), \qquad \text{(B-3)}$$

where:

$\underline{A}(m)$	equals $\frac{-\underline{S}}{\Delta t(m)} + \underline{K} + \underline{P}(m)$ [L^2/T],
$\underline{S}$	is a diagonal matrix of specific storage multiplied by cell volume, or specific yield multiplied by cell area [L^2],
$\Delta t(m)$	is the length of time step *m* [T],
$\underline{K}$	is a matrix of horizontal and vertical conductances [L^2/T],
$\underline{P}(m)$	is a diagonal matrix of conductances at head-dependent boundaries [L^2/T],
$\underline{h}(m)$	is a vector of hydraulic heads at time step *m* [L],
$\underline{B}(m)$	equals $\frac{-\underline{S}}{\Delta t(m)}$ [L^2/T],
$\underline{TP}$	is a vector of the top elevation of each cell [L], and
$\underline{f}(m)$	is the forcing function [L^3/T].

The derivative of equation B-3 is given as:

$$\underline{A}(m)\left[\frac{\partial \underline{h}(m)}{\partial b_l}\right]^r = -\frac{\partial \underline{A}(m)}{\partial \underline{h}(m)}\left[\frac{\partial \underline{h}(m)}{\partial b_l}\right]^{r-1}\underline{h}(m) + \frac{\partial \underline{B}(m-1)}{\partial b_l}\underline{h}(m-1) + \underline{B}(m-1)\frac{\partial \underline{h}(m-1)}{\partial b_l}$$

$$-\frac{\partial \underline{B}(m-1)}{\partial b_l}\underline{TP} + \frac{\partial \underline{B}(m)}{\partial b_l}\underline{TP} - \frac{\partial \underline{A}(m)}{\partial b_l}\underline{h}(m) - \frac{\partial \underline{f}(m)}{\partial b_l}, \qquad \text{(B-4a)}$$

which differs slightly from equation 71b of Hill (1992) to account for cells which convert between confined and unconfined conditions. It is only during the transition from confined to unconfined conditions and conversely that $\underline{B}(m-1) \neq \underline{B}(m)$, otherwise the terms $-\frac{\partial \underline{B}(m-1)}{\partial b_l}\underline{TP}$ and $\frac{\partial \underline{B}(m)}{\partial b_l}\underline{TP}$ cancel each other and equation B-4 is identical to equation 71b of Hill (1992). The first term on the right-hand side is accumulated in Subroutine SENHUF1UN; the remaining terms, except the $-\frac{\partial \underline{f}(m)}{\partial b_l}$, are accumulated in Subroutine SENHUF1FM.

During the transition from confined to unconfined conditions in time step *n*, $\underline{B}(m-1)$ is only sensitive to an SS parameter and $\underline{B}(m)$ is only sensitive to an SY parameter which simplifies eq. B-4a. For an SS parameter during the transition to unconfined conditions, the following equation holds:

$$\underline{A}(m)\left[\frac{\partial \underline{h}(n)}{\partial SS}\right]^r = -\frac{\partial \underline{A}(m)}{\partial \underline{h}(m)}\left[\frac{\partial \underline{h}(m)}{\partial SS}\right]^{r-1}\underline{h}(m) + \underline{B}(m-1)\frac{\partial \underline{h}(m-1)}{\partial SS}$$

$$+\frac{\partial \underline{B}(m-1)}{\partial SS}\left(\underline{h}(m-1) - \underline{TP}\right), \qquad \text{(B-4b)}$$

and for an SY parameter, recognizing that $\frac{\partial \underline{B}(m)}{\partial SY} = \frac{\partial \underline{A}(m)}{\partial SY}$, the following equation holds:

$$\underline{A}(m)\left[\frac{\partial \underline{h}(m)}{\partial SY}\right]^r = -\frac{\partial \underline{A}(m)}{\partial \underline{h}(m)}\left[\frac{\partial \underline{h}(m)}{\partial SY}\right]^{r-1}\underline{h}(m) + \underline{B}(m-1)\frac{\partial \underline{h}(m-1)}{\partial SY}$$

$$+\frac{\partial \underline{B}(m)}{\partial SY}\left(\underline{TP} - \underline{h}(m)\right). \qquad \text{(B-4c)}$$

During the transition from unconfined to confined conditions, $\underline{B}(m-1)$ is only sensitive to an SY parameter and $\underline{B}(m)$ is only sensitive to an SS parameter. For an SS parameter during the transition to confined conditions, recognizing that $\frac{\partial \underline{B}(m)}{\partial SS} = \frac{\partial \underline{A}(m)}{\partial SS}$, the following equations hold:

$$\underline{A}(m)\left[\frac{\partial \underline{h}(m)}{\partial SS}\right]^{r} = -\frac{\partial \underline{A}(m)}{\partial \underline{h}(m)}\left[\frac{\partial \underline{h}(m)}{\partial SS}\right]^{r-1} \underline{h}(m) + \underline{B}(m-1)\frac{\partial \underline{h}(m-1)}{\partial SS} + \frac{\partial \underline{B}(m)}{\partial SS}\left(\underline{TP} - \underline{h}(m)\right) \tag{B-4d}$$

$$\underline{A}(m)\left[\frac{\partial \underline{h}(m)}{\partial SY}\right]^{r} = -\frac{\partial \underline{A}(m)}{\partial \underline{h}(m)}\left[\frac{\partial \underline{h}(m)}{\partial SY}\right]^{r-1} \underline{h}(m) + \underline{B}(m-1)\frac{\partial \underline{h}(m-1)}{\partial SY} + \frac{\partial \underline{B}(m-1)}{\partial SY}\left(\underline{h}(m-1) - \underline{TP}\right). \tag{B-4e}$$

HK Parameters

Horizontal hydraulic conductivity parameters affect matrix A. The CC and CR terms are treated nearly the same. CR terms are used in the derivation. Each CR term is of the form

$$CR_{i,j+1/2,k} = 2\Delta c_i \frac{TR_{i,j,k} TR_{i,j+1,k}}{TR_{i,j,k}\Delta r_{j+1} + TR_{i,j+1,k}\Delta r_j}, \tag{B-5}$$

where

$$TR_{i,j,k} = \sum_{g=1}^{n} KH_{i,j,g}\, thk_{g_{i,j,k}} \; ; \; KH_{i,j,g} = \sum_{l=1}^{p} Kh_l m_{l_{i,j,g}} \, , \tag{B-6a}$$

and

$$TR_{i,j+1,k} = \sum_{g=1}^{n} KH_{i,j+1,g}\, thk_{g_{i,j+1,k}} \; ; \; KH_{i,j+1,g} = \sum_{l=1}^{p} Kh_l m_{l_{i,j+1,g}} \, , \tag{B-6b}$$

where

n is the number of hydrogeologic units within the finite-difference cell,
$thk_{g_{i,j,k}}$ is the thickness of hydrogeologic unit *g* in cell *i*, *j*, *k*,
p is the number of additive parameters that define the hydraulic conductivity of hydrogeologic unit *g*,
Kh_l is the horizontal hydraulic conductivity of parameter *l*, and

$m_{l_{i,j,g}}$ is the multiplication factor for parameter *l*.

Because these are fairly complicated expressions, it is useful to proceed through a few elementary steps to determine the derivatives. Consider a ratio of two functions of a parameter named *b*, *u(b)/v(b)*. Basic calculus yields that

$$\frac{\partial}{\partial b}\left[\frac{u}{v}\right]=\frac{v\dfrac{\partial u}{\partial b}-u\dfrac{\partial v}{\partial b}}{v^2}. \tag{B-7}$$

For equation B-5 above, *u* and v can be defined as:

$$u=TR_{i,j,k}TR_{i,j+1,k} \tag{B-8a}$$

$$v=TR_{i,j,k}\Delta r_{j+1}+TR_{i,j+1,k}\Delta r_j\ , \tag{B-8b}$$

so that

$$\frac{\partial u}{\partial b}=\frac{\partial u}{\partial Kh_l}=TR_{i,j,k}\frac{\partial TR_{i,j+1,k}}{\partial Kh_l}+TR_{i,j+1,k}\frac{\partial TR_{i,j,k}}{\partial Kh_l}\ , \tag{B-9a}$$

and

$$\frac{\partial v}{\partial b}=\frac{\partial v}{\partial Kh_l}=\frac{\partial TR_{i,j,k}}{\partial Kh_l}\Delta r_{j+1}+\frac{\partial TR_{i,j+1,k}}{\partial Kh_l}\Delta r_{j+1}\,. \tag{B-9b}$$

Using equation B-7 with these expressions yields:

$$\frac{\partial CR_{i,j+1/2,k}}{\partial Kh_l}=2\Delta c_i\frac{v\dfrac{\partial u}{\partial Kh_l}-u\dfrac{\partial v}{\partial Kh_l}}{v^2}\,. \tag{B-10}$$

The remaining derivatives needed are:

$$\frac{\partial TR_{i,j,k}}{\partial Kh_l}=\sum_{g=1}^{n}m_{l_{i,j,g}}thk_{g_{i,j,k}} \tag{B-11a}$$

$$\frac{\partial TR_{i,j+1,k}}{\partial Kh_l}=\sum_{g=1}^{n}m_{l_{i,j+1,g}}thk_{g_{i,j+1,k}} \tag{B-11b}$$

and

$$\frac{\partial u}{\partial b} = \frac{\partial u}{\partial Kh_l} = TR_{i,j,k}\sum_{g=1}^{n} m_{l_{i,j+1,g}} thk_{g_{i,j+1,k}} + TR_{i,j+1,k}\sum_{g=1}^{n} m_{l_{i,j,g}} thk_{g_{i,j,k}} \qquad \text{(B-12a)}$$

$$\frac{\partial v}{\partial b} = \frac{\partial v}{\partial Kh_l} = \Delta r_{j+1}\sum_{g=1}^{n} m_{l_{i,j,g}} thk_{g_{i,j,k}} + \Delta r_j \sum_{g=1}^{n} m_{l_{i,j+1,g}} thk_{g_{i,j+1,k}} \; . \qquad \text{(B-12b)}$$

Contributions to the right-hand side are:

$$RHS_{i,j,k} = RHS_{i,j,k} + \frac{\partial CR_{i,j+1/2,k}}{\partial Kh_l}\left(h_{i,j,k} - h_{i,j+1,k}\right) \qquad \text{(B-13a)}$$

$$RHS_{i,j+1,k} = RHS_{i,j+1,k} - \frac{\partial CR_{i,j+1/2,k}}{\partial Kh_l}\left(h_{i,j,k} - h_{i,j+1,k}\right). \qquad \text{(B-13b)}$$

A similar set of equations could be derived for CC.

HANI Parameters

HANI parameters affect the CC terms of matrix A. Each CC term is of the form

$$CC_{i+1/2,j,k} = 2\Delta r_j \, \frac{TC_{i+1,j,k} TC_{i,j,k}}{TC_{i,j,k}\Delta c_{i+1} + TC_{i+1,j,k}\Delta c_i} \, , \qquad \text{(B-14)}$$

where

$$\begin{aligned} TC_{i,j,k} &= \sum_{g=1}^{n} KH_{i,j,g} thk_{g_{i,j,k}} HANI_{i,j,g} \, ; HANI_{i,j,g} = \sum_{l=1}^{p} Hani_l m_{l_{i,j,g}} \\ TC_{i+1,j,k} &= \sum_{g=1}^{n} KH_{i+1,j,g} thk_{g_{i+1,j,k}} HANI_{i+1,j,g} \, ; HANI_{i+1,j,g} = \sum_{l=1}^{p} Hani_l m_{l_{i+1,j,g}} \, . \end{aligned} \qquad \text{(B-15)}$$

For equation B-14 above, *u* and *v* can be defined as:

$$u = TC_{i+1,j,k} TC_{i,j,k} \qquad \text{(B-16a)}$$

$$v = TC_{i,j,k}\Delta c_{i+1} + TC_{i+1,j,k}\Delta c_i \qquad \text{(B-16b)}$$

$$\frac{\partial u}{\partial Hani_l} = \frac{\partial TC_{i+1,j,k}}{\partial Hani_l} TC_{i,j,k} + \frac{\partial TC_{i,j,k}}{\partial Hani_l} TC_{i+1,j,k} \qquad \text{(B-17a)}$$

and

$$\frac{\partial v}{\partial Hani_l} = \frac{\partial TC_{i,j,k}}{\partial Hani_l}\Delta c_{i+1} + \frac{\partial TC_{i+1,j,k}}{\partial Hani_l}\Delta c_i \,, \tag{B-17B}$$

also

$$\begin{aligned} \frac{\partial TC_{i,j,k}}{\partial Hani_l} &= \sum_{g=1}^{n} KH_{i,j,g}\, thk_{g\,i,j,k}\, m_{l\,i,j,g} \\ \frac{\partial TC_{i+1,j,k}}{\partial Hani_l} &= \sum_{g=1}^{n} KH_{i+1,j,g}\, thk_{g\,i+1,j,k}\, m_{l\,i+1,j,g} \,. \end{aligned} \tag{B-18}$$

VK Parameters

Vertical conductance (CV) represents the block of subsurface material between a cell center and the cell center below, and for approximately horizontal hydrogeologic layers is calculated as:

$$CV_{i,j,k+1/2} = \frac{\Delta r_j \Delta c_i}{\sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}}}{KV_{i,j,g}}} \,;\, KV_{i,j,g} = \sum_{l=1}^{p} Kv_l m_{l_{i,j,g}} \,, \tag{B-19}$$

where

Δr_j	is the cell width of column *j*,
Δc_i	is the cell width of row *i*,
n	is the number of hydrogeologic units that occur vertically between the two cell centers,
$thk_{g_{i,j,k+1/2}}$	is the hydrogeologic unit *g* thickness that occurs between the two cell centers,
p	is the number of additive parameters that define the hydraulic conductivity of hydrogeologic unit *g*,
Kv_l	is the vertical hydraulic conductivity of parameter *l*, and
$m_{l_{i,j,g}}$	is the multiplication factor for parameter *l*.

The Kv_l terms are the parameters. For this equation, if *u* and *v* are defined as:

$$u = \Delta r_j \Delta c_i \tag{B-20a}$$

$$v = \sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}}}{KV_{i,j,g}} \,, \tag{B-20b}$$

then

$$\frac{\partial u}{\partial b} = \frac{\partial u}{\partial Kv_l} = 0 \tag{B-21}$$

and

$$\frac{\partial v}{\partial b} = \frac{\partial v}{\partial Kv_l} = -\sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}} \dfrac{\partial KV_{i,j,g}}{\partial Kv_l}}{KV_{i,j,g}^2} . \tag{B-22}$$

The remaining derivative is

$$\frac{\partial KV_{i,j,g}}{\partial Kv_l} = m_{l_{i,j,g}} . \tag{B-23}$$

Assembling these terms yields:

$$\frac{\partial CV_{i,j,k+1/2}}{\partial Kv_l} = \frac{-\Delta r_j \Delta c_i \left[-\sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}} \dfrac{\partial KV_{i,j,g}}{\partial Kv_l}}{\left(KV_{i,j,g}\right)^2} \right]}{\left(\sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}}}{KV_{i,j,g}} \right)^2} = \frac{CV_{i,j,k+1/2}^2}{\Delta r_j \Delta c_i} \left[\sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}} m_{l_{i,j,g}}}{\left(KV_{i,j,g}\right)^2} \right]. \tag{B-24}$$

These terms would be contributed to the right-hand side as:

$$RHS_{i,j,k} = RHS_{i,j,k} + \frac{\partial CV_{i,j,k+1/2}}{\partial Kv_{l_{i,j,k+1/2}}} \left(h_{i,j,k} - h_{i,j,k+1}\right) \tag{B-25a}$$

$$RHS_{i,j,k+1} = RHS_{i,j,k+1} - \frac{\partial CV_{i,j,k+1/2}}{\partial Kv_{l_{i,j,k+1/2}}} \left(h_{i,j,k} - h_{i,j,k+1}\right). \tag{B-25b}$$

VANI Parameters

For VANI parameters, vertical conductance is expressed as:

$$CV_{i,j,k+1/2} = \frac{\Delta r_j \Delta c_i}{\sum_{g=1}^{n}\left[\dfrac{thk_{g_{i,j,k+1/2}}}{\frac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}}\right]}, \tag{B-26}$$

which is dependent on both ANIV and Kh. The sensitivity of CV to VANI is derived first. Because this is a complicated expression, it is useful to derive the sensitivity equation in several steps using equation B-7. First, assume the following definitions of u_1 and v_1, which results in the derivatives shown:

$$u_1 = \sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}; \quad \frac{\partial u_1}{\partial VANI_g} = 0 \tag{B-27a}$$

$$v_1 = VANI_g m_{g_{i,j}}; \quad \frac{\partial v_1}{\partial VANI_g} = m_{g_{i,j}}. \tag{B-27b}$$

Then, using equation B-7,

$$\frac{\partial \frac{u_1}{v_1}}{\partial VANI_g} = -\frac{m_{g_{i,j}} \sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{\left(VANI_g m_{g_{i,j}}\right)^2}. \tag{B-27c}$$

Next, assume the following definitions of u_2 and v_2,

$$u_2 = thk_{g_{i,j,k+1/2}}; \quad \frac{\partial u_2}{\partial VANI_g} = 0 \tag{B-28a}$$

$$v_2 = \frac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}; \quad \frac{\partial v_2}{\partial VANI_g} = \frac{\partial \frac{u_1}{v_1}}{\partial VANI_g}, \tag{B-28b}$$

which is shown in equation B-27c. Then, using equation B-7,

$$\frac{\partial \sum_{g=1}^{n} \frac{u_2}{v_2}}{\partial VANI_g} = \sum_{g=1}^{n} \frac{\partial \frac{u_2}{v_2}}{\partial VANI_g} = \sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}} \dfrac{m_{g_{i,j}} \sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{\left(VANI_g m_{g_{i,j}}\right)^2}}{\left(\dfrac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}\right)^2}. \tag{B-28c}$$

Finally, assume the following definitions of u_3 and v_3,

$$u_3 = \Delta r_j \Delta c_i; \quad \frac{\partial u_3}{\partial VANI_g} = 0 \tag{B-29a}$$

$$v_3 = \sum_{g=1}^{n}\left[\frac{thk_{g_{i,j,k+1/2}}}{\frac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}}\right]; \quad \frac{\partial v_3}{\partial VANI_g} = \sum_{g=1}^{n}\left[\frac{\frac{\partial u_2}{\partial v_2}}{\partial VANI_g}\right], \tag{B-29b}$$

where the final term is given by equation B-28c. Applying equation B-7 one final time gives

$$\frac{\partial CV_{i,j,k+1/2}}{\partial VANI_g} = \frac{-\Delta r_j \Delta c_i \sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}} \frac{m_{g_{i,j}} \sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{\left(VANI_g m_{g_{i,j}}\right)^2}}{\left(\frac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}\right)^2}}{\left(\sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}}}{\frac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}}\right)^2}$$

$$= -\frac{CV_{i,j,k+1/2}^2}{\Delta r_j \Delta c_i} \sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}} \frac{m_{g_{i,j}} \sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{\left(VANI_g m_{g_{i,j}}\right)^2}}{\left(\frac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}\right)^2}. \tag{B-29c}$$

The sensitivity of CV to Kh is derived in a similar manner. First, assume the following definitions of u_1 and v_1 which results in the derivatives shown:

$$u_1 = thk_{g_{i,j,k+1/2}}; \quad \frac{\partial u_1}{\partial Kh_l} = 0 \tag{B-30a}$$

$$v_1 = \frac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}; \quad \frac{\partial v_1}{\partial Kh_l} = \frac{m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}. \tag{B-30b}$$

Then, using equation B-7,

$$\frac{\partial \sum_{g=1}^{n} \frac{u_1}{v_1}}{\partial Kh_l} = \sum_{g=1}^{n} \frac{\partial \frac{u_1}{v_1}}{\partial Kh_l} = \sum_{g=1}^{n} \frac{-thk_{g_{i,j,k+1/2}} \frac{m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}}{\left(\frac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}} \right)^2} . \qquad \text{(B-30c)}$$

Next, assume the following definitions of u_2 and v_2,

$$u_2 = \Delta r_j \Delta c_i ; \quad \frac{\partial u_2}{\partial Kh_l} = 0 \qquad \text{(B-31a)}$$

$$v_2 = \sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}}}{\frac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}} ; \quad \frac{\partial v_2}{\partial Kh_l} = \frac{\partial \frac{u_1}{v_1}}{\partial Kh_l} , \qquad \text{(B-31b)}$$

which is shown in equation B-30c. Then, using equation B-7,

$$\frac{\partial CV_{i,j,k+1/2}}{\partial Kh_l} = \frac{\Delta r_j \Delta c_i \sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}} \frac{m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}}{\left(\frac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}} \right)^2}}{\left(\sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}}}{\frac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}} \right)^2}$$

$$= \frac{CV_{i,j,k+1/2}^2}{\Delta r_j \Delta c_i} \sum_{g=1}^{n} \frac{thk_{g_{i,j,k+1/2}} \frac{m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}}}{\left(\frac{\sum_{l=1}^{p} Kh_l m_{l_{i,j,g}}}{VANI_g m_{g_{i,j}}} \right)^2} . \qquad \text{(B-31c)}$$

SS Parameters

SS parameters are used to populate the SC1 array using the following equation:

$$SC1_{i,j,k} = \Delta r_j \Delta c_i \sum_{g=1}^{n} SS_{i,j,g} thk_{g_{i,j,k}} \; ; \; SS_{i,j,g} = \sum_{l=1}^{p} Ss_l m_{l_{i,j,g}} \; , \qquad \text{(B-32)}$$

which affects matrix A. Taking the derivative with respect to the SS parameter yields

$$\frac{\partial SC1_{i,j,k}}{\partial Ss_l} = \Delta r_j \Delta c_i thk_{g_{i,j,k}} m_{l_{i,j,k}} \; . \qquad \text{(B-33)}$$

SY Parameters

The HUF Package was implemented such that the specific yield for the hydrogeologic unit in which the water table resides is used to calculate the contribution to the storage flow for a given cell. Should the water table span several hydrogeologic units during a time step, the specific yields for each of those units are used with the corresponding thickness of the units to calculate the contributions to the mass balance for that particular cell. SY parameters are used to calculate the SC2 value for each cell using the following equation

$$SC2_{i,j,k} = \Delta r_j \Delta c_i SY_{i,j,g} \; ; \; SY_{i,j,g} = \sum_{l=1}^{p} Sy_l m_{l_{i,j,g}} \; , \qquad \text{(B-34)}$$

which affects matrix A. Taking the derivative with respect to the SY parameter yields

$$\frac{\partial SC2_{i,j,k}}{\partial Sy_l} = \Delta r_j \Delta c_i m_{l_{i,j,k}} \; . \qquad \text{(B-35)}$$