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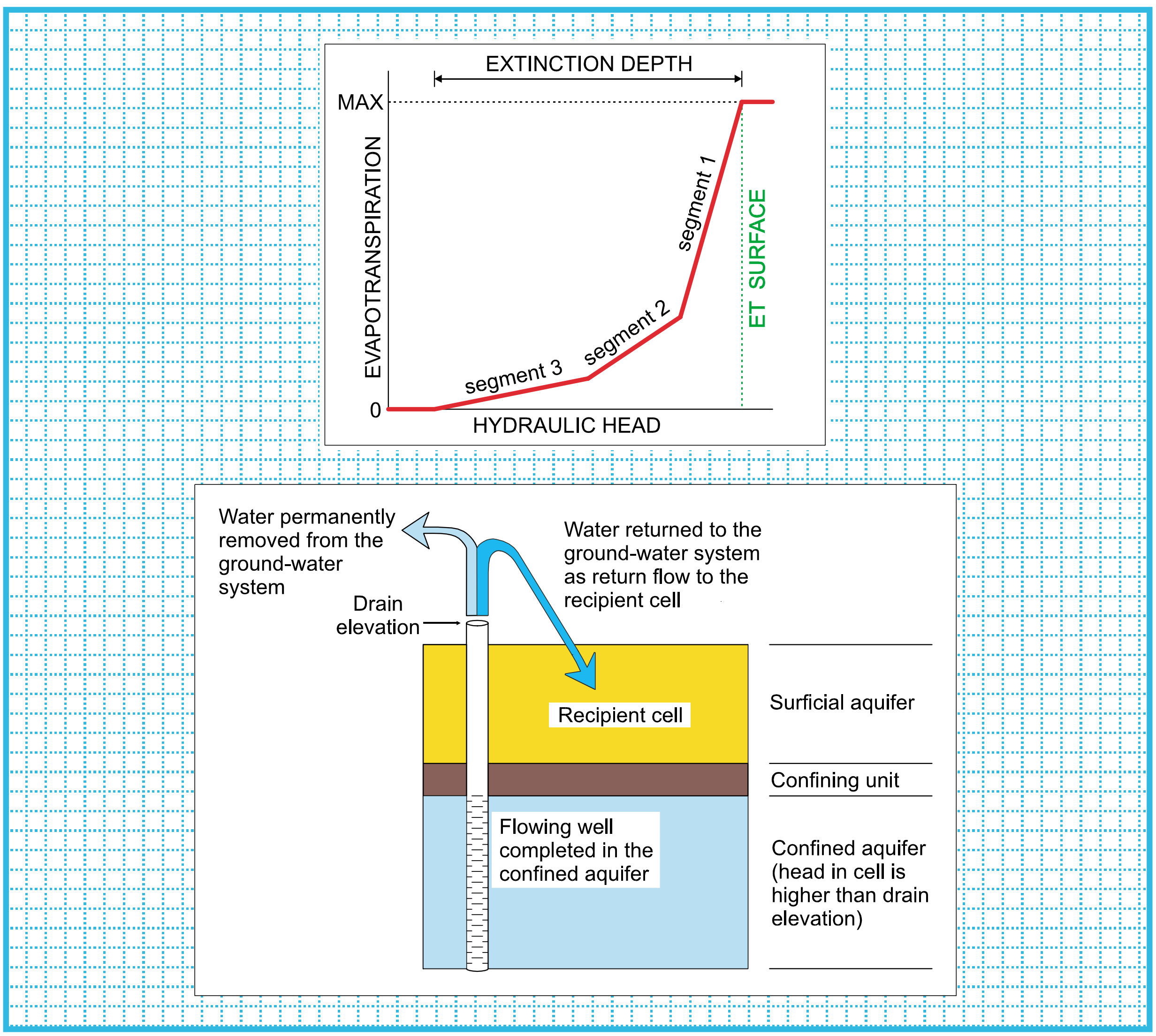
MODFLOW-2000, THE U.S. GEOLOGICAL SURVEY MODULAR GROUND-WATER MODEL—DOCUMENTATION OF PACKAGES FOR SIMULATING EVAPOTRANSPIRATION WITH A SEGMENTED FUNCTION (ETS1) AND DRAINS WITH RETURN FLOW (DRT1)

Open-File Report 00–466



U.S. Department of the Interior
U.S. Geological Survey

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By Edward R. Banta

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Denver, Colorado
2000

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PREFACE

This report documents two computer-program packages designed to work with the U.S. Geological Survey modular ground-water-flow model, MODFLOW-2000. The packages are designed to simulate (1) evapotranspiration using a segmented-line relation of evapotranspiration rate to hydraulic head, and (2) drainage of water from a ground-water system, with an option to simulate return flow of some of the drained water.

The code for the packages is contained in this report and is included in MODFLOW-2000, which is available for downloading over the Internet from a U.S. Geological Survey software repository. The repository is accessible on the World Wide Web from the U.S. Geological Survey Water Resources web page at the Universal Resource Locator (URL) http://water.usgs.gov/. The URL for the software repository is http://water.usgs.gov/software/. If revisions are made to the packages, the revised code will be made available from the software repository.

CONTENTS

FIGURES

TABLE

CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
square foot per day (ft^2/d)	0.09290	square meter per day

Other abbreviations, terms, and symbols used in this report:

length (L)
time (T)

MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model—Documentation of Packages for Simulating Evapotranspiration with a Segmented Function (ETS1) and Drains with Return Flow (DRT1)

By Edward R. Banta

ABSTRACT

Two new packages for the U.S. Geological Survey modular finite-difference ground-water-flow model MODFLOW-2000 are documented. The new packages provide flexibility in simulating evapotranspiration and drain features not provided by the MODFLOW-2000 Evapotranspiration (EVT) and Drain (DRN) Packages. The report describes conceptualization of the packages, input instructions, listings and explanations of the source code, and example simulations.

The new Evapotranspiration Segments (ETS1) Package allows simulation of evapotranspiration with a user-defined relation between evapotranspiration rate and hydraulic head. This capability provides a degree of flexibility not supported by the EVT Package, which has been available in MODFLOW since its initial release. In the ETS1 Package, the relation of evapotranspiration rate to hydraulic head is conceptualized as a segmented line between an evaporation surface, defined as the elevation where the evapotranspiration rate reaches a maximum, and an elevation located at an extinction depth below the evaporation surface, where the evapotranspiration rate reaches zero. The user supplies input to define as many intermediate segment endpoints as desired to define the relation of evapotranspiration rate to head between these two elevations. The EVT Package, in contrast, simulates evapotranspiration with a single linear function.

The new Drain Return (DRT1) Package can be used to simulate the return flow of water discharged from a drain feature back into the ground-water system. The DRN Package, which has been available in MODFLOW since its initial release, does not have the capability to simulate return of flow. If the return-flow option of the DRT1 Package is selected, for each cell designated as a drain-return cell, the user has the option of specifying a proportion of the water simulated as leaving the ground-water system through the drain feature that is to be simulated as returning simultaneously to one other cell in the model.

INTRODUCTION

The U.S. Geological Survey (USGS) modular three-dimensional finite-difference ground-water-flow model (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996a, 1996b), commonly known as MODFLOW, has included support for simulating evapotranspiration and flow to drains since its initial release. In the modular design of MODFLOW, such stresses to a ground-water system are simulated by using groups of subroutines called packages. In previous versions of MODFLOW, evapotranspiration can be simulated using the Evapotranspiration (EVT) Package, and flow to drain features—for example, springs or agricultural drains—can be simulated using the Drain (DRN) Package. However, the conceptual models underlying these capabilities are not sufficiently complex to simulate certain field situations. The U.S. Geological Survey, in cooperation with the Colorado Water Conservation Board and the Colorado Division of Water Resources, developed two new MODFLOW-2000 packages to allow simulation of more complex field situations.

This report documents two new MODFLOW packages. The Evapotranspiration Segments (ETS1) Package allows the user to specify a complex relation between evapotranspiration rate and hydraulic head. The Drain Return (DRT1) Package allows the user to specify that a certain proportion of the simulated flow out of the ground-water system at a drain cell be returned as simulated flow into any cell in the model. The report presents the conceptualization for each package, input instructions, listings and explanations of the source code, and example simulations.

The modular design of MODFLOW was enhanced with the release of MODFLOW-2000 by the addition of the concept of processes (Harbaugh and others, 2000). In MODFLOW-2000, the simulation of ground-water flow, which earlier versions of MODFLOW performed, is handled by the Ground-Water Flow Process. In addition, MODFLOW-2000 includes the Observation, Sensitivity, and Parameter-Estimation Processes (Hill and others, 2000). The ETS1 Package includes support for the Ground-Water Flow, Sensitivity, and Parameter-Estimation Processes. The DRT1 Package includes support for the Ground-Water Flow, Observation, Sensitivity, and Parameter-Estimation Processes. This report assumes the user is familiar with MODFLOW-2000 and its Ground-Water Flow, Observation, Sensitivity, and Parameter-Estimation Processes. Familiarity with the GLOBAL and LIST output files (Harbaugh and others, 2000) also is assumed.

The source code for the subroutines of the ETS1 and DRT1 Packages generally conforms to FORTRAN 77 (American National Standards Institute, 1978), with the exception that some symbolic names exceed the 6-character length limit. In addition, MODFLOW-2000 uses Fortran 90 (American National Standards Institute, 1992) statements for dynamic memory allocation. The source code can be converted to use only static memory allocation by following the instructions in Appendix B of Hill and others (2000). The program can be used on any computer or operating system for which an appropriate Fortran compiler is available.

EVAPOTRANSPIRATION SEGMENTS PACKAGE

Evapotranspiration can account for a substantial fraction of the water budget for a ground-water system. When modeling flow in a ground-water system where a large fraction of the water budget is lost through evapotranspiration, the method by which evapotranspiration is simulated can affect calculated hydraulic heads, and thus interpretations regarding the system dynamics. The Evapotranspiration (EVT) Package (McDonald and Harbaugh, 1988) provides a useful method for simulating evapotranspiration that may be based on a more simplified conceptual model of evapotranspiration than is warranted by knowledge of actual field conditions. The method of simulating evapotranspiration used in the ETS1 Package documented in this report provides the flexibility to represent a complex relation of evapotranspiration rate to hydraulic head.

In the EVT Package, which has always been in MODFLOW, the evapotranspiration rate for a particular cell is calculated based on the simulated hydraulic head in the cell, an “ET surface,” an “extinction depth” (fig. 1), and a maximum evapotranspiration flux rate. If the elevation of the calculated hydraulic head (head) in the cell is at or above the ET surface, the evapotranspiration rate is the maximum evapotranspiration rate. If the depth of the head below the ET surface equals or exceeds the extinction depth, the evapotranspiration rate is zero. When the head is below the ET surface but the depth of the head below the surface is less than the extinction depth, the evapotranspiration rate is variable and depends on the depth of the head below the ET surface. This interval, between the ET surface and the elevation defined as the ET surface minus the extinction depth, is referred to as the “variable interval” in this report. In the EVT Package, when the head is in the variable interval, the evapotranspiration rate is a simple linear function of depth of the head below the ET surface, such that the evapotranspiration rate is the maximum evapotranspiration rate when the depth is zero, and the evapotranspiration rate is zero when the depth equals the extinction depth. This relation is defined by equation (1):

$$Q = Q_{ETM} \times \left(1 - \frac{D}{X}\right) \qquad (1)$$

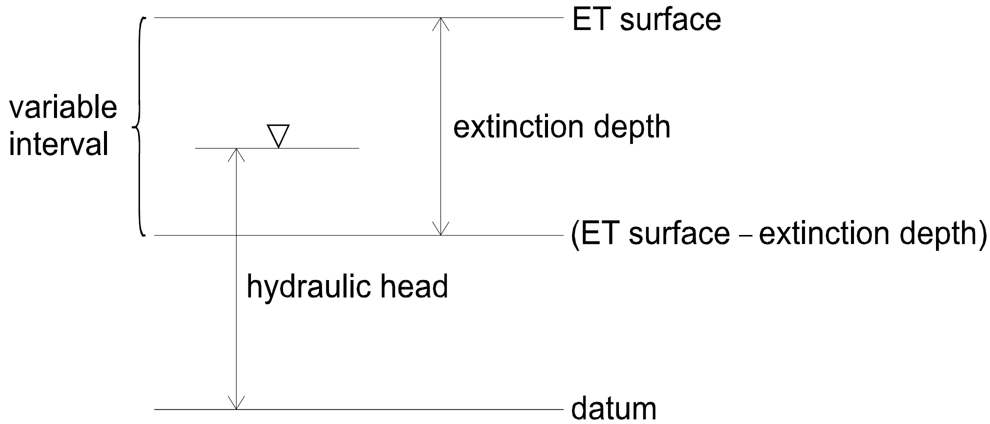

Figure 1.-- Conceptual surfaces used in simulating evapotranspiration. In the ETS1 Package, segments are defined in the variable interval.

where

Q is the volumetric evapotranspiration rate for the cell (L^3/T),

Q_{ETM} is the maximum evapotranspiration flux rate times the area of the cell (L^3/T),

D is the depth of the head below the ET surface (L), and

X is the extinction depth (L).

The ETS1 Package differs from the EVT Package in that the ETS1 Package allows the user to specify a segmented function for the relation of evapotranspiration rate to depth of head below the ET surface in the variable interval (fig. 1). The user can specify as many segments as desired to approximate a curve or other type of relation.

Conceptualization of Evapotranspiration Segments

In the ETS1 Package, the functional relation of evapotranspiration rate to head is conceptualized as a segmented line in the variable interval. The segments that determine the shape of the function in the variable interval are defined by intermediate points where adjacent segments join. The ends of the segments at the top and bottom of the variable interval are defined by the ET surface, the maximum evapotranspiration rate, and the extinction depth. The number of intermediate points that must be defined is one less than the number of segments in the variable interval. For each intermediate point, two values, PXDP and PETM, are entered to define the point. PXDP is a proportion (between zero and one) of the extinction depth, and PETM is a proportion of the maximum evapotranspiration rate. PXDP is 0.0 at the ET surface and is 1.0 at the bottom of the variable interval. PETM is 1.0 at the ET surface and is 0.0 at the bottom of the variable interval. Segments are numbered such that segment one is the segment with its upper endpoint at the ET surface, and segment numbers increase downward. The relation of evapotranspiration rate to head is defined over the model grid by a series of two-dimensional arrays; therefore, PXDP and PETM also are specified as arrays.

When MODFLOW-2000 solves for heads, the ETS1 Package calculates an evapotranspiration rate for each cell where evapotranspiration is simulated by first determining which segment should be used based on the head, then calculating the evapotranspiration rate by interpolation. The interpolated evapotranspiration rate for a cell is defined by equation (2):

$$Q = PETM_{n-1} \times Q_{ETM} - \frac{(PETM_{n-1} - PETM_n)}{(PXDP_n - PXDP_{n-1})} \times \frac{Q_{ETM}}{X} \times (D - PXDP_{n-1} \times X) \qquad (2)$$

where n is the segment number of the applicable segment and refers to the point at the bottom of the segment, and other symbols are as defined above or for equation (1). When n is 1, n–1 refers to the upper end of the first segment, where $PXDP$ = 0.0 and $PETM$ = 1.0. Similarly, for the last segment, n is the total number of segments, $PXDP_n$ = 1.0, and $PETM_n$ = 0.0. The maximum evapotranspiration flux rate may be defined in program input either directly, by entering an array of numeric values, or indirectly, by using parameters. The concept of using parameters to define model input is described by Harbaugh and others (2000). When a parameter is used to define the maximum evapotranspiration flux rate, Q_{ETM} is the product of the parameter value, the multiplier from the multiplier array (if defined for the parameter), and the cell area. As with any head-dependent flow boundary, the head used in the calculation, in this case the calculation of D, is the head that resulted from the previous solver iteration. For this reason, to obtain an accurate head solution, solver input must specify that an iterative method be used.

Figure 2 illustrates a possible function relating volumetric evapotranspiration rate to head for a situation where three segments are used. The function in the variable interval is defined by the segments AB, BC, and CD. Points A and D are determined by the ET surface (ETSS), the product of the maximum evapotranspiration flux rate and the cell area (Q_{ETM}), and the extinction depth (ETSX). Points B and C are intermediate segment endpoints. The user inputs PXDP and PETM to define each intermediate endpoint. For the cell corresponding to figure 2, $PXDP_B$ equals 0.2, $PETM_B$ equals 0.3, $PXDP_C$ equals 0.5, and $PETM_C$ equals 0.1.

In some cases a segmented relation between evapotranspiration rate and head in one part of the model area and a simple linear relation in another part may be desired. The simple linear relation can be modeled by specifying PXDP and PETM such that PETM = (1 – PXDP) for each intermediate endpoint. To use a simple linear relation everywhere in the model area, the modeler can specify that only one segment is to be used; use of this approach results in evapotranspiration being simulated using the methodology of the EVT Package.

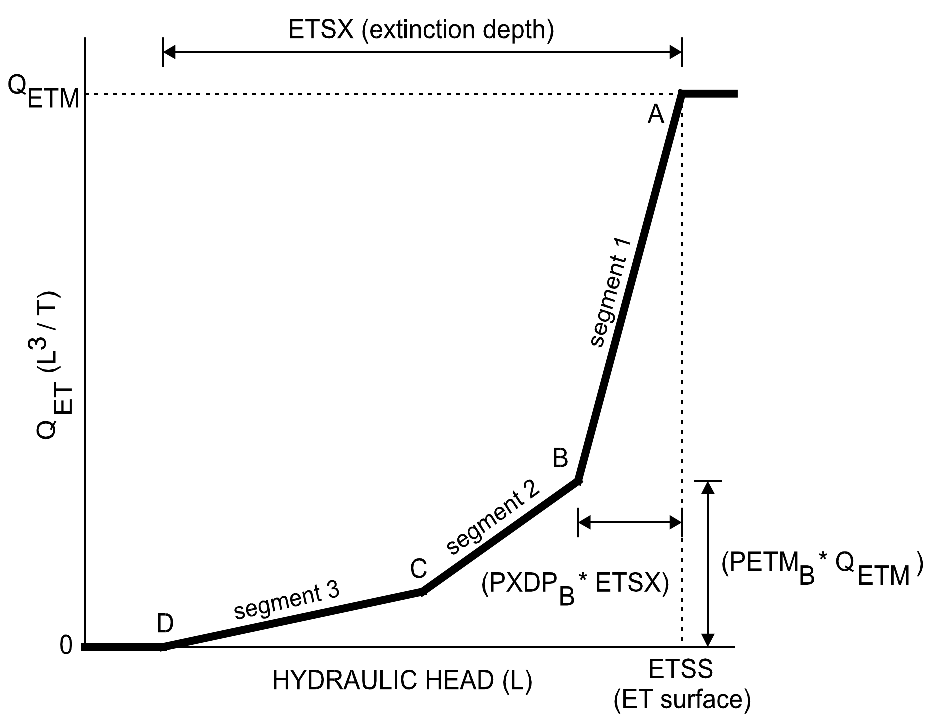

Figure 2.-- Volumetric evapotranspiration rate, Q_{ET}, as a function of head for a situation in which the function in the variable interval is defined using three segments. ETSX is the extinction depth, ETSS is the ET surface, and Q_{ETM} is the product of the maximum evapotranspiration flux rate and the cell area. $PETM_B$ and $PXDP_B$ define the location of point B.

As for the EVT Package, the ETS1 Package provides two options for specifying the layer from which evapotranspiration is to be extracted. Figure 3 shows a hypothetical field situation. Figure 3a shows a hydrogeologic section of the situation under study, and figure 3b shows the distribution of variable-head, constant-head, and inactive (no-flow) cells. When option 1 (fig. 3c) is used, evapotranspiration is drawn only from the uppermost model layer; in the problem shown, the presence of no-flow-cells in this layer eliminates evapotranspiration from the right side of the model. Figure 3d illustrates the use of option 2, where the user specifies layer numbers to indicate which layer is allowed to have evapotranspiration in each vertical column of cells.

Input Instructions for the Evapotranspiration Segments Package

Input to the ETS1 Package is read from the file that is type "ETS" in the name file. All single-valued variables are free format if the option "FREE" is specified in the Basic Package input file; otherwise, the variables have 10-character fields. Arrays are read by an array-reading utility module, either U2DREL or U2DINT (Harbaugh and others, 2000), as indicated. Optional variables are shown in brackets.

FOR EACH SIMULATION

0. `[#Text]`

   Item 0 is optional—"#" must be in column 1. Item 0 can be repeated as many times as desired.

1. `NETSOP  IETSCB  NPETS  NETSEG`

2. `[PARNAM  PARTYP  Parval  NCLU]`

3. `[Mltarr  Zonarr  IZ]`

   Each repetition of Item 3 record is called a parameter cluster. Repeat Item 3 NCLU times.
   Repeat Items 2 and 3 for each parameter to be defined (that is, NPETS times). Items 2 and 3 are omitted if NPETS = 0.

FOR EACH STRESS PERIOD

4. `INETSS  INETSR  INETSX  [INIETS  [INSGDF]]`

5. `[ETSS(NCOL,NROW)]` – U2DREL – If INETSS ≥ 0

6. `[ETSR(NCOL,NROW)]` – U2DREL – If NPETS = 0 and if INETSR ≥ 0

7. `[Pname  [IETSPF]]` – If NPETS > 0 and if INETSR > 0

   Either Item 6 or Item 7 may be read, but not both. If Item 7 is read, it is repeated INETSR times.

8. `[ETSX(NCOL,NROW)]` – U2DREL – If INETSX ≥ 0

9. `[IETS(NCOL,NROW)]` – U2DINT – If NETSOP = 2 and if INIETS ≥ 0

10. `[PXDP(NCOL,NROW)]` – U2DREL – If NETSEG > 1 and INSGDF ≥ 0

11. `[PETM(NCOL,NROW)]` – U2DREL – If NETSEG > 1 and INSGDF ≥ 0

    If NETSEG > 1, (NETSEG – 1) repetitions of items 10 and 11 are read. If NETSEG > 2, items 10 and 11 are read for the uppermost segment intersection, followed by repetitions of items 10 and 11 for successively lower intersections.

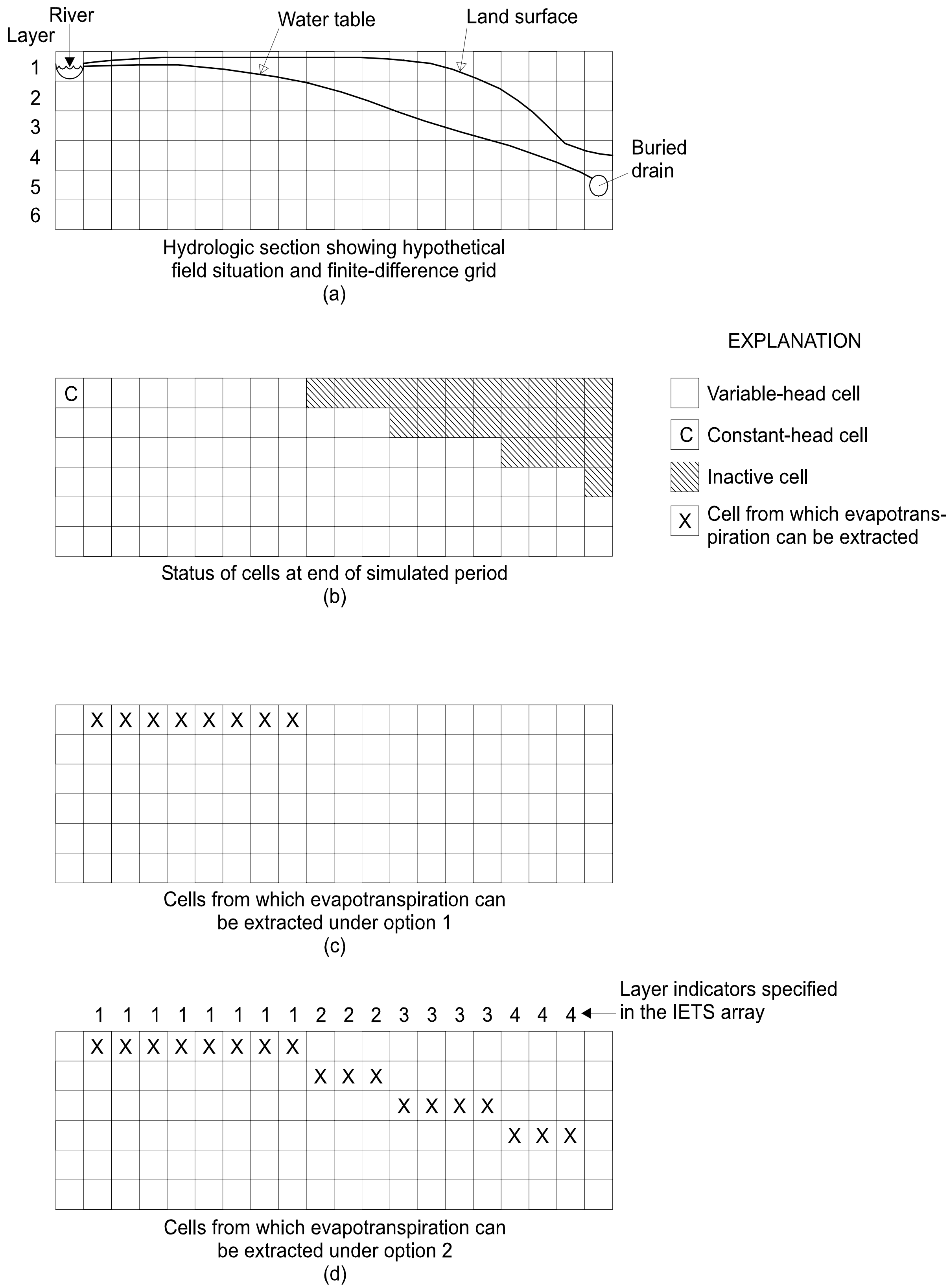

Figure 3.-- Hypothetical field situation showing cells from which evapotranspiration can be extracted under the two options available in the ETS1 Package.

Explanation of Variables Read by the Evapotranspiration Segments Package

Text—is a character variable (79 characters) that starts in column 2. Any characters can be included in Text. The "#" character must be in column 1. Lines beginning with "#" are restricted to these first lines of the input file. Text is written to the LIST output file when the input file is read and provides an opportunity for the user to include information about the model both in the input file and the associated output file.

NETSOP—is the evapotranspiration (ET) option code. ET variables (ET surface, maximum ET rate, and extinction depth) are specified in layer variables, ETSS, ETSR, and ETSX, with one value for each vertical column of cells in the model grid. Accordingly, ET is calculated for one cell in each vertical column. The option codes determine the cell within a column for which ET will be calculated.

If NETSOP = 1, ET is calculated only for cells in the top grid layer.
If NETSOP = 2, the cell for each vertical column is specified by the user in variable IETS.

IETSCB—is a flag and a unit number.

If IETSCB > 0, it is the unit number to which ETS1-Package 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). IETSCB must be a unit number associated with a file listed with type "DATA(BINARY)" or "DATAGLO(BINARY)" in the name file.
If IETSCB ≤ 0, ETS1-Package cell-by-cell flow terms will not be written.

NPETS—is the number of evapotranspiration-segments parameters.

NETSEG—is the number of segments used to define the relation of evapotranspiration rate to hydraulic head in the interval where the evapotranspiration rate is variable.

PARNAM—is the name of a parameter to be defined. This name can consist of 1 to 10 characters and is not case sensitive. That is, any combination of the same characters with different case will be equivalent.

PARTYP—is the type of parameter to be defined. For the ETS1 Package, the only allowed parameter type is "ETS," which defines values of the maximum ET flux.

Parval—is the parameter value. The units of Parval times Mltarr (if used) must be (LT^{-1}). This parameter value may be overridden by a value in the Sensitivity Process input file or by a value generated by the Parameter-Estimation Process.

NCLU—is the number of clusters required to define a parameter. Each repetition of Item 3 record is a cluster (variables Mltarr, Zonarr, and IZ). Usually only one cluster is needed to define an ETS parameter; however, more than one cluster may be listed.

Mltarr—is the name of the multiplier array to be used to define the values determined by a parameter. The units of Parval times Mltarr must be (LT^{-1}). The name "NONE" means there is no multiplier array, and the values will be set equal to Parval.

Zonarr—is the name of the zone array to be used to define the cells associated with a parameter. The name "ALL" means there is no zone array, and all cells are associated with the parameter.

IZ—is up to 10 zone numbers (separated by spaces) that define the cells associated with a parameter. These values are not used if Zonarr is specified as "ALL." Values can be positive or negative, but 0 is not allowed. The end of the line, a zero value, or a non-numeric entry terminates the list of values.

INETSS—is the ET surface (ETSS) read flag.

If INETSS ≥ 0, a layer variable containing the ET surface (ETSS) will be read from item 5 in the ETS1 input file.
If INETSS < 0, the ET surface from the preceding stress period will be reused.

INETSR—is the ETSR read flag. Its function depends on whether or not parameters are being used.

If no parameters are being used (NPETS = 0):

If INETSR ≥ 0, a layer variable containing the maximum ET rate (ETSR) will be read from item 6 in the ETS1 input file.
If INETSR < 0, the maximum ET rate from the preceding stress period will be reused.

If parameters are being used (NPETS > 0):

If INETSR > 0, INETSR is the number of parameters used to define ETSR in the current stress period. Item 7 defines the names of the parameters.
If INETSR < 0, ETS parameters from the preceding stress period are used.
INETSR = 0 is not allowed. That is, when parameters are used, at least one parameter must be specified for each stress period.

INETSX—is the extinction depth (ETSX) read flag.

If INETSX ≥ 0, a layer variable containing the extinction depth (ETSX) will be read from item 8 in the ETS1 input file.
If INETSX < 0, the extinction depth from the preceding stress period will be reused.

INIETS—is the layer indicator (IETS) read flag. It is read if the ET option (NETSOP) is equal to two or if NETSEG > 1. If NETSEG > 1 and NETSOP is not equal to two, INIETS is ignored and IETS is not read.

If INIETS ≥ 0, a layer variable containing the layer indicators (IETS) will be read from item 9 in the ETS1 input file.
If INIETS < 0, layer indicators used during the preceding stress period will be reused.

INSGDF—is the segment definition read flag. It is read only if NETSEG > 1.

If INSGDF ≥ 0, two layer variables to define PXDP and PETM for each of (NETSEG – 1) segment intersections are read from items 10 and 11, respectively, of the ETS1 input file.
If INSGDF < 0, PXDP and PETM from the preceding stress period will be reused.

ETSS—is the elevation of the ET surface (L).

ETSR—is the maximum ET flux (volumetric flow rate per unit area, LT^{-1}).

Pname—is the name of a parameter that will be used to define the ETSR variable in the current stress period.

IETSPF—is an optional format code for printing the ETSR variable after it has been defined by parameters. The format codes are the same as those used in the U2DREL array reading utility module (Harbaugh and others, 2000).

ETSX—is the ET extinction depth (L). This variable is read only if INETSX ≥ 0.

IETS—is the layer indicator variable. For each horizontal location, IETS indicates the layer from which ET is removed. It is read only if the ET option (NETSOP) is equal to two and if INIETS ≥ 0.

PXDP—is a proportion of the extinction depth (dimensionless), measured downward from the ET surface, which, with PETM, defines the shape of the relation between the evapotranspiration rate and head. The value of PXDP must be between 0.0 and 1.0, inclusive. Repetitions of PXDP and PETM are read in sequence such that the first occurrence represents the bottom of the first segment, and subsequent repetitions represent the bottom of successively lower segments. Accordingly, PXDP values for later repetitions (representing lower segments) should be greater than PXDP values for earlier repetitions.

PETM—is a proportion of the maximum evapotranspiration rate (dimensionless) which, with PXDP, defines the shape of the relation between the evapotranspiration rate and head. The value of PETM should be between 0.0 and 1.0, inclusive. Repetitions of PXDP and PETM are read in sequence such that the first occurrence represents the bottom of the first segment, and subsequent repetitions represent the bottoms of successively lower segments. Accordingly, PETM values for later repetitions (representing lower segments) generally would be less than PETM values for earlier repetitions.

ETS1 Example Problem

A simple example problem was devised to demonstrate that the ETS1 Package correctly calculates evapotranspiration when the relation of evapotranspiration rate to head is segmented. For this problem a grid of 11 rows by 11 columns in one layer was used to simulate an unconfined aquifer with a uniform base elevation of 0 ft. All row and column widths were 100 ft. All cells in column 1 had a specified head of 50 ft, and all cells in column 11 had a specified head of 100 ft. Hydraulic conductivity of the aquifer material was 0.05 ft/d, and the system was modeled in steady state. Evapotranspiration was the only stress, and it was simulated with the ETS1 Package for one simulation and with the EVT Package (Harbaugh and others, 2000) for a second simulation. The input files for these simulations are listed in Appendix A.

A two-segment function was assumed to relate evapotranspiration rate to head for both simulations (fig. 4). The ET surface for the modeled area was defined as 100 ft, and the maximum evapotranspiration rate at the ET surface was 0.01 ft/d. Each cell in the model had an area of 10,000 ft^2, so the maximum evapotranspiration rate over the area of one cell was 100 ft^3/d. Segment 1 applies where the head is between 82 and 100 ft, and segment 2 applies where the head is between 64 and 82 ft. The two segments intersect at a depth below the ET surface of 18 ft, which corresponds to an elevation of 82 ft. At the intersection of the two segments, the evapotranspiration rate is 0.001 ft/d (10 ft^3/d over the cell area). The evapotranspiration rate is zero where the head is at or below 64 ft, which represents an extinction depth of 36 ft.

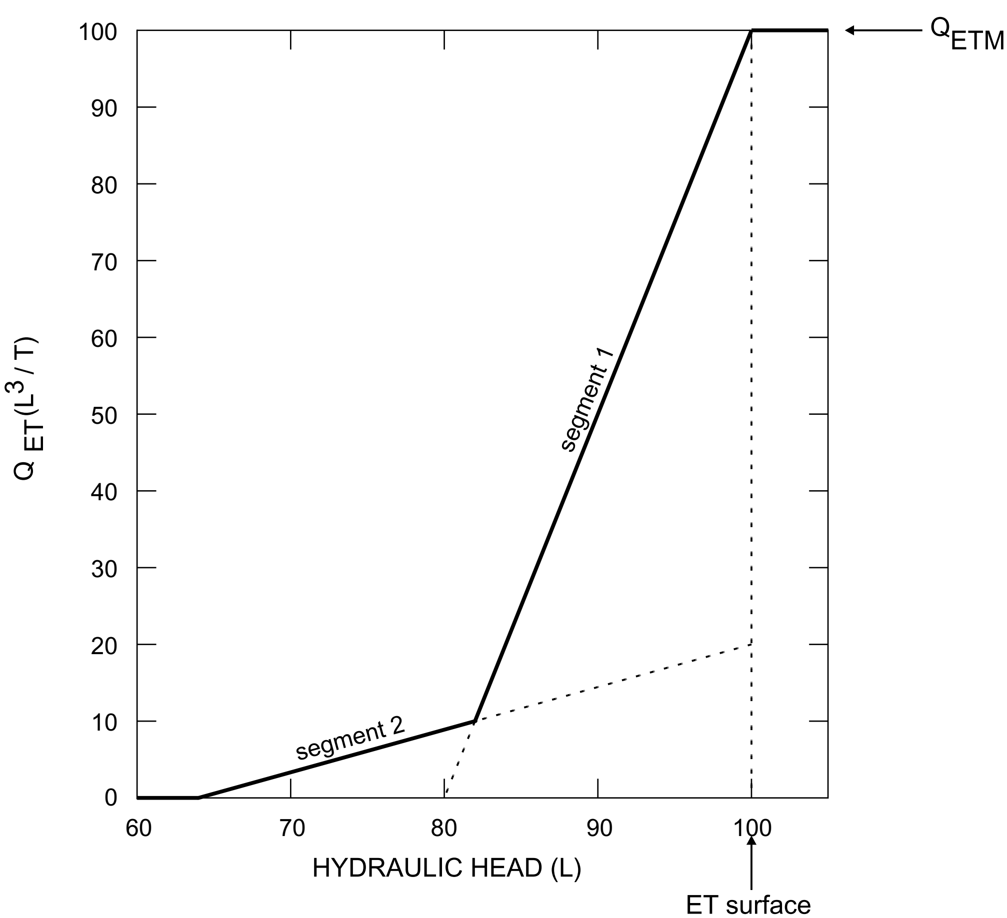

Figure 4.-- Segmented relation of volumetric evapotranspiration rate to head for one cell in the ETS1 example problem.

For the simulation using the ETS1 Package, the two-segment relation of evapotranspiration rate to head was specified uniformly over the model domain. The extinction depth was specified as 36 ft, and the maximum evapotranspiration rate was specified as 0.01 ft/d. The two-segment function requires definition of one PXDP array and one PETM array. PXDP was specified as 0.5 (18 ft / 36 ft) everywhere, and PETM was specified as 0.1 [(0.001 ft/d) / (0.01 ft/d)] everywhere. Appendix A lists the output file for this simulation. When evapotranspiration is simulated with the ETS1 Package, as calculated head changes with changing stresses, the correct segment is applied at each cell without the need for intervention by the modeler.

For the simulation using the EVT Package, the model domain was divided into two zones such that segment 1 would apply in zone 1 (columns 1 through 9) and segment 2 would apply in zone 2 (columns 10 and 11). Segment 1 was simulated in zone 1 by specifying an extinction depth of 20 ft and a maximum evapotranspiration rate of 0.01 ft/d. Segment 2 was simulated in zone 2 by specifying an extinction depth of 36 ft and a maximum evapotranspiration rate of 0.002 ft/d. Appendix A includes the calculated head distribution and volumetric water budget for this simulation. The calculated head distribution was identical to that obtained with the ETS1 Package, and the volumetric budgets were identical within round-off error. Note that if head at a particular cell changes as a result of changing stresses, the function that applies at the cell does not change, even if the head change causes the head to become less than or greater than the intersection elevation of 82 ft. To ensure that each cell is simulated with the appropriate function, the modeler would need to adjust the zone distribution manually.

Module Documentation for the Evapotranspiration Segments Package

The ETS1 Package is composed of six modules. Five of these are primary modules that are part of the Ground-Water Flow Process (Harbaugh and others, 2000). Primary modules are called directly from the main MODFLOW-2000 program unit. The sixth module is a primary module that is part of the Sensitivity Process (Hill and others, 2000). The six modules are:

GWF1ETS1AL—Reads options and allocates memory for data arrays. GWF1ETS1AL is part of the Ground-Water Flow Process and is in source-code file gwf1ets1.f.

GWF1ETS1RQ—Reads parameter definitions. GWF1ETS1RQ is part of the Ground-Water Flow Process and is in source-code file gwf1ets1.f.

GWF1ETS1RP—Reads ETS1 data arrays and, if ETS parameters are defined, performs substitution using parameter values. GWF1ETS1RP is part of the Ground-Water Flow Process and is in source-code file gwf1ets1.f.

GWF1ETS1FM—Formulates terms needed to solve the ground-water flow equation and adds them to the head-coefficient array (HCOF) and to the right-hand side array (RHS). GWF1ETS1FM is part of the Ground-Water Flow Process and is in source-code file gwf1ets1.f.

GWF1ETS1BD—Computes flow rates simulated as evapotranspiration and writes cell-by-cell flow rates if that option is selected. GWF1ETS1BD is part of the Ground-Water Flow Process and is in source-code file gwf1ets1.f.

SEN1ETS1FM—Formulates terms needed to solve the sensitivity equation and adds them to the right-hand side array (RHS). SEN1ETS1FM is part of the Sensitivity Process and is in source-code file sen1ets1.f.

Module GWF1ETS1AL

Narrative for Module GWF1ETS1AL

This module reads package options from item 1 of the ETS1 input file and allocates space in the RX and IR arrays (Harbaugh and others, 2000). Output is written to the LIST file.

1. Print a message identifying the ETS1 Package.

2. Read and print comment lines (item 0) introduced with the “#” character.

3. Read values for the option indicator (NETSOP), the unit number for cell-by-cell flow terms (IETSCB), the number of parameters (NPETS), and number of segments (NETSEG). Ensure option is valid and print messages showing option and, if IETSCB is greater than zero, the unit number. Print numbers of parameters and segments.

4. Allocate space in the RX array for the ETSR, ETSX, and ETSS arrays and for the PXDP and PETM arrays if needed. Allocate space in the IR array for the IETS array.

5. Print a message showing amount of storage required by the ETS1 Package.

Listing for Module GWF1ETS1AL

```
      SUBROUTINE GWF1ETS1AL(ISUM,ISUMI,LCIETS,LCETSR,LCETSX,LCETSS,NCOL,
     &                      NROW,NETSOP,IN,IOUT,IETSCB,IFREFM,NPETS,
     &                      IETSPF,NETSEG,LCPXDP,LCPETM,NSEGAR)
C
C-----VERSION 20000620 ERB
C     ******************************************************************
C     ALLOCATE ARRAY STORAGE FOR EVAPOTRANSPIRATION SEGMENTS
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      CHARACTER*200 LINE
C     ------------------------------------------------------------------
  500 FORMAT(1X,/
     &1X,'ETS1 -- EVAPOTRANSPIRATION SEGMENTS PACKAGE, VERSION 1,',
     &     ' 5/2/2000',/,9X,'INPUT READ FROM UNIT',I3)
  510 FORMAT(
     &1X,I5,' SEGMENTS DEFINE EVAPOTRANSPIRATION RATE FUNCTION')
  520 FORMAT(' EVAPOTRANSPIRATION RATE FUNCTION IS LINEAR')
  530 FORMAT(
     &' ERROR: EVAPOTRANSPIRATION RATE FUNCTION MUST CONTAIN AT',/,
     &' LEAST ONE SEGMENT -- STOP EXECUTION (GWF1ETS1AL)')
  540 FORMAT(1X,'ILLEGAL ET OPTION CODE. SIMULATION ABORTING')
  550 FORMAT(1X,'OPTION 1 -- EVAPOTRANSPIRATION FROM TOP LAYER')
  560 FORMAT(1X,'OPTION 2 -- EVAPOTRANSPIRATION FROM ONE SPECIFIED',
     &   ' NODE IN EACH VERTICAL COLUMN')
  570 FORMAT(1X,'CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT',I3)
  580 FORMAT(1X,I10,' ELEMENTS IN RX ARRAY ARE USED BY ETS')
  590 FORMAT(1X,I10,' ELEMENTS IN IR ARRAY ARE USED BY ETS')
C
C1------IDENTIFY PACKAGE.
      IETSPF=20
      WRITE(IOUT,500)IN
C
C     READ COMMENT LINE(S) (ITEM 0)
      CALL URDCOM(IN,IOUT,LINE)
```

```
C
C2------READ ET OPTION (NETSOP), UNIT OR FLAG FOR CELL-BY-CELL FLOW
C       TERMS (IETSCB), NUMBER OF PARAMETERS (NPETS), AND NUMBER OF
C       SEGMENTS (NETSEG) (ITEM 1)
      IF (IFREFM.EQ.0) THEN
        READ(LINE,'(4I10)') NETSOP,IETSCB,NPETS,NETSEG
      ELSE
        LLOC=1
        CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,NETSOP,R,IOUT,IN)
        CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,IETSCB,R,IOUT,IN)
        CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,NPETS,R,IOUT,IN)
        CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,NETSEG,R,IOUT,IN)
      ENDIF
C
C3------CHECK TO SEE THAT ET OPTION IS LEGAL.
      IF (NETSOP.GE.1.AND.NETSOP.LE.2) GO TO 10
C
C3A-----OPTION IS ILLEGAL -- PRINT A MESSAGE & ABORT SIMULATION.
      WRITE(IOUT,540)
      STOP
C
C4------OPTION IS LEGAL -- PRINT THE OPTION CODE.
   10 CONTINUE
      IF (NETSOP.EQ.1) WRITE(IOUT,550)
      IF (NETSOP.EQ.2) WRITE(IOUT,560)
C
C5------IF CELL-BY-CELL FLOWS ARE TO BE SAVED, THEN PRINT UNIT NUMBER.
      IF (IETSCB.GT.0) WRITE(IOUT,570) IETSCB
C
C-----PRINT NUMBER OF PARAMETERS TO BE USED
      CALL UPARARRAL(-1,IOUT,LINE,NPETS)
C
C     PRINT MESSAGE IDENTIFYING NUMBER OF SEGMENTS IN ET VS. HEAD CURVE
      IF(NETSEG.GT.1) THEN
        WRITE(IOUT,510) NETSEG
        NSEGAR = NETSEG - 1
      ELSEIF (NETSEG.EQ.1) THEN
        WRITE(IOUT,520)
        NSEGAR = 1
      ELSE
        WRITE(IOUT,530)
        STOP
      ENDIF
C
C6------ALLOCATE SPACE FOR THE ARRAYS ETSR, ETSX, ETSS, PXDP, AND PETM.
      IRK=ISUM
      LCETSR=ISUM
      ISUM=ISUM+NCOL*NROW
      LCETSX=ISUM
      ISUM=ISUM+NCOL*NROW
      LCETSS=ISUM
      ISUM=ISUM+NCOL*NROW
      IF (NETSEG.GT.1) THEN
        LCPXDP=ISUM
        ISUM=ISUM+NCOL*NROW*(NETSEG-1)
        LCPETM=ISUM
        ISUM=ISUM+NCOL*NROW*(NETSEG-1)
      ELSE
        LCPXDP=1
        LCPETM=1
      ENDIF
C
```

```
C7------ALLOCATE SPACE FOR LAYER INDICATOR ARRAY (IETS) EVEN IF ET
C7------OPTION IS NOT 2, TO AVOID ERROR OF ARRAY (IR) NOT LARGE ENOUGH
      LCIETS=ISUMI
      ISUMI=ISUMI+NCOL*NROW
C
C8------CALCULATE & PRINT AMOUNT OF SPACE USED BY ET PACKAGE.
      IRK=ISUM-IRK
      WRITE(IOUT,580)IRK
      IRK=NCOL*NROW
      WRITE(IOUT,590)IRK
C
C9------RETURN.
      RETURN
      END
```

List of Variables for Module GWF1ETS1AL

Variable	**Range**	**Definition**
IETSCB	Package	Cell-by-cell flag and unit number
IETSPF	Package	Format code for printing the ETSR array when defined by parameters
IFREFM	Process	Flag indicating if variables are to be read in free format
IN	Module	Unit number of input file
IOUT	Global	Unit number of LIST output file
IRK	Module	Number of array elements required
ISTART	Module	Starting position of parsed word
ISTOP	Module	Ending position of parsed word
ISUM	Module	Pointer used to keep track of position in RX
ISUMI	Module	Pointer used to keep track of position in IR
LCETSR	Package	Position in RX of first element of ETSR
LCETSS	Package	Position in RX of first element of ETSS
LCETSX	Package	Position in RX of first element of ETSX
LCIETS	Package	Position in IR of first element of IETS
LCPETM	Package	Position in RX of first element of PETM
LCPXDP	Package	Position in RX of first element of PXDP
LINE	Module	Contents of one line read from input file
LLOC	Module	Pointer used to keep track of position in LINE
NCOL	Global	Number of columns in model grid
NETSEG	Package	Number of segments used to relate evapotranspiration rate to head
NETSOP	Package	Flag identifying layer distribution method for simulating evapotranspiration
NPETS	Package	Number of evapotranspiration parameters
NROW	Global	Number of rows in model grid
NSEGAR	Package	Dimensioning variable for PXDP and PETM
R	Module	Dummy real variable

Module GWF1ETS1RQ

Narrative for Module GWF1ETS1RQ

This module reads parameter definitions from items 2 and 3 of the ETS1 input file. Output is written to the GLOBAL file.

1. Print a message indicating how many evapotranspiration-segments parameters are being used.

2. For each evapotranspiration-segments parameter, call a utility that reads the parameter definition. The utility reads a record containing the parameter name, type, value, and number of clusters used to define the parameter, then reads one or more records containing a multiplier array name, zone array name, and a list of zone numbers.

Listing for Module GWF1ETS1RQ

```
      SUBROUTINE GWF1ETS1RQ(IN,IOUT,NPETS,ITERP)
C
C-----VERSION 20000620 ERB
C     ******************************************************************
C     READ EVAPOTRANSPIRATION SEGMENTS PARAMETER DEFINITIONS
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      CHARACTER*4 PTYP
C     ------------------------------------------------------------------
C
C-------READ NAMED PARAMETERS
      IF (ITERP.EQ.1) WRITE(IOUT,5) NPETS
    5 FORMAT(1X,//1X,I5,' Evapotranspiration segments parameters')
      IF (NPETS.GT.0) THEN
        DO 20 K=1,NPETS
C         UPARARRRP READS PARAMETER NAME AND DEFINITION (ITEMS 2 AND 3)
          CALL UPARARRRP(IN,IOUT,N,0,PTYP,ITERP)
          IF(PTYP.NE.'ETS') THEN
            WRITE(IOUT,7)
    7       FORMAT(1X,'Parameter type must be ETS')
            STOP
          ENDIF
   20   CONTINUE
      ENDIF
C
C8------RETURN
   60 RETURN
      END
```

List of Variables for Module GWF1ETS1RQ

Variable	Range	Definition
IN	Module	Unit number of input file
IOUT	Global	Unit number of GLOBAL output file
ITERP	Global	Parameter-estimation iteration number
K	Module	Counter for parameters
N	Module	Dummy integer variable
NPETS	Package	Number of evapotranspiration-segments parameters
PTYP	Global	Parameter type

Module GWF1ETS1RP

Narrative for Module GWF1ETS1RP

This module is called each stress period to read items 4 through 11 of the ETS1 input file. Output is written to the LIST file.

1. Read INETSS, INETSR, INETSX, INIETS, and INSGDF or a subset of these, depending on the option selected and the number of segments. These flags indicate which arrays need to be defined (or redefined) for the stress period.

2. If INETSS ≥ 0, call a utility to read data into ETSS; otherwise, print a message indicating that ETSS used in the previous stress period will be reused.

3. If INETSR ≥ 0, define ETSR either by reading directly (if NPETS = 0) or by calling a utility that generates the array by substitution, using evapotranspiration-segments parameters and their definitions. Multiply ETSR by the cell area to get a volumetric rate. If INETSR < 0, print a message indicating that ETSR used in the previous stress period will be reused.

4. If INETSX ≥ 0, call a utility to read data into ETSX; otherwise, print a message indicating that ETSX used in the previous stress period will be reused.

5. If NETSOP = 2 and INIETS ≥ 0, call a utility to read data into IETS. If NETSOP = 2 and INIETS < 0, print a message indicating that IETS used in the previous stress period will be reused.

6. If NETSEG > 1 and INSGDF ≥ 0, make calls to a utility to read data into PXDP and PETM for (NETSEG – 1) segment intersections. If NETSEG > 1 and INSGDF < 0, print a message indicating that PXDP and PETM used in the previous stress period will be reused.

Listing for Module GWF1ETS1RP

```
      SUBROUTINE GWF1ETS1RP(NETSOP,IETS,ETSR,ETSX,ETSS,DELR,DELC,NCOL,
     &                      NROW,IN,IOUT,IFREFM,NPETS,RMLT,IZON,NMLTAR,
     &                      NZONAR,IETSPF,NETSEG,PXDP,PETM,NSEGAR)
C
C     VERSION 20000620 ERB
C     ******************************************************************
C     READ EVAPOTRANSPIRATION DATA, AND PERFORM SUBSTITUTION USING
C     PARAMETER VALUES IF ETS PARAMETERS ARE DEFINED
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      CHARACTER*24 ANAME(6)
      DIMENSION IETS(NCOL,NROW),ETSR(NCOL,NROW),ETSX(NCOL,NROW),
     &          ETSS(NCOL,NROW),DELR(NCOL),DELC(NROW),
     &          RMLT(NCOL,NROW,NMLTAR),IZON(NCOL,NROW,NZONAR),
     &          PXDP(NCOL,NROW,NSEGAR),PETM(NCOL,NROW,NSEGAR)
C
      DATA ANAME(1) /'   ET LAYER INDEX (IETS)'/
      DATA ANAME(2) /'       ET SURFACE (ETSS)'/
      DATA ANAME(3) /' EVAPOTRANS. RATE (ETSR)'/
      DATA ANAME(4) /' EXTINCTION DEPTH (ETSX)'/
      DATA ANAME(5) /'EXTINCT. DEP. PROPORTION'/
      DATA ANAME(6) /'      ET RATE PROPORTION'/
C     ------------------------------------------------------------------
C
C1------READ FLAGS SHOWING WHETHER DATA FROM PREVIOUS STRESS PERIOD ARE
C       TO BE REUSED.
```

```
      IF (NETSEG.GT.1) THEN
        IF(IFREFM.EQ.0) THEN
          READ(IN,'(5I10)') INETSS,INETSR,INETSX,INIETS,INSGDF
        ELSE
          READ(IN,*) INETSS,INETSR,INETSX,INIETS,INSGDF
        ENDIF
      ELSE
        IF(NETSOP.EQ.2) THEN
          IF(IFREFM.EQ.0) THEN
            READ(IN,'(4I10)') INETSS,INETSR,INETSX,INIETS
          ELSE
            READ(IN,*) INETSS,INETSR,INETSX,INIETS
          ENDIF
        ELSE
          IF(IFREFM.EQ.0) THEN
            READ(IN,'(3I10)') INETSS,INETSR,INETSX
          ELSE
            READ(IN,*) INETSS,INETSR,INETSX
          ENDIF
        ENDIF
      ENDIF
C
C2------TEST INETSS TO SEE WHERE SURFACE ELEVATION COMES FROM.
      IF (INETSS.LT.0) THEN
C2A------IF INETSS<0 THEN REUSE SURFACE ARRAY FROM LAST STRESS PERIOD
        WRITE(IOUT,10)
   10   FORMAT(1X,/1X,'REUSING ETSS FROM LAST STRESS PERIOD')
      ELSE
C3-------IF INETSS=>0 THEN CALL MODULE U2DREL TO READ SURFACE.
        CALL U2DREL(ETSS,ANAME(2),NROW,NCOL,0,IN,IOUT)
      ENDIF
C
C4------TEST INETSR TO SEE WHERE MAX ET RATE COMES FROM.
      IF (INETSR.LT.0) THEN
C4A-----IF INETSR<0 THEN REUSE MAX ET RATE.
        WRITE(IOUT,20)
   20   FORMAT(1X,/1X,'REUSING ETSR FROM LAST STRESS PERIOD')
      ELSE
C5------IF INETSR=>0 CALL MODULE U2DREL TO READ MAX ET RATE.
        IF(NPETS.EQ.0) THEN
          CALL U2DREL(ETSR,ANAME(3),NROW,NCOL,0,IN,IOUT)
        ELSE
C    INETSR is the number of parameters to use this stress period
          CALL PRESET('ETS')
          WRITE(IOUT,30)
   30     FORMAT(1X,///1X,
     &        'ETSR array defined by the following parameters:')
          IF (INETSR.EQ.0) THEN
            WRITE(IOUT,35)
   35       FORMAT(' ERROR: When parameters are defined for the ETS',
     &      ' Package, at least one parameter',/,' must be specified',
     &      ' each stress period -- STOP EXECUTION (GWF1ETS1RP)')
            STOP
          ENDIF
          CALL UPARARRSUB2(ETSR,NCOL,NROW,0,INETSR,IN,IOUT,'ETS',
     &                     ANAME(3),'ETS',IETSPF,RMLT,IZON,NMLTAR,
     &                     NZONAR)
        ENDIF
C
C6------MULTIPLY MAX ET RATE BY CELL AREA TO GET VOLUMETRIC RATE
        DO 50 IR=1,NROW
          DO 40 IC=1,NCOL
            ETSR(IC,IR)=ETSR(IC,IR)*DELR(IC)*DELC(IR)
   40     CONTINUE
   50   CONTINUE
      ENDIF
```

```
C
C7------TEST INETSX TO SEE WHERE EXTINCTION DEPTH COMES FROM
      IF (INETSX.LT.0) THEN
C7A------IF INETSX<0 REUSE EXTINCTION DEPTH FROM LAST STRESS PERIOD
        WRITE(IOUT,60)
   60   FORMAT(1X,/1X,'REUSING ETSX FROM LAST STRESS PERIOD')
      ELSE
C8-------IF INETSX=>0 CALL MODULE U2DREL TO READ EXTINCTION DEPTH
        CALL U2DREL(ETSX,ANAME(4),NROW,NCOL,0,IN,IOUT)
      ENDIF
C
C9------IF OPTION(NETSOP) IS 2 THEN WE NEED AN INDICATOR ARRAY.
      IF (NETSOP.EQ.2) THEN
C10------IF INIETS<0 THEN REUSE LAYER INDICATOR ARRAY.
        IF (INIETS.LT.0) THEN
          WRITE(IOUT,70)
   70     FORMAT(1X,/1X,'REUSING IETS FROM LAST STRESS PERIOD')
        ELSE
C11------IF INIETS=>0 THEN CALL MODULE U2DINT TO READ INDICATOR ARRAY.
          CALL U2DINT(IETS,ANAME(1),NROW,NCOL,0,IN,IOUT)
        ENDIF
      ENDIF
C
C12------IF ET FUNCTION IS SEGMENTED PXDP AND PETM ARRAYS ARE NEEDED.
      IF (NETSEG.GT.1) THEN
C13------IF INSGDF<0 THEN REUSE PXDP AND PETM ARRAYS.
        IF (INSGDF.LT.0) THEN
          WRITE(IOUT,80)
   80     FORMAT(1X,/1X,
     &           'REUSING PXDP AND PETM FROM LAST STRESS PERIOD')
C14------IF INSGDF=>0 THEN CALL MODULE U2DREL TO READ PXDP AND PETM
C         ARRAYS.
        ELSE
          DO 90 I = 1,NETSEG-1
            WRITE(IOUT,100) I
            CALL U2DREL(PXDP(1,1,I),ANAME(5),NROW,NCOL,0,IN,IOUT)
            CALL U2DREL(PETM(1,1,I),ANAME(6),NROW,NCOL,0,IN,IOUT)
   90     CONTINUE
        ENDIF
      ENDIF
  100 FORMAT(/,' PXDP AND PETM ARRAYS FOR INTERSECTION ',I4,
     &' OF HEAD/ET RELATION:')
C
C15-----RETURN
      RETURN
      END
```

List of Variables for Module GWF1ETS1RP

Variable	Range	Definition
ANAME	Module	Array content label
DELC	Global	Cell dimension in the column direction
DELR	Global	Cell dimension in the row direction
ETSR	Package	Maximum evapotranspiration rate
ETSS	Package	Evapotranspiration (ET) surface
ETSX	Package	Extinction depth
I	Module	Counter for segments
IC	Module	Column index

Variable	Range	Definition
IETS	Package	Layer indicator
IETSPF	Package	Format code for printing the ETSR array when defined by parameters
IFREFM	Process	Flag indicating if variables are to be read in free format
IN	Module	Unit number of input file
INETSR	Module	Flag indicating if ETSR is to be defined or redefined
INETSS	Module	Flag indicating if ETSS is to be read
INETSX	Module	Flag indicating if ETSX is to be read
INIETS	Module	Flag indicating if IETS is to be read
INSGDF	Module	Flag indicating if PXDP and PETM are to be read
IOUT	Global	Unit number of LIST output file
IR	Module	Row index
IZON	Global	Zone arrays
NCOL	Global	Number of columns in model grid
NETSEG	Package	Number of segments used to relate evapotranspiration rate to head
NETSOP	Package	Flag identifying layer distribution method for simulating evapotranspiration
NMLTAR	Global	Dimensioning variable for RMLT
NPETS	Package	Number of evapotranspiration parameters
NROW	Global	Number of rows in model grid
NSEGAR	Package	Dimensioning variable for PXDP and PETM
NZONAR	Global	Dimensioning variable for IZON
PETM	Package	Proportion of maximum evapotranspiration rate
PXDP	Package	Proportion of extinction depth
RMLT	Global	Multiplier arrays

Module GWF1ETS1FM

Narrative for Module GWF1ETS1FM

This module adds terms to the finite-difference equations to account for loss of water from the ground-water system by evapotranspiration.

1. For each cell in the horizontal model grid, determine the layer in which evapotranspiration is simulated and add the terms to the equation for the cell. Do steps 2 through 10 for each cell in the horizontal model grid.

2. Set the layer index to 1.

3. If NETSOP = 2, get the layer index from the layer indicator array (IETS).

4. If the cell is inactive or constant-head, skip steps 5 through 10.

5. If the head in the cell is greater than or equal to the ET surface, add ETSR to the right-hand side array (RHS) and move on to the next cell location. Skip steps 6 through 10.

6. If the head in the cell is less than the extinction elevation (ET surface minus extinction depth), no terms need to be added to the finite-difference equation. Move on to the next cell location. Skip steps 7 through 10.

7. If NETSEG = 1, add the term [–ETSR/ETSX] to HCOF and subtract the term [–ETSR*(ETSX – ETSS)/ETSX] from RHS. Skip steps 8 through 10.

8. If NETSEG > 1, set the proportion of extinction depth to 0.0 and the proportion of maximum ET rate to 1.0 to correspond to the top of the first segment, which is at the ET surface.

9. Find the segment that applies to the head elevation by comparing the head with the bottom of successively lower segments until the head is at or above the bottom of a segment. For the bottom of the final segment, set the proportion of extinction depth to 1.0 and the proportion of maximum ET rate to 0.0.

10. Add the term [–($PETM_1$–$PETM_2$)*ETSR/(($PXDP_2$–$PXDP_1$)*ETSX)] to HCOF and subtract the term [($PETM_1$–$PETM_2$)*ETSR/(($PXDP_2$–$PXDP_1$)*ETSX)*(ETSS–$PXDP_1$*ETSX) – $PETM_1$*ETSR] from RHS, where the subscript 1 refers to the point at the top of the segment, and subscript 2 refers to the point at the bottom of the segment.

Listing for Module GWF1ETS1FM

```
      SUBROUTINE GWF1ETS1FM(NETSOP,IETS,ETSR,ETSX,ETSS,RHS,HCOF,IBOUND,
     &                      HNEW,NCOL,NROW,NLAY,NETSEG,PXDP,PETM,
     &                      NSEGAR)
C
C-----VERSION 20000620 ERB
C     ******************************************************************
C        ADD EVAPOTRANSPIRATION TO RHS AND HCOF
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      DOUBLE PRECISION HNEW, HH, SS, XX, DD, PXDP1, PXDP2
      DIMENSION IETS(NCOL,NROW), ETSR(NCOL,NROW), ETSX(NCOL,NROW),
     &          ETSS(NCOL,NROW), RHS(NCOL,NROW,NLAY),
     &          HCOF(NCOL,NROW,NLAY), IBOUND(NCOL,NROW,NLAY),
     &          HNEW(NCOL,NROW,NLAY), PXDP(NCOL,NROW,NSEGAR),
     &          PETM(NCOL,NROW,NSEGAR)
C     ------------------------------------------------------------------
C
C1------PROCESS EACH HORIZONTAL CELL LOCATION
      DO 30 IR=1,NROW
        DO 20 IC=1,NCOL
C
C2------SET THE LAYER INDEX EQUAL TO 1      .
          IL=1
C
C3------IF OPTION 2 IS SPECIFIED THEN GET LAYER INDEX FROM IETS ARRAY
          IF (NETSOP.EQ.2) IL=IETS(IC,IR)
C
C4------IF THE CELL IS EXTERNAL IGNORE IT.
          IF (IBOUND(IC,IR,IL).GT.0) THEN
            C=ETSR(IC,IR)
            S=ETSS(IC,IR)
            SS=S
            HH=HNEW(IC,IR,IL)
C
C5------IF HEAD IN CELL IS GREATER THAN OR EQUAL TO ETSS, ET IS CONSTANT
            IF(HH.GE.SS) THEN
C
```

```
C5A-----SUBTRACT -ETSR FROM RHS
              RHS(IC,IR,IL)=RHS(IC,IR,IL) + C
            ELSE
C
C6------IF DEPTH TO WATER>=EXTINCTION DEPTH THEN ET IS 0
              DD=SS-HH
              X=ETSX(IC,IR)
              XX=X
              IF (DD.LT.XX) THEN
C7------VARIABLE RANGE. ADD ET TERMS TO BOTH RHS AND HCOF.
C
                IF (NETSEG.GT.1) THEN
C                 DETERMINE WHICH SEGMENT APPLIES BASED ON HEAD, AND
C                 CALCULATE TERMS TO ADD TO RHS AND HCOF
C
C                 SET PROPORTIONS CORRESPONDING TO ETSS ELEVATION
                  PXDP1 = 0.0
                  PETM1 = 1.0
                  DO 10 ISEG = 1,NETSEG
C                   SET PROPORTIONS CORRESPONDING TO LOWER END OF
C                   SEGMENT
                    IF (ISEG.LT.NETSEG) THEN
                      PXDP2 = PXDP(IC,IR,ISEG)
                      PETM2 = PETM(IC,IR,ISEG)
                    ELSE
                      PXDP2 = 1.0
                      PETM2 = 0.0
                    ENDIF
                    IF (DD.LE.PXDP2*XX) THEN
C                     HEAD IS IN DOMAIN OF THIS SEGMENT
                      GOTO 15
                    ENDIF
C                   PROPORTIONS AT LOWER END OF SEGMENT WILL BE FOR
C                   UPPER END OF SEGMENT NEXT TIME THROUGH LOOP
                    PXDP1 = PXDP2
                    PETM1 = PETM2
   10             CONTINUE
   15             CONTINUE
C                 CALCULATE TERMS TO ADD TO RHS AND HCOF BASED ON
C                 SEGMENT THAT APPLIES AT HEAD ELEVATION
                  THCOF = -(PETM1-PETM2)*C/((PXDP2-PXDP1)*X)
                  TRHS = THCOF*(S-PXDP1*X) + PETM1*C
                ELSE
C                 CALCULATE TERMS TO ADD TO RHS AND HCOF BASED ON SIMPLE
C                 LINEAR RELATION OF ET VS. HEAD
                  TRHS = C-C*S/X
                  THCOF = -C/X
                ENDIF
                RHS(IC,IR,IL)=RHS(IC,IR,IL)+TRHS
                HCOF(IC,IR,IL)=HCOF(IC,IR,IL)+THCOF
              ENDIF
            ENDIF
          ENDIF
   20   CONTINUE
   30 CONTINUE
C
C8------RETURN
      RETURN
      END
```

List of Variables for Module GWF1ETS1FM

Variable	Range	Definition
C	Module	Maximum evapotranspiration rate for a cell
DD	Module	Depth of head below ET surface
ETSR	Package	Maximum evapotranspiration rate
ETSS	Package	ET surface
ETSX	Package	Extinction depth
HCOF	Global	Head-coefficient array
HH	Module	Head in a cell
HNEW	Global	Head
IBOUND	Global	Boundary-status indicator
IC	Module	Column index
IETS	Package	Layer indicator
IL	Module	Layer index
IR	Module	Row index
ISEG	Module	Counter for segments
NCOL	Global	Number of columns in model grid
NETSEG	Package	Number of segments used to relate evapotranspiration rate to head
NETSOP	Package	Flag identifying layer distribution method for simulating evapotranspiration
NLAY	Global	Number of layers in model grid
NROW	Global	Number of rows in model grid
NSEGAR	Package	Dimensioning variable for PXDP and PETM
PETM	Package	Proportion of maximum evapotranspiration rate
PETM1	Module	Proportion of maximum evapotranspiration rate at the top of a segment
PETM2	Module	Proportion of maximum evapotranspiration rate at the bottom of a segment
PXDP	Package	Proportion of extinction depth
PXDP1	Module	Proportion of extinction depth at the top of a segment
PXDP2	Module	Proportion of extinction depth at the bottom of a segment
RHS	Global	Right-hand side
S	Module	ET surface for a cell
SS	Module	ET surface for a cell
THCOF	Module	Term to be added to HCOF
TRHS	Module	Term to be added to RHS
X	Module	Extinction depth for a cell
XX	Module	Extinction depth for a cell

Module GWF1ETS1BD

Narrative for Module GWF1ETS1BD

This module calculates rates and volumes of water removed from the simulated system by evapotranspiration. Output is written to the LIST file and, optionally, to the unformatted file associated with unit IETSCB.

1. Set the rate accumulator RATOUT to zero.
2. If budget terms will be saved, clear the buffer (BUFF) in which the budget terms will be accumulated.
3. For each cell in the horizontal model grid calculate flow to evapotranspiration (steps 4 through 14).
4. Set the layer index (IL) equal to 1.
5. If NETSOP = 2, get the layer indicator (IETS).
6. If the cell is inactive or constant-head, skip steps 7 through 14.
7. If the head in the cell is greater than the elevation of the ET surface, set the ET rate for the cell equal to the maximum ET rate. Skip steps 8 through 12.
8. If the depth of the head in the cell below the ET surface is greater than the extinction depth, skip steps 9 through 12.
9. If NETSEG = 1, calculate the evapotranspiration rate for the cell using the linear relation defined by equation (1). Skip steps 10 through 12.
10. If NETSEG > 1, set the proportion of extinction depth to 0.0 and the proportion of maximum ET rate to 1.0 to correspond to the top of the first segment, which is at the ET surface.
11. Find the segment that applies to the head elevation by comparing the head with the bottom of successively lower segments until the head is at or above the bottom of a segment. For the bottom of the final segment, set the proportion of extinction depth to 1.0 and the proportion of maximum ET rate to 0.0.
12. Using the end points of the applicable segment and equation (2), calculate the evapotranspiration rate for the cell.
13. Subtract the ET flow rate from the accumulator (RATOUT).
14. If the cell-by-cell flow terms are to be saved, add the ET flow rate to the buffer (BUFF).
15. If the cell-by-cell flow terms are to be saved, call a utility to write the flow rates to the unformatted file associated with unit IETSCB.
16. Move RATOUT into the VBVL array for printing.
17. Add RATOUT multiplied by the time-step length to the volume accumulators in VBVL for printing.
18. Move the ET budget-term labels to VBNM for printing.
19. Increment the budget-term counter.

Listing for Module GWF1ETS1BD

```
      SUBROUTINE GWF1ETS1BD(NETSOP,IETS,ETSR,ETSX,ETSS,IBOUND,HNEW,NCOL,
     &                      NROW,NLAY,DELT,VBVL,VBNM,MSUM,KSTP,KPER,
     &                      IETSCB,ICBCFL,BUFF,IOUT,PERTIM,TOTIM,NETSEG,
     &                      PXDP,PETM,NSEGAR)
C-----VERSION 20000620 ERB
C     ******************************************************************
C     CALCULATE VOLUMETRIC BUDGET FOR EVAPOTRANSPIRATION SEGMENTS
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      CHARACTER*16 VBNM(MSUM), TEXT
      DOUBLE PRECISION HNEW, RATOUT, QQ, HH, SS, DD, XX, HHCOF, RRHS,
     &                 PXDP1, PXDP2
      DIMENSION IETS(NCOL,NROW), ETSR(NCOL,NROW), ETSX(NCOL,NROW),
     &          ETSS(NCOL,NROW), IBOUND(NCOL,NROW,NLAY),
     &          VBVL(4,MSUM), HNEW(NCOL,NROW,NLAY),
     &          BUFF(NCOL,NROW,NLAY), PXDP(NCOL,NROW,NSEGAR),
     &          PETM(NCOL,NROW,NSEGAR)
C
      DATA TEXT /'     ET SEGMENTS'/
C     ------------------------------------------------------------------
C
C1------CLEAR THE RATE ACCUMULATOR.
      ZERO=0.
      RATOUT=ZERO
C
C2------SET CELL-BY-CELL BUDGET SAVE FLAG (IBD) AND CLEAR THE BUFFER.
      IBD=0
      IF(IETSCB.GT.0) IBD=ICBCFL
      DO 30 IL=1,NLAY
        DO 20 IR=1,NROW
          DO 10 IC=1,NCOL
            BUFF(IC,IR,IL)=ZERO
   10     CONTINUE
   20   CONTINUE
   30 CONTINUE
C
C3------PROCESS EACH HORIZONTAL CELL LOCATION.
      DO 70 IR=1,NROW
        DO 60 IC=1,NCOL
C
C4------SET THE LAYER INDEX EQUAL TO 1.
          IL=1
C
C5------IF OPTION 2 IS SPECIFIED THEN GET LAYER INDEX FROM IETS ARRAY.
          IF (NETSOP.EQ.2) IL=IETS(IC,IR)
C
C6------IF CELL IS EXTERNAL THEN IGNORE IT.
          IF (IBOUND(IC,IR,IL).GT.0) THEN
            C=ETSR(IC,IR)
            S=ETSS(IC,IR)
            SS=S
            HH=HNEW(IC,IR,IL)
C
C7------IF AQUIFER HEAD => ETSS,SET Q=MAX ET RATE.
            IF (HH.GE.SS) THEN
             QQ=-C
            ELSE
C
C8------IF DEPTH=>EXTINCTION DEPTH, ET IS 0.
```

```
              X=ETSX(IC,IR)
              XX=X
              DD=SS-HH
              IF (DD.LT.XX) THEN
C9------VARIABLE RANGE.  CALCULATE Q DEPENDING ON NUMBER OF SEGMENTS
C
                IF (NETSEG.GT.1) THEN
C                 DETERMINE WHICH SEGMENT APPLIES BASED ON HEAD, AND
C                 CALCULATE TERMS TO ADD TO RHS AND HCOF
C
C                 SET PROPORTIONS CORRESPONDING TO ETSS ELEVATION
                  PXDP1 = 0.0
                  PETM1 = 1.0
                  DO 40 ISEG = 1,NETSEG
C                   SET PROPORTIONS CORRESPONDING TO LOWER END OF
C                   SEGMENT
                    IF (ISEG.LT.NETSEG) THEN
                      PXDP2 = PXDP(IC,IR,ISEG)
                      PETM2 = PETM(IC,IR,ISEG)
                    ELSE
                      PXDP2 = 1.0
                      PETM2 = 0.0
                    ENDIF
                    IF (DD.LE.PXDP2*XX) THEN
C                     HEAD IS IN DOMAIN OF THIS SEGMENT
                      GOTO 50
                    ENDIF
C                   PROPORTIONS AT LOWER END OF SEGMENT WILL BE FOR
C                   UPPER END OF SEGMENT NEXT TIME THROUGH LOOP
                    PXDP1 = PXDP2
                    PETM1 = PETM2
   40             CONTINUE
   50             CONTINUE
C9------CALCULATE ET RATE BASED ON SEGMENT THAT APPLIES AT HEAD
C9------ELEVATION
                  HHCOF = -(PETM1-PETM2)*C/((PXDP2-PXDP1)*X)
                  RRHS = -HHCOF*(S-PXDP1*X) - PETM1*C
                ELSE
C10-----SIMPLE LINEAR RELATION.  Q=-ETSR*(HNEW-(ETSS-ETSX))/ETSX, WHICH
C10-----IS FORMULATED AS Q= -HNEW*ETSR/ETSX + (ETSR*ETSS/ETSX -ETSR).
                  HHCOF = -C/X
                  RRHS = (C*S/X) - C
                ENDIF
                QQ = HH*HHCOF + RRHS
              ELSE
                QQ = 0.0
              ENDIF
            ENDIF
C
C10-----ACCUMULATE TOTAL FLOW RATE.
            Q=QQ
            RATOUT=RATOUT-QQ
C
C11-----ADD Q TO BUFFER.
            BUFF(IC,IR,IL)=Q
          ENDIF
   60   CONTINUE
   70 CONTINUE
C
C12-----IF CELL-BY-CELL FLOW TO BE SAVED, CALL APPROPRIATE UTILITY
C12-----MODULE SAVE THEM.
      IF(IBD.EQ.1) CALL UBUDSV(KSTP,KPER,TEXT,IETSCB,BUFF,NCOL,NROW,
     &                         NLAY,IOUT)
```

```
      IF(IBD.EQ.2) CALL UBDSV3(KSTP,KPER,TEXT,IETSCB,BUFF,IETS,NETSOP,
     &                   NCOL,NROW,NLAY,IOUT,DELT,PERTIM,TOTIM,IBOUND)
C
C13-----MOVE TOTAL ET RATE INTO VBVL FOR PRINTING BY BAS1OT.
      ROUT=RATOUT
      VBVL(3,MSUM)=ZERO
      VBVL(4,MSUM)=ROUT
C
C14-----ADD ET(ET_RATE TIMES STEP LENGTH) TO VBVL.
      VBVL(2,MSUM)=VBVL(2,MSUM)+ROUT*DELT
C
C15-----MOVE BUDGET TERM LABELS TO VBNM FOR PRINT BY MODULE BAS1OT.
      VBNM(MSUM)=TEXT
C
C16-----INCREMENT BUDGET TERM COUNTER.
      MSUM=MSUM+1
C
C17-----RETURN.
      RETURN
      END
```

List of Variables for Module GWF1ETS1BD

Variable	Range	Definition
BUFF	Global	Buffer used to accumulate information before printing or recording it
C	Module	Maximum evapotranspiration rate at a cell
DD	Module	Depth of head below the ET surface
DELT	Global	Length of the current time step
ETSR	Package	Maximum evapotranspiration rate
ETSS	Package	Elevation of the ET surface
ETSX	Package	Extinction depth
HH	Module	Head in a cell
HHCOF	Module	Coefficient of head in expression to calculate ET rate
HNEW	Global	Head
IBD	Module	Cell-by-cell budget save flag
IBOUND	Global	Boundary-status indicator
IC	Module	Column index
ICBCFL	Process	Cell-by-cell flow-term write flag
IETS	Package	Layer indicator
IETSCB	Package	Cell-by-cell flow-term write flag for evapotranspiration package
IL	Module	Layer index
IOUT	Global	Unit number of LIST output file
IR	Module	Row index
ISEG	Module	Counter for segments
KPER	Global	Stress period counter
KSTP	Global	Time step counter

Variable	Range	Definition
MSUM	Global	Counter for budget entries and labels in VBVL and VBNM
NCOL	Global	Number of columns in model grid
NETSEG	Package	Number of segments used to relate evapotranspiration rate to head
NETSOP	Package	Flag identifying layer distribution method for simulating evapotranspiration
NLAY	Global	Number of layers in model grid
NROW	Global	Number of rows in model grid
NSEGAR	Package	Dimensioning variable for PXDP and PETM
PERTIM	Global	Elapsed time since beginning of stress period
PETM	Package	Proportion of maximum evapotranspiration rate
PETM1	Module	Proportion of maximum evapotranspiration rate at the top of a segment
PETM2	Module	Proportion of maximum evapotranspiration rate at the bottom of a segment
PXDP	Package	Proportion of extinction depth
PXDP1	Module	Proportion of extinction depth at the top of a segment
PXDP2	Module	Proportion of extinction depth at the bottom of a segment
Q	Module	Flow from ET into the cell. (Reverse the sign to get the flow to ET.)
QQ	Module	Flow from ET into the cell. (Reverse the sign to get the flow to ET.)
RATOUT	Module	Accumulator for the total flow out of ground-water system to evapotranspiration
ROUT	Module	Total flow out of ground-water system to evapotranspiration
RRHS	Module	Constant term in expression to calculate ET rate
S	Module	Elevation of the ET surface for a cell
SS	Module	Elevation of the ET surface for a cell
TEXT	Module	Label to be printed or recorded with the array data
TOTIM	Global	Elapsed time since beginning of simulation
VBNM	Global	Labels for entries in the volumetric budget
VBVL	Global	Entries for the volumetric budget
X	Module	Extinction depth for a cell
XX	Module	Extinction depth for a cell
ZERO	Module	0.0

Module SEN1ETS1FM

Narrative for Module SEN1ETS1FM

This module formulates a derivative needed to solve the sensitivity equation for one evapotranspiration-segments parameter and adds the derivative to the RHS array.

1. If the parameter is not active during current time step, return.

2. For each cluster in the parameter definition, do steps 3 through 13.

3. Get the multiplier array number, zone array number, and index of the last zone number for this cluster.

4. For each cell in the horizontal model grid, do steps 5 through 13.

5. Set a multiplication factor equal to the value in the multiplier array, or set the factor to one if no multiplier array applies.

6. If a zone array applies, check to see if the current cell is in a zone to which this parameter applies. If not, set the multiplication factor to zero.

7. If the multiplication factor equals zero, skip steps 8 through 13.

8. Set a variable that accumulates contributions to the derivative equal to the negative of the product of the multiplication factor and the cell area. Based on the NETSOP option selected, determine the layer index of the cell to which evapotranspiration applies.

9. If the head in the cell is at or above the ET surface, skip steps 10 through 12.

10. If the depth of head in the cell below the ET surface is greater than or equal to the extinction depth, skip steps 11 through 13.

11. If NETSEG = 1, calculate the contribution to RHS as the accumulator variable, adjusted by the ratio of the depth of the head below the ET surface to the extinction depth. Skip step 12.

12. If NETSEG > 1, determine which segment contains the head elevation and determine the endpoints of the segment. Calculate the contribution to RHS as the accumulator variable, with an adjustment based on the segment and the head elevation.

13. Subtract the contribution from RHS.

Listing for Module SEN1ETS1FM

```
      SUBROUTINE SEN1ETS1FM(NCOL,NROW,NLAY,DELR,DELC,RMLT,NETSOP,IETS,
     &                      IBOUND,RHS,ETSS,ETSX,HNEW,IZON,NMLTAR,
     &                      NZONAR,IP,NETSEG,PXDP,PETM,NSEGAR)
C-----VERSION 20000328 ERB
C     ******************************************************************
C     CALCULATE FORCING FUNCTION DERIVATIVE FOR ETS AND ADD TO RHS.
C     ******************************************************************
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      REAL DDD, DELC, DELR, ETSX, H, RHS, S, SM, RMLT, ETSS, XXX, ZERO
      INTEGER IBOUND, IC, IFL, NETSOP, IETS, IR, IZ, K, KK, IZON, NCOL,
     &        NLAY, NROW, NZ
      DOUBLE PRECISION RO, HNEW(NCOL,NROW,NLAY), PXDP1, PXDP2
      DIMENSION DELR(NCOL), DELC(NROW), IETS(NCOL,NROW),
     &          RMLT(NCOL,NROW,NMLTAR), IBOUND(NCOL,NROW,NLAY),
     &          RHS(NCOL,NROW,NLAY), ETSS(NCOL,NROW),
     &          ETSX(NCOL,NROW), IZON(NCOL,NROW,NZONAR),
     &          PXDP(NCOL,NROW,NSEGAR), PETM(NCOL,NROW,NSEGAR)
      INCLUDE 'param.inc'
C     ------------------------------------------------------------------
      IF (IACTIVE(IP).EQ.0) RETURN
      ZERO = 0.0
      ICL1 = IPLOC(1,IP)
      ICL2 = IPLOC(2,IP)
C-----LOOP THROUGH CLUSTERS
      DO 70 K = ICL1, ICL2
        M = IPCLST(2,K)
        LZ1 = IPCLST(3,K)
        LASTZ = IPCLST(4,K)
C-------LOOP THROUGH CELLS
```

```
        DO 60 IR = 1, NROW
          DO 50 IC = 1, NCOL
            SM = 1.
            IF (M.GT.0) SM = RMLT(IC,IR,M)
            IF (LZ1.GT.0) THEN
              IFL = 0
              DO 10 IZ = 5, LASTZ
                NZ = IPCLST(IZ,K)
                IF (NZ.EQ.0 .OR. IFL.EQ.1) GOTO 20
                IF (NZ.EQ.IZON(IC,IR,LZ1)) IFL = 1
   10         CONTINUE
   20         IF (IFL.EQ.0) SM = ZERO
            ENDIF
            IF (SM.EQ.ZERO) GOTO 50
C--------NETSOP=1
            IF (NETSOP.EQ.1 .AND. IBOUND(IC,IR,1).LT.1) GOTO 50
            IF (NETSOP.EQ.1 .AND. IBOUND(IC,IR,1).GT.0) THEN
              RO = SM*DELR(IC)*DELC(IR)
              KK = 1
            ENDIF
C--------NETSOP=2
            IF (NETSOP.EQ.2) THEN
              IF (IBOUND(IC,IR,(IETS(IC,IR))).LT.1) GOTO 50
              IF (IBOUND(IC,IR,(IETS(IC,IR))).GT.0) THEN
                RO = SM*DELR(IC)*DELC(IR)
                KK = IETS(IC,IR)
              ENDIF
            ENDIF
C--------ADJUST
            RO = -RO
            S = ETSS(IC,IR)
            H = HNEW(IC,IR,KK)
            IF (H.LT.S) THEN
              DDD = S - H
              XXX = ETSX(IC,IR)
              IF (DDD.GE.XXX) GOTO 50
C--------VARIABLE RANGE. CALCULATE DERIVATIVE AND ADD TO RHS
C
              IF (NETSEG.GT.1) THEN
C               DETERMINE WHICH SEGMENT APPLIES BASED ON HEAD
C
C               SET PROPORTIONS CORRESPONDING TO ETSS ELEVATION
                PXDP1 = 0.0
                PETM1 = 1.0
                DO 30 ISEG = 1,NETSEG
C                 SET PROPORTIONS CORRESPONDING TO LOWER END OF
C                 SEGMENT
                  IF (ISEG.LT.NETSEG) THEN
                    PXDP2 = PXDP(IC,IR,ISEG)
                    PETM2 = PETM(IC,IR,ISEG)
                  ELSE
                    PXDP2 = 1.0
                    PETM2 = 0.0
                  ENDIF
                  IF (DDD.LE.PXDP2*XXX) THEN
C                   HEAD IS IN DOMAIN OF THIS SEGMENT
                    GOTO 40
                  ENDIF
C                 PROPORTIONS AT LOWER END OF SEGMENT WILL BE FOR
C                 UPPER END OF SEGMENT NEXT TIME THROUGH LOOP
                  PXDP1 = PXDP2
                  PETM1 = PETM2
   30           CONTINUE
```

```
   40           CONTINUE
C               CALCULATE FORCING FUNCTION DERIVATIVE BASED ON
C               SEGMENT THAT APPLIES AT HEAD ELEVATION
                PSLOPE = (PETM1-PETM2)/(PXDP2-PXDP1)
                RO = RO*(PETM1+PSLOPE*(PXDP1-DDD/XXX))
              ELSE
                RO = RO*(1.-(DDD/XXX))
              ENDIF
            ENDIF
C--------CONTRIBUTIONS TO RHS.
            RHS(IC,IR,KK) = RHS(IC,IR,KK) - RO
   50     CONTINUE
   60   CONTINUE
   70 CONTINUE
C
      RETURN
      END
```

List of Variables for Module SEN1ETS1FM

Variable	Range	Definition
DDD	Module	Depth of head below ET surface in a cell
DELC	Global	Cell dimension in the column direction
DELR	Global	Cell dimension in the row direction
ETSS	Package	Elevation of the ET surface
ETSX	Package	Extinction depth
H	Module	Head in a cell
HNEW	Global	Head
IACTIVE	Global	Flag indicating if a parameter is active
IBOUND	Global	Boundary-status indicator
IC	Module	Column index
ICL1	Module	Location in IPCLST array of first cluster in a parameter definition
ICL2	Module	Location in IPCLST array of last cluster in a parameter definition
IETS	Package	Layer indicator
IFL	Module	Indicator that cell is in zone included in a cluster of a parameter definition
IP	Module	Parameter number
IPCLST	Global	Array of parameter clusters
IPLOC	Global	First and last locations in IPCLST of clusters associated with each parameter
IR	Module	Row index
ISEG	Module	Segment index
IZ	Module	Zone-number index
IZON	Global	Zone arrays
K	Module	Cluster index
KK	Module	Layer number where ET may be simulated

Variable	Range	Definition
LASTZ	Module	Index of last zone number for cluster
LZ1	Module	Zone-array number
M	Module	Multiplier-array number
NCOL	Global	Number of columns in model grid
NETSEG	Package	Number of segments used to relate evapotranspiration rate to head
NETSOP	Package	Flag identifying layer distribution method for simulating evapotranspiration
NLAY	Global	Number of layers in model grid
NMLTAR	Global	Dimensioning variable for RMLT
NROW	Global	Number of rows in model grid
NSEGAR	Package	Dimensioning variable for PXDP and PETM
NZ	Module	Zone number
NZONAR	Global	Dimensioning variable for IZON
PETM	Package	Proportion of maximum evapotranspiration rate
PETM1	Module	Proportion of maximum evapotranspiration rate at the top of a segment
PETM2	Module	Proportion of maximum evapotranspiration rate at the bottom of a segment
PSLOPE	Module	Normalized slope of a segment
PXDP	Package	Proportion of extinction depth
PXDP1	Module	Proportion of extinction depth at the top of a segment
PXDP2	Module	Proportion of extinction depth at the bottom of a segment
RHS	Global	Right hand side
RMLT	Global	Multiplier arrays
RO	Module	Derivative of volumetric ET rate with respect to an ETS parameter
S	Module	ET surface at a cell
SM	Module	Parameter multiplier
XXX	Module	Extinction depth at a cell
ZERO	Module	0.0

DRAIN RETURN PACKAGE

In the Drain (DRN) Package, which has been included in MODFLOW since its initial release, ground water simulated as exiting the ground-water system by way of drain cells is accounted for in the volumetric budget, but otherwise is removed from the system. In the Drain Return (DRT1) Package documented in this report, the user can specify that a certain fraction of the simulated drain flow be returned simultaneously to any cell in the system. One use for this capability would be to simulate a situation where water discharging from a well, which is completed in a confined aquifer and has a hydraulic head above land surface, flows onto the land surface and may infiltrate and recharge a shallow aquifer. Flowing wells can be simulated with either the DRN Package or the DRT1 Package. If the fraction of well discharge recharging the shallow aquifer can be estimated, the DRT1 Package can be used effectively to more accurately simulate the ground-water system.

Conceptualization of Drains with Return Flow

When the DRT1 Package is used, activation of the return-flow capability is optional. If the return-flow capability is not selected, the internal functioning of the DRT1 Package is identical to the DRN Package (Harbaugh and others, 2000; Hill and others, 2000), although the formats of the first few lines of the input files differ.

When the return-flow option of the DRT1 Package is selected, each cell designated as having a drain may have either zero or one associated cell where some portion of the flow simulated as exiting the system at the drain may be simulated as returning to the system. In the context of the DRT1 Package, the cell where the drain is located is referred to as the drain-return cell. The cell where flow returns to the system is referred to as the recipient cell.

To help distinguish the DRT1 Package from the DRN Package, the cell where the drain is located will be referred to as the drain-return cell in this documentation, even if the return-flow option is not selected. In some cases, to conserve space in the model output, “drain cell” or “drain” is used to refer to drain-return cells. In these cases, additional text (for example, “DRT”) is printed to avoid possible confusion with output of the DRN Package.

The functioning of drain-return cells and the return-flow capability is conceptually simple. For each drain-return cell, the user identifies a recipient cell and a return-flow proportion in the range 0.0 to 1.0. Flow out of the ground-water system at the drain-return cell is governed by one of two equations, depending on the head in the cell relative to the drain elevation:

$$QD_{i,\,j,\,k} = CD_{i,\,j,\,k}(h_{i,\,j,\,k} - d_{i,\,j,\,k}) \tag{3}$$

$$QD_{i,\,j,\,k} = 0 \tag{4}$$

where

$QD_{i,j,k}$ is the volumetric flow rate (L^3/T) computed from cell *i,j,k* for the drain-return feature,

$CD_{i,j,k}$ is the drain conductance (L^2/T) for the drain-return feature in cell *i,j,k*,

$h_{i,j,k}$ is the hydraulic head (L) computed for cell *i,j,k*, and

$d_{i,j,k}$ is the drain elevation (L) for the drain-return feature in cell *i,j,k*.

When the head in the drain-return cell is higher than the drain elevation, equation (3) applies. Otherwise, equation (4) applies.

Return flow into the ground-water system at an associated recipient cell is governed by the following equation:

$$QRF_{ir,\,jr,\,kr} = RFPROP_{i,\,j,\,k} \times QD_{i,\,j,\,k} \tag{5}$$

where

$QRF_{ir,jr,kr}$ is the volumetric flow rate (L^3/T) into the recipient cell associated with the drain-return feature in cell *i,j,k*, and

$RFPROP_{i,j,k}$ is the return-flow proportion (dimensionless) specified for the drain-return feature in cell *i,j,k*.

If the return-flow proportion is greater than 0.0, water is simulated as entering the ground-water system at the recipient cell at a rate equal to the product of the rate of flow exiting the system at the drain-return cell and the return-flow proportion. Figure 5 illustrates a conceptual model for one possible application of the DRT1 Package; however, other applications and conceptual models are possible.

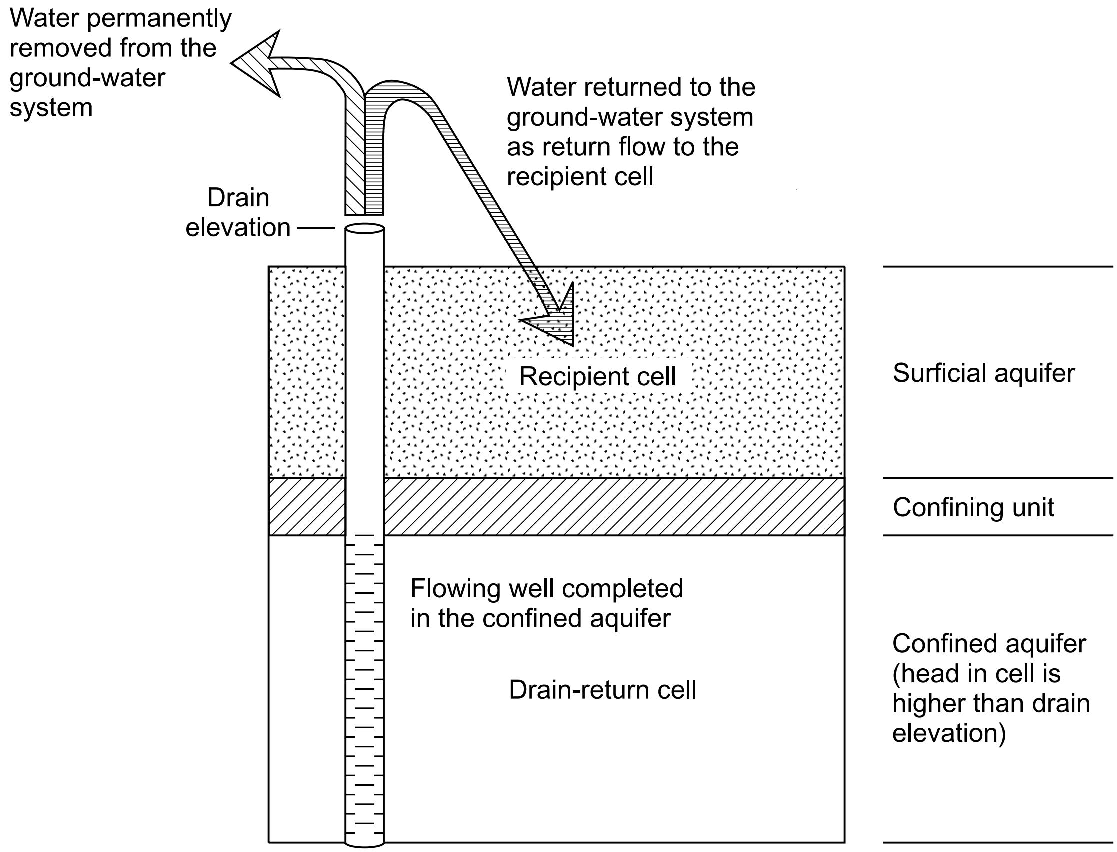

Figure 5.-- Conceptual model of the use of the DRT1 Package to simulate the return flow of a portion of discharge from a flowing well. When the head in the drain-return cell is higher than the drain elevation, water discharges from the ground-water system; a user-specified proportion of this discharge returns to the ground-water system at the recipient cell.

When the DRT1 Package is used, the volumetric budget written to the LIST output file includes DRT1-Package entries in both the “IN” and “OUT” sections. The volume and rate of flow listed for the DRT1 Package in the “IN” section include the return flow to all recipient cells. The volume and rate of flow listed in the “OUT” section include all water flowing out of all drain-return cells, and so include both the water permanently removed from the ground-water system and the water returned to the ground-water system as return flow.

The DRT1 Package supports the use of parameters as discussed in Harbaugh and others (2000) and Hill and others (2000). Drain-return parameters control the hydraulic conductance of drain-return features. Drain-return features can be specified using parameters, without using parameters, or using a combination of the two methods.

More than one drain-return feature may be specified at a single cell for the same stress period, with or without the use of parameters. The need for more than one such feature could arise if multiple flowing wells with differing well-head elevations are located in a cell or if return flow is to be directed to more than one recipient cell. Hill and others (2000) describe how to construct input files so that flow observations for different features in the same cell are interpreted by the program as intended by the user.

Input Instructions for the Drain Return Package

Input to the DRT1 Package is read from the file that has type “DRT” in the name file. Optional variables are shown in brackets. All variables are free format if the option “FREE” is specified in the Basic Package input file; otherwise, the non-optional variables have 10-character fields and the optional variables are free format.

FOR EACH SIMULATION

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

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

```
1.  MXADRT  IDRTCB  NPDRT  MXL  [Option]
```

```
2.  [PARNAM  PARTYP  Parval  NLST]
```

```
3.  Layer Row Column Elevation Condfact [LayR RowR ColR Rfprop] [xyz]
```

NLST repetitions of Item 3 records are required; they are read by module ULSTRD (Harbaugh and others, 2000). (SFAC of the ULSTRD utility module applies to Condfact.)
Repeat Items 2 and 3 for each parameter to be defined (that is, NPDRT times). Items 2 and 3 are omitted if NPDRT = 0.

FOR EACH STRESS PERIOD

```
4.  ITMP  NP
```

```
5.  Layer Row Column Elevation Cond [LayR RowR ColR Rfprop] [xyz]
```

ITMP repetitions of Item 5 records are read by module ULSTRD (Harbaugh and others, 2000) if ITMP > 0. (SFAC of the ULSTRD utility module applies to Cond). Item 5 is not read if ITMP ≤ 0.

```
6.  Pname
```

(Item 6 is repeated NP times. It is not read if NP ≤ 0.)

Explanation of Variables Read by the Drain Return Package

Text—is a character variable (79 characters) that starts in column 2. Any characters can be included in Text. The “#” character must be in column 1. Lines beginning with “#” are restricted to these first lines of the input file. Text is written to the LIST output file when the input file is read.

MXADRT—is the maximum number of drain-return cells in use during any stress period, including those defined using parameters. **Recipient cells are not included in MXADRT**.

IDRTCB—is a flag and a unit number.

If IDRTCB > 0, it is the unit number to which DRT1-Package 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). IDRTCB must be a unit number associated with a file listed with type “DATA(BINARY)” or “DATAGLO(BINARY)” in the name file.
If IDRTCB = 0, DRT1-Package cell-by-cell flow terms will not be written.
If IDRTCB < 0, drain leakage for each drain-return cell and return flow to each recipient cell will be written to the LIST file when “SAVE BUDGET” or a non-zero value for ICBCFL is specified in Output Control.

NPDRT—is the number of drain-return parameters.

MXL—is the maximum number of drain-return cells that will be defined using parameters. Recipient cells are not included in MXL.

Option—is an optional list of character values.

“AUXILIARY abc” or “AUX abc”—defines an auxiliary variable (Harbaugh and McDonald, 1996a, p. 9, item 4), named “abc,” which will be read for each drain as part of items 3 and 5. Up to five variables can be specified, each of which must be preceded by “AUXILIARY” or “AUX.” These variables will not be used by the Ground-Water Flow Process, but they will be available for use by other processes. The auxiliary variable values will be read after the Cond variable.

“CBCALLOCATE” or “CBC”—indicates that memory should be allocated to store cell-by-cell flow for each drain in order to make these flows available for use in other packages.

“RETURNFLOW”—activates the return-flow option of the DRT1 Package. If “RETURNFLOW” is listed as an option, LayR, and, optionally, RowR, ColR, and Rfprop are read from items 3 and(or) 5.

PARNAM—is the name of a parameter to be defined. This name can consist of 1 to 10 characters and is not case sensitive. That is, any combination of the same characters with different case will be equivalent.

PARTYP—is the type of parameter to be defined. For the DRT1 Package, the only allowed parameter type is “DRT,” which defines values of the drain hydraulic conductance.

Parval—is the parameter value. This parameter value may be overridden by a value in the Sensitivity Process input file or by a value generated by the Parameter-Estimation Process.

NLST—is the number of drain-return cells included in the parameter.

Layer—is the layer number of the cell containing the drain.

Row—is the row number of the cell containing the drain.

Column—is the column number of the cell containing the drain.

Elevation—is the elevation of the drain.

Condfact—is the factor used to calculate drain hydraulic conductance from the parameter value. The conductance (L^2/T) is the product of Condfact and the parameter value.

LayR—is a flag and, if greater than 0, a layer number. If auxiliary variables are being read, LayR must be greater than zero, so that RowR, ColR, and Rfprop are read. LayR is not read if “RETURNFLOW” is not listed as an option in item 1.

If LayR > 0, it is the layer number of the recipient cell.

If LayR = 0, there is no return flow for the drain cell, and RowR, ColR, and Rfprop are not read.

RowR—is the row number of the recipient cell. RowR is not read if “RETURNFLOW” is not listed as an option in item 1.

ColR—is the column number of the recipient cell. ColR is not read if “RETURNFLOW” is not listed as an option in item 1.

Rfprop—is the return-flow proportion. Valid values are in the range 0.0 to 1.0, inclusive. Rfprop is the proportion of the drain flow, if any, calculated for the drain-return cell simulated as returning to the recipient cell. If Rfprop equals 0.0, the return-flow capability is deactivated for the cell. Rfprop is not read if “RETURNFLOW” is not listed as an option in item 1.

[xyz]—is up to five auxiliary variables for a drain-return cell that have been defined in item 1. The auxiliary variables must be present in each repetition of items 3 and 5 record if they are defined in item 1.

ITMP—is a flag and a counter.

If ITMP < 0, non-parameter drain-return data from the last stress period will be reused.

If ITMP ≥ 0, ITMP will be the number of non-parameter drain-return cells read for the current stress period.

NP—is the number of drain-return parameters in use in the current stress period.

Cond—is the hydraulic conductance of the interface between the aquifer and the drain.

Pname—is the name of a parameter being used in the current stress period. NP parameter names will be read.

Flow Observations Using the Drain Return Package

The concept of flow observations and related equations are presented in chapter 4 of Hill and others (2000). The method for specifying flow observations for features simulated using the DRT1 Package is nearly identical to the method used for features simulated using the DRN Package (Hill and others, 2000). For each observation specified, MODFLOW-2000 calculates a simulated equivalent, which can be compared to the user-specified observed value. The simulated equivalents calculated by the DRT1 Package include the flow from the drain-return cells and are not adjusted for any return flow to recipient cells. The differences between use of the DRN Package and use of the DRT1 Package to specify flow observation are: (1) the file type “DTOB” is used in the name file for the DRT1 Package instead of “DROB,” which is used for the DRN Package; and (2) the variable names differ.

When more than one drain-return feature is specified at the same cell in the same stress period, care must be taken to ensure that flow observations are associated with the correct feature. Hill and others (2000) provide instructions for preparing an input file to address this situation.

Input Instructions for Flow Observations

Input for the file used to specify flow observations using the DRT1 Package is read from a file that is specified with “DTOB” as the file type listed in the name file.

`0.  [#Text]`

Item 0 is optional and can include as many lines as desired. Each line needs to begin with the “#” character in the first column.

`1.  NQDT  NQCDT  NQTDT` (free format)

`2.  TOMULTDT  EVFDT  IOWTQDT` (free format)

Read items 3, 4, and 5 for each of NQDT groups of cells for which flow observations are to be specified for features simulated with the DRT1 Package.

`3.  NQOBDT  NQCLDT` (free format)

Read item 4 for each of NQOBDT observation times for this group of cells. STATISTIC and STAT-FLAG are ignored if IOWTQDT > 0.

`4.  OBSNAM IREFSP TOFFSET HOBS STATISTIC STAT-FLAG PLOT-SYMBOL` (free format)

Read item 5 for each cell in this group; the number of cells equals the absolute value of NQCLDT from item 3.

`5.  Layer  Row  Column  Factor` (free format)

Read items 6 and 7 if IOWTQDT > 0.

`6.  FMTIN  IPRN` (free format)

`7.  WTQ(1,1), WTQ(1,2), WTQ(1,3), ... , WTQ(1,NQTDT)` (format: FMTIN)

```
WTQ(2,1), WTQ(2,2), WTQ(2,3), ... , WTQ(2,NQTDT)
...
WTQ(NQTDT,1), WTQ(NQTDT,2), WTQ(NQTDT,3), ... , WTQ(NQTDT,NQTDT)
```

Explanation of Variables for Flow Observations

Text—is a character variable (79 characters) that starts in column 2. Any characters can be included in Text. The “#” character must be in column 1. Lines beginning with “#” are restricted to these first lines of the input file. Text is written to the LIST output file when the input file is read and provides an opportunity for the user to include information about the model both in the input file and the associated output file.

NQDT—is the number of cell groups for which drain-return flow observations are listed. A group consists of the drain-return cells needed to represent one flow measurement. Recipient cells are not included in NQDT.

NQCDT—is greater than or equal to the total number of drain-return cells in all cell groups. NQCDT must be greater than or equal to the sum of all |NQCLDT|. Recipient cells are not included in NQCDT.

NQTDT—is the total number of drain-return observations for all cell groups. NQTDT must equal the sum of all NQOBDT, which are specified in repetitions of item 3 in the DTOB input file.

TOMULTDT—is the time-offset multiplier for drain-return observations [-- or T/T]. The product of TOMULTDT and TOFFSET must produce a time value in units consistent with other model input. TOMULTDT can be dimensionless or can be used to convert the units of TOFFSET to the time unit used in the simulation.

EVFDT—is the error variance multiplier for observations represented by the DRT1 Package, and is used to calculate the weights as described below in the explanation of STATISTIC. EVFDT makes it easy to change the weights uniformly for all flow observations represented using the DRT1 Package.

IOWTQDT—is a flag that indicates that the variance-covariance matrix on drain-return flow observations is to be read into array WTQ of item 7. If IOWTQDT equals zero, weights are calculated using STATISTIC of item 4; if it is greater than zero, items 6 and 7 are read and used to calculate the weights.

NQOBDT—is the number of times at which flows are observed for the group of cells.

NQCLDT—is a flag, and the absolute value of NQCLDT is the number of drain-return cells in the group. If NQCLDT is less than zero, FACTOR = 1.0 for all cells in the group. Recipient cells are not included in NQCLDT.

OBSNAM—is a string of 1 to 12 non-blank characters used to identify the observation.

IREFSP—is the reference stress period to which observation times are referenced. The reference point is the beginning of the stress period.

TOFFSET—is the time offset of the observation from the beginning of stress period IREFSP [T]. TOFFSET must be in units such that the product of TOMULTDT and TOFFSET is in time units consistent with other model input. TOFFSET and TOMULTDT from the DTOB file and values of PERLEN, NSTP, and TSMULT from the DIS file (Harbaugh and others, 2000) are used to determine the stress period, time step, and time during the time step for the observation. To specify that an observation is for a steady-state model solution, specify IREFSP as the stress-period number of the steady-state stress period, and specify TOFFSET such that TOMULTDT$\times$TOFFSET is less than or equal to PERLEN for the stress period; if PERLEN is zero, set TOFFSET to zero. If the observation falls within a time step, the simulated equivalent is calculated by linearly interpolating between values for the beginning and end of the time step. If the first stress period is transient and the observation falls within the first time step, the simulated equivalent from the end of the time step is used because no flow from the beginning of the time step is available for interpolation.

HOBS—is the observed drain-return-boundary flow [L^3/T]. For the DRT1 Package, only negative values of HOBS are expected. Negative values indicate flow out of the ground-water system.

STATISTIC—is the value from which the weight for the observation is calculated as determined using STAT-FLAG. STATISTIC is ignored if IOWTQDT is greater than zero, in which case WTQ of item 7 is used to define the weighting.

STAT-FLAG—is a flag identifying what STATISTIC is and how the weight is calculated. STAT-FLAG is ignored if IOWTQDT is greater than zero.

STAT-FLAG = 0, STATISTIC is a scaled variance [$(L^3/T)^2$], weight = 1/(STATISTIC $\times$ EVFDT)
STAT-FLAG = 1, STATISTIC is a scaled standard deviation [L^3/T], weight = 1/(STATISTIC^2 $\times$ EVFDT)
STAT-FLAG = 2, STATISTIC is a scaled coefficient of variation [dimensionless], weight = 1/[(STATISTIC $\times$ HOBS)^2 $\times$ EVFDT]

PLOT-SYMBOL—is an integer that will be written to output files intended for graphical analysis to allow control of the symbols used when plotting data (Hill and others, 2000).

LAYER—is the layer index of a drain-return cell included in the cell group.

ROW—is the row index of a drain-return cell included in the cell group.

COLUMN—is the column index of a drain-return cell included in the cell group.

FACTOR—is the portion of the simulated drain flow in the cell that is included in the total simulated drain flow for this cell group (f_n of eq. 9 in Hill and others, 2000).

FMTIN—is the Fortran format to be used in reading each line of the variance-covariance matrix used to calculate the weighting. The format needs to be enclosed in parentheses and needs to accommodate real numbers.

IPRN—is a flag identifying the format in which the variance-covariance matrix is to be printed. If IPRN is less than zero, the matrix is not printed. Permissible values of IPRN and corresponding formats are:

Output requires more than 80 columns		**Output requires 80 columns or less**	
IPRN	**Format**	**IPRN**	**Format**
1	10G12.3	6	5G12.3
2	10G12.4	7	5G12.4
3	9G12.5	8	5G12.5
4	8G13.6	9	4G13.6
5	8G14.7	10	4G14.7

WTQ—is an NQTDT by NQTDT array containing the variance-covariance matrix on drain-return flow observations $[(L^3/T)^2]$. For elements WTQ(I,J), if I ≠ J, WTQ(I,J) is the covariance between observations I and J; if I = J, WTQ(I,J) is the variance of observation I. Note that the variance-covariance matrix is symmetric, but the entire matrix (upper and lower parts) must be entered.

DRT1 Example Problem

A simple example problem was devised to demonstrate that the DRT1 Package correctly calculates flow out of a drain-return cell and into a recipient cell when the RETURNFLOW option is selected. For this problem, a grid of 11 rows by 11 columns in one layer was used to simulate an unconfined aquifer with a uniform base elevation of 0 ft. All row and column widths were 100 ft. All cells in column 1 had a specified head of 50 ft, and all cells in column 11 had a specified head of 100 ft. Hydraulic conductivity of the aquifer material was 0.05 ft/d, and the system was modeled in steady state. A drain was simulated in row 5, column 8, and 40 percent of the flow from the drain was assumed to return to the ground-water system in row 7, column 3 (fig. 6). The drain elevation was 60 ft and the conductance of the drain was 2 ft^2/d. This system was simulated with the DRT1 Package for one simulation and with the DRN and WEL Packages (Harbaugh and others, 2000) for a second simulation. The input files for these simulations are listed in Appendix B.

For the simulation using the DRT1 Package, a drain-return feature was defined in the cell in row 5, column 8. The corresponding recipient cell was specified in row 7, column 3. The return-flow proportion was specified as 0.4. Results of the model run showed that flow out of the ground-water system at the drain-return cell was 45.2126 ft^3/d. Note that, in general, model results would be presented with no more significant digits than are supported by the input data; however, for this demonstration of model accuracy, all digits shown in the LIST file are reported. Flow into the system at the recipient cell was 18.0850 ft^3/d, which equals 40 percent of the flow out of the system at the drain-return cell. The LIST output file generated by this simulation is in Appendix B. When the DRT1 Package is used to simulate the system, the ratio of flow into the system at the recipient cell to flow out of the system at the drain-return cell always would equal 0.40, even if calculated head at the drain-return cell changes with changing stresses.

For the simulation using the DRN and WEL Packages, a drain was simulated in row 5, column 8, and an injection well was simulated in row 7, column 3. The injection rate was specified as 18.0850 ft^3/d to agree with the results from the simulation that used the DRT1 Package. Flow out of the ground-water system at the drain was calculated as 45.2125 ft^3/d, matching the outflow obtained using the DRT1 Package. The calculated head distribution and volumetric budget for this simulation are listed in Appendix B. The head distribution was identical to that obtained with the DRT1 Package, and the volumetric budgets were identical within round-off error. Note that if different stresses were applied to the system and were to result in a different calculated head at the drain cell, the user would need to manually change the specified injection rate to maintain the assumed 40-percent ratio of inflow to outflow.

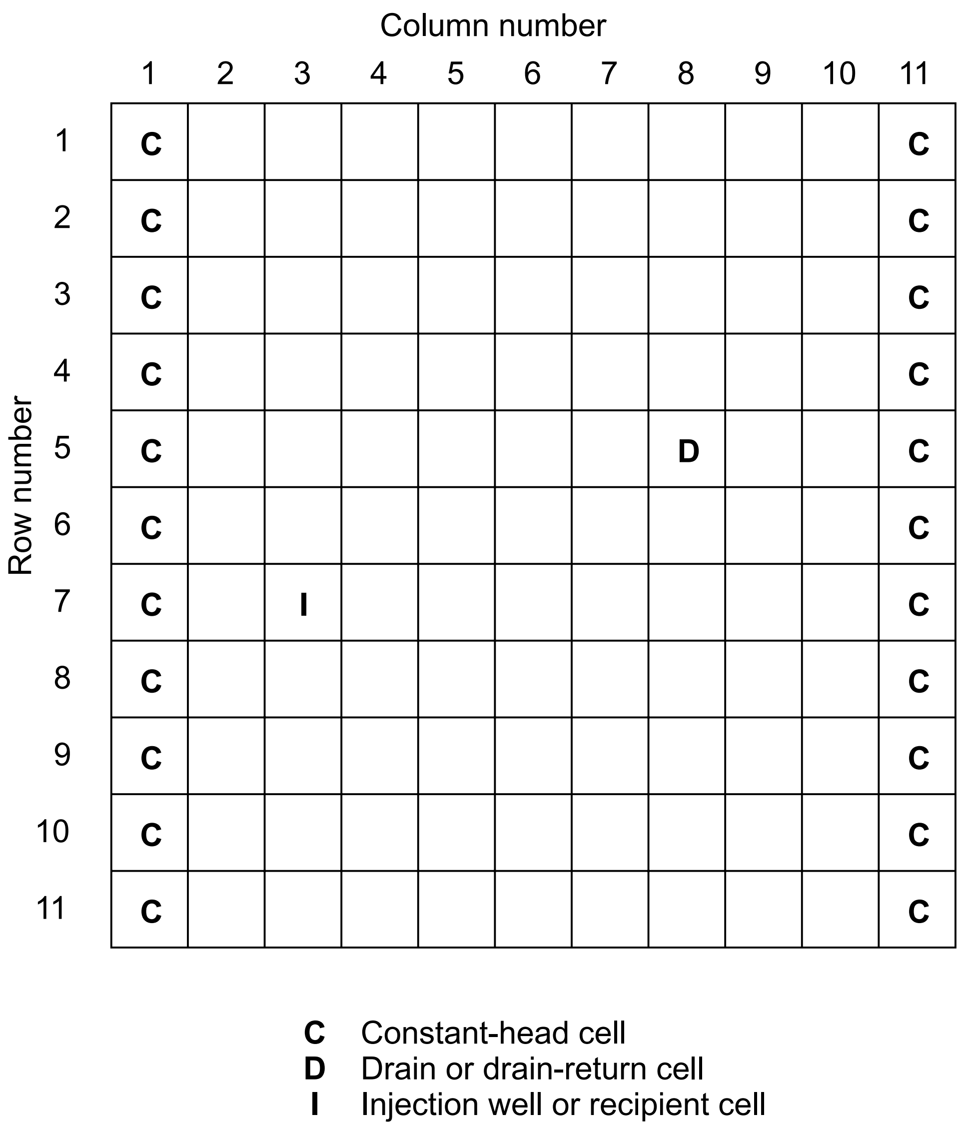

Figure 6.-- Location of features simulated in the DRT1 example problem.

Module Documentation for the Drain Return Package

The DRT1 Package is composed of 14 modules. Five of these are primary modules that are part of the Ground-Water Flow Process. Four are primary modules that are part of the Observation Process. One is a primary module that is part of the Sensitivity Process. Primary modules are called directly from the main program unit. In addition, the DRT1 Package includes two secondary modules that are part of the Ground-Water Flow Process and two secondary modules that are part of the Observation Process. Secondary modules are called from other modules. The 14 modules are:

GWF1DRT1AL—Reads options and allocates memory for data arrays. GWF1DRT1AL is a primary module of the Ground-Water Flow Process and is in source-code file gwf1drt1.f.

GWF1DRT1RQ—Reads drain-return parameter definitions. GWF1DRT1RQ is a primary module of the Ground-Water Flow Process and is in source-code file gwf1drt1.f.

GWF1DRT1RP—Reads drain-return cell data and, if DRT parameters are defined, performs substitution using parameter values. GWF1DRT1RP is a primary module of the Ground-Water Flow Process and is in source-code file gwf1drt.f.

GWF1DRT1FM—Formulates terms needed to solve the ground-water flow equation and adds them to the head-coefficient array (HCOF) and to the right-hand side array (RHS). GWF1DRT1FM is a primary module of the Ground-Water Flow Process and is in source-code file gwf1drt1.f.

GWF1DRT1BD—Computes flow rates simulated as flow from drain-return cells and to recipient cells and writes cell-by-cell flow rates if that option is selected. GWF1DRT1BD is a primary module of the Ground-Water Flow Process and is in source-code file gwf1drt1.f.

SGWF1DRT1LR—Reads and prints a list of drain-return cell data. SGWF1DRT1LR is a secondary module of the Ground-Water Flow Process and in source-code file gwf1drt1.f.

SGWF1DRT1LS—Reads a DRT parameter name and performs substitution for associated drain-return cells using the current parameter value. SGWF1DRT1LS is a secondary module of the Ground-Water Flow Process and is in source-code file gwf1drt1.f.

OBS1DRT1AL—Reads data from the DTOB file regarding numbers of observations at drain-return cells and allocates memory. OBS1DRT1AL is a primary module of the Observation Process and is in source-code file obs1drt1.f.

OBS1DRT1RP—Reads and checks flow-observation data for drain-return cells. OBS1DRT1RP is a primary module of the Observation Process and is in source-code file obs1drt1.f.

OBS1DRT1FM—Calculates simulated equivalents for flow observations at drain-return cells. OBS1DRT1FM is a primary module of the Observation Process and is in source-code file obs1drt1.f.

OBS1DRT1DR—Calculates sensitivities for flow observations at drain-return cells. OBS1DRT1DR is a primary module of the Observation Process and is in source-code file obs1drt1.f.

SOBS1DRT1OH—Calculates and prints weighted residuals for flow observations at drain-return cells. SOBS1DRT1OH is a secondary module of the Observation Process and is in source-code file obs1drt1.f.

SOBS1DRT1QC—Populates QCLS array with Condfact from parameter definition for one DRT parameter. SOBS1DRT1QC is a secondary module of the Observation Process and is in source-code file obs1drt1.f.

SEN1DRT1FM—Formulates terms needed to solve the sensitivity equation and adds them to the right-hand side array (RHS). SEN1DRT1FM is a primary module of the Sensitivity Process and is in source-code file sen1drt1.f.

Module GWF1DRT1AL

Narrative for Module GWF1DRT1AL

This primary module reads package options from item 1 of the DRT1 input file and allocates space in the RX and IR arrays (Harbaugh and others, 2000). Output is written to the LIST file.

1. Print a message identifying the DRT1 Package.

2. Read and print comment lines (item 0) introduced with the “#” character.

3. Read maximum number of DRT1 cells that can be active at one time (MXADRT), the unit number for cell-by-cell flow terms (IDRTCB), the number of parameters (NPDRT), the maximum number of drain-return cells to be defined using parameters (MXL), and any package options from item 1. Print messages related to number of cells, number of parameters, options and, if IDRTCB is greater than zero, the unit number.

4. Allocate space in the RX array for the DRTF array.

5. Print a message showing amount of storage required by the DRT1 Package.

Listing for Module GWF1DRT1AL

```
      SUBROUTINE GWF1DRT1AL(ISUM,LCDRTF,MXDRT,NDRTCL,IN,IOUT,IDRTCB,
     &                      NDRTVL,IDRTAL,IFREFM,NPDRT,IDRTPB,NDRTNP,
     &                      IDRTFL)
C
C-----VERSION 20000620 ERB
C     ******************************************************************
C     ALLOCATE ARRAY STORAGE FOR DRAINS AND RETURN FLOWS
C     ******************************************************************
C
C     SPECIFICATIONS:
C     ------------------------------------------------------------------
      COMMON /DRTCOM/DRTAUX(5)
      CHARACTER*16 DRTAUX
      CHARACTER*200 LINE
C     ------------------------------------------------------------------
C
C1------IDENTIFY PACKAGE AND INITIALIZE NDRTCL.
      WRITE(IOUT,1)IN
    1 FORMAT(1X,/
     &1X,'DRT1 -- DRAIN RETURN PACKAGE, VERSION 1, 5/2/2000',/,
     &' INPUT READ FROM UNIT',I3)
      NDRTCL=0
      NDRTNP=0
      IDRTFL=0
C
C2------READ MAXIMUM NUMBER OF DRAINS AND UNIT OR FLAG FOR
C2------CELL-BY-CELL FLOW TERMS.
C     READ COMMENTS (ITEM 0)
      CALL URDCOM(IN,IOUT,LINE)
C     READ ITEM 1
      IF (IFREFM.EQ.0) THEN
        READ(LINE,'(4I10)') MXADRT,IDRTCB,NPDRT,MXL
```

```
          LLOC=21
        ELSE
          LLOC=1
          CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,MXADRT,R,IOUT,IN)
          CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,IDRTCB,R,IOUT,IN)
          CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,NPDRT,R,IOUT,IN)
          CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,MXL,R,IOUT,IN)
        ENDIF
        WRITE(IOUT,3) MXADRT
      3 FORMAT(1X,'MAXIMUM OF',I5,
       &' ACTIVE DRAINS WITH RETURN FLOW AT ONE TIME')
        IF (IDRTCB.LT.0) WRITE(IOUT,7)
      7 FORMAT(1X,'CELL-BY-CELL FLOWS WILL BE PRINTED WHEN ICBCFL NOT 0')
        IF (IDRTCB.GT.0) WRITE(IOUT,8) IDRTCB
      8 FORMAT(1X,'CELL-BY-CELL FLOWS WILL BE SAVED ON UNIT',I3)
C
        IF (NPDRT.GT.0) THEN
          WRITE(IOUT,9) NPDRT,MXL
      9   FORMAT(1X,I5,' Named Parameters     ',I5,' List entries')
        ELSE
          WRITE(IOUT,'(A)') ' No named parameters'
        END IF

C3------READ AUXILIARY VARIABLES AND CBC ALLOCATION OPTION.
        IDRTAL=0
        NAUX=0
     10 CALL URWORD(LINE,LLOC,ISTART,ISTOP,1,N,R,IOUT,IN)
        IF (LINE(ISTART:ISTOP).EQ.'CBCALLOCATE' .OR.
       &    LINE(ISTART:ISTOP).EQ.'CBC') THEN
          IDRTAL=1
          WRITE(IOUT,11)
     11   FORMAT(1X,'MEMORY IS ALLOCATED FOR CELL-BY-CELL BUDGET TERMS')
          GOTO 10
        ELSEIF(LINE(ISTART:ISTOP).EQ.'AUXILIARY' .OR.
       &       LINE(ISTART:ISTOP).EQ.'AUX') THEN
          CALL URWORD(LINE,LLOC,ISTART,ISTOP,1,N,R,IOUT,IN)
          IF (NAUX.LT.5) THEN
            NAUX=NAUX+1
            DRTAUX(NAUX)=LINE(ISTART:ISTOP)
            WRITE(IOUT,12) DRTAUX(NAUX)
     12     FORMAT(1X,'AUXILIARY DRAIN-RETURN FLOW VARIABLE: ',A)
          ENDIF
          GOTO 10
        ELSEIF (LINE(ISTART:ISTOP).EQ.'RETURNFLOW') THEN
          IDRTFL=4
          WRITE(IOUT,13)
          GOTO 10
     13 FORMAT(1X,'RETURN FLOW OPTION IS SELECTED')
        ENDIF
        IF (IDRTAL.EQ.1 .AND. IDRTFL.EQ.4) IDRTAL = 2
        NDRTVL=5+NAUX+IDRTAL+IDRTFL
C
C4------ALLOCATE SPACE IN THE RX ARRAY FOR THE DRTF ARRAY.
        IDRTPB=MXADRT+1
        MXDRT=MXADRT+MXL
        ISOLD=ISUM
        LCDRTF=ISUM
        ISUM=ISUM+NDRTVL*MXDRT
C
C5------PRINT AMOUNT OF SPACE USED BY DRAIN PACKAGE.
        ISP=ISUM-ISOLD
        WRITE (IOUT,14)ISP
     14 FORMAT(1X,I10,' ELEMENTS IN RX ARRAY ARE USED BY DRT')
C
C6------RETURN.
        RETURN
        END
```

List of Variables for Module GWF1DRT1AL

Variable	Range	Definition
DRTAUX	Package	Auxiliary-variable names
IDRTAL	Package	Indicator for saving cell-by-cell budget terms
IDRTCB	Package	Indicator and unit number for writing cell-by-cell flows
IDRTFL	Package	Indicator for return-flow option
IDRTPB	Package	First position in DRTF array used for storing parameter data
IFREFM	Global	Flag indicating if variables are to be read in free format
IN	Module	Unit number for input file
IOUT	Global	Unit number of LIST output file
ISOLD	Module	ISUM value before allocation
ISP	Module	Number of elements allocated in RX array
ISTART	Module	Starting position of parsed word
ISTOP	Module	Ending position of parsed word
ISUM	Module	Pointer used to keep track of position in RX
LCDRTF	Package	Position in RX of first element of DRTF
LINE	Module	Contents of one line read from input file
LLOC	Module	Pointer used to keep track of position in LINE
MXADRT	Package	Maximum number of drain-return cells that can be active in a stress period
MXDRT	Package	Dimensioning variable for DRTF
MXL	Module	Maximum number of drain-return cells that will be defined using parameters
N	Module	Dummy integer variable
NAUX	Module	Number of auxiliary variables
NDRTCL	Package	Number of drain-return cells used in a stress period
NDRTNP	Package	Number of non-parameter drain-return cells in use during a stress period
NDRTVL	Package	Dimensioning variable for DRTF
NPDRT	Package	Number of drain-return parameters
R	Module	Dummy real variable

Module GWF1DRT1RQ

Narrative for Module GWF1DRT1RQ

This primary module reads parameter definitions (items 2 and 3) from the DRT1 input file. Output is written to the GLOBAL file.

1. Print a message indicating how many drain-return parameters are being used.

2. For each drain-return parameter, call a utility and a secondary DRT1 module to read the parameter definition. The utility reads item 2 and prints the parameter name, type, value, and number of list entries used to define the parameter. The secondary module reads item 3 and prints the list entries, including drain-return cell location, drain elevation, a factor, recipient-cell location, and return-flow proportion.

Listing for Module GWF1DRT1RQ

```
      SUBROUTINE GWF1DRT1RQ(IN,IOUT,NDRTVL,IDRTAL,NCOL,NROW,NLAY,NPDRT,
     &                      DRTF,IDRTPB,MXDRT,IFREFM,ITERP,IDRTFL)
C
C-----VERSION 20000620 ERB
C     ******************************************************************
C     READ DRAIN-RETURN PARAMETERS
C     ******************************************************************
C
C     SPECIFICATIONS:
C     ------------------------------------------------------------------
      DIMENSION DRTF(NDRTVL,MXDRT)
      COMMON /DRTCOM/DRTAUX(5)
      CHARACTER*16 DRTAUX
C     ------------------------------------------------------------------
C
C-------READ NAMED PARAMETERS.
      IF (ITERP.EQ.1) WRITE(IOUT,500) NPDRT
  500 FORMAT(1X,//1X,I5,' Drain-return parameters')
      IF (NPDRT.GT.0) THEN
        NAUX=NDRTVL-5-IDRTAL-IDRTFL
        LSTSUM=IDRTPB
        DO 10 K=1,NPDRT
          LSTBEG=LSTSUM
C         READ ITEM 2
          CALL UPARLSTRP(LSTSUM,MXDRT,IN,IOUT,IP,'DRT','DRT',ITERP)
          NLST=LSTSUM-LSTBEG
C         READ ITEM 3
          CALL SGWF1DRT1LR(NLST,DRTF,LSTBEG,NDRTVL,MXDRT,IDRTAL,IN,IOUT,
     &                     DRTAUX,5,NAUX,IFREFM,NCOL,NROW,NLAY,ITERP,
     &                     IDRTFL)
   10   CONTINUE
      ENDIF
C
C6------RETURN
      RETURN
      END
```

List of Variables for Module GWF1DRT1RQ

Variable	Range	Definition
DRTAUX	Package	Auxiliary-variable names
DRTF	Package	Drain-return cell data
IDRTAL	Package	Indicator for saving cell-by-cell budget terms
IDRTFL	Package	Indicator for return-flow option
IDRTPB	Package	First position in DRTF array used for storing parameter data
IFREFM	Global	Flag indicating if variables are to be read in free format
IN	Module	Unit number of input file
IOUT	Global	Unit number of GLOBAL output file
IP	Module	Parameter number
ITERP	Global	Parameter-estimation iteration number
K	Module	Index for parameters
LSTBEG	Module	First position in DRTF of a list of parameter-controlled drain-return cells
LSTSUM	Module	Position in DRTF following a list of parameter-controlled drain-return cells

Variable	Range	Definition
MXDRT	Package	Dimensioning variable for DRTF
NAUX	Module	Number of auxiliary variables
NCOL	Global	Number of columns in model grid
NDRTVL	Package	Dimensioning variable for DRTF
NLAY	Global	Number of layers in model grid
NLST	Module	Number of drain-return cells in list
NPDRT	Package	Number of drain-return parameters
NROW	Global	Number of rows in model grid

Module GWF1DRT1RP

Narrative for Module GWF1DRT1RP

This primary module, for each stress period, reads items 4 through 6 of the DRT1 input file and prepares data. Output is written to the LIST file.

1. Read ITMP and, if DRT1 parameters are defined, NP from item 4 of the DRT1 file.

2. Determine how many auxiliary variables need to be read.

3. Determine the number of non-parameter drain-return cells to be read. If ITMP > 0, this number is ITMP.

4. If non-parameter drain-return cells are to be read, call a secondary module to read data for them from item 5.

5. If NP > 0, DRT1 parameters are active this stress period; so, for each of NP parameters, call a secondary module to read the name from item 6 and prepare data using the current parameter values.

6. Determine how many of the drain-return cells can return a portion of the flow to a recipient cell. Drain-return cells that have a non-zero layer index can return flow to a recipient cell.

7. Print a message showing how many drain-return cells are active this stress period.

Listing for Module GWF1DRT1RP

```
      SUBROUTINE GWF1DRT1RP(DRTF,NDRTCL,MXDRT,IN,IOUT,NDRTVL,IDRTAL,
     &                      IFREFM,NCOL,NROW,NLAY,NDRTNP,NPDRT,IDRTPB,
     &                      IDRTFL,NRFLOW)
C
C-----VERSION 20000620 ERB
C     ******************************************************************
C     READ DRAIN HEAD, CONDUCTANCE AND BOTTOM ELEVATION.  IF THE
C     RETURNFLOW OPTION IS SELECTED, READ RECIPIENT CELL AND PROPORTION.
C     ******************************************************************
C
C     SPECIFICATIONS:
C     ------------------------------------------------------------------
      DIMENSION DRTF(NDRTVL,MXDRT)
      COMMON /DRTCOM/DRTAUX(5)
      CHARACTER*16 DRTAUX
C     ------------------------------------------------------------------
C
C1------READ ITMP (NUMBER OF DRAINS OR FLAG TO REUSE DATA) AND
```

```
C1------NUMBER OF PARAMETERS.
      IF (NPDRT.GT.0) THEN
        IF (IFREFM.EQ.0) THEN
          READ(IN,'(2I10)') ITMP,NP
        ELSE
          READ(IN,*) ITMP,NP
        ENDIF
      ELSE
        NP=0
        IF (IFREFM.EQ.0) THEN
          READ(IN,'(I10)') ITMP
        ELSE
          READ(IN,*) ITMP
        ENDIF
      ENDIF
C
C------CALCULATE SOME CONSTANTS
      NAUX=NDRTVL-5-IDRTAL-IDRTFL
C
C2------DETERMINE THE NUMBER OF NON-PARAMETER DRAIN-RETURN CELLS.
      IF (ITMP.LT.0) THEN
        WRITE(IOUT,7)
    7   FORMAT(1X,/,
     &' REUSING NON-PARAMETER DRAIN-RETURN CELLS FROM',
     &' LAST STRESS PERIOD')
      ELSE
        NDRTNP=ITMP
      ENDIF
C
C3------IF THERE ARE NEW NON-PARAMETER DRAIN-RETURN CELLS, READ THEM.
      MXADRT=IDRTPB-1
      IF (ITMP.GT.0) THEN
        IF (NDRTNP.GT.MXADRT) THEN
          WRITE(IOUT,500) NDRTNP,MXADRT
  500     FORMAT(1X,/1X,'THE NUMBER OF ACTIVE DRT DRAINS (',I4,
     &           ') IS GREATER THAN MXADRT(',I4,')')
          STOP
        ENDIF
        CALL SGWF1DRT1LR(NDRTNP,DRTF,1,NDRTVL,MXDRT,IDRTAL,IN,IOUT,
     &                   DRTAUX,5,NAUX,IFREFM,NCOL,NROW,NLAY,1,IDRTFL)
      ENDIF
      NDRTCL=NDRTNP
C
C1C-----IF THERE ARE ACTIVE DRT PARAMETERS, READ THEM AND SUBSTITUTE
      CALL PRESET('DRT')
      IF (NP.GT.0) THEN
        NREAD=NDRTVL-IDRTAL
        DO 30 N=1,NP
          CALL SGWF1DRT1LS(IN,IOUT,DRTF,NDRTVL,MXDRT,NREAD,MXADRT,
     &                     NDRTCL,DRTAUX,5,NAUX,IDRTFL)
   30   CONTINUE
      ENDIF
C
C     COUNT NUMBER OF DRAIN-RETURN CELLS THAT CAN HAVE RETURN FLOW
      NRFLOW = 0
      IF (IDRTFL.GT.0) THEN
        DO 40 I=1,NDRTCL
          IF (DRTF(6,I) .GT. 0.0) NRFLOW = NRFLOW + 1
   40   CONTINUE
      ENDIF
C
C3------PRINT NUMBER OF DRAIN-RETURN CELLS IN CURRENT STRESS PERIOD.
      WRITE (IOUT,510) NDRTCL
  510 FORMAT(1X,/1X,I5,' DRAIN-RETURN CELLS')
C
C8------RETURN.
      RETURN
      END
```

List of Variables for Module GWF1DRT1RP

Variable	Range	Definition
DRTAUX	Package	Auxiliary-variable names
DRTF	Package	Drain-return cell data
I	Module	Index for drain-return cells
IDRTAL	Package	Indicator for saving cell-by-cell budget terms
IDRTFL	Package	Indicator for return-flow option
IDRTPB	Package	First position in DRTF array used for storing parameter data
IFREFM	Global	Flag indicating if variables are to be read in free format
IN	Module	Unit number of input file
IOUT	Global	Unit number of LIST output file
ITMP	Module	Flag and number of non-parameter drain-return cells
MXADRT	Package	Maximum number of drain-return cells that can be active in a stress period
MXDRT	Package	Dimensioning variable for DRTF
N	Module	Index for DRT parameters active this stress period
NAUX	Module	Number of auxiliary variables
NCOL	Global	Number of columns in model grid
NDRTCL	Package	Number of drain-return cells used in a stress period
NDRTNP	Package	Number of non-parameter drain-return cells in use during current stress period
NDRTVL	Package	Dimensioning variable for DRTF
NLAY	Global	Number of layers in model grid
NP	Module	Number of DRT parameters active this stress period
NPDRT	Package	Number of drain-return parameters
NREAD	Module	Number of values to be substituted for each drain-return cell
NRFLOW	Package	Number of drain-return cells with a positive return-flow proportion
NROW	Global	Number of rows in model grid

Module GWF1DRT1FM

Narrative for Module GWF1DRT1FM

This primary module adds terms to the finite-difference equations to account for loss of water from the ground-water system through drain-return cells. Terms are added for recipient cells where a portion of the drain flow is returned.

1. For each cell in the drain-return cell list, do steps 2 through 5.
2. If the cell is inactive or designated as constant-head, skip steps 3 through 5.
3. If the head in the cell is at or below the drain elevation, skip steps 4 and 5.

4. Add terms to HCOF and RHS for the drain-return cell to account for loss of water.

5. If a recipient cell is specified to receive return flow, add term to RHS for the recipient cell to account for return flow.

Listing for Module GWF1DRT1FM

```
      SUBROUTINE GWF1DRT1FM(NDRTCL,MXDRT,DRTF,HNEW,HCOF,RHS,IBOUND,
     &                      NCOL,NROW,NLAY,NDRTVL,IDRTFL)
C
C-----VERSION 20000620 ERB
C     ******************************************************************
C     ADD DRAIN-RETURN FLOW TO SOURCE TERMS FOR BOTH DRAIN-RETURN CELLS
C     AND RECIPIENT CELLS
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      DOUBLE PRECISION HNEW,EEL
C
      DIMENSION DRTF(NDRTVL,MXDRT),HNEW(NCOL,NROW,NLAY),
     &         RHS(NCOL,NROW,NLAY),IBOUND(NCOL,NROW,NLAY),
     &         HCOF(NCOL,NROW,NLAY)
C     ------------------------------------------------------------------
C
C1------IF NDRTCL<=0 THERE ARE NO DRAINS. RETURN.
      IF (NDRTCL.LE.0) RETURN
C
C2------PROCESS EACH CELL IN THE DRAIN-RETURN CELL LIST.
      DO 100 L=1,NDRTCL
C
C3------GET COLUMN, ROW AND LAYER OF CELL CONTAINING DRAIN.
        IL=DRTF(1,L)
        IR=DRTF(2,L)
        IC=DRTF(3,L)
C
C4-------IF THE CELL IS EXTERNAL SKIP IT.
        IF (IBOUND(IC,IR,IL).LE.0) GOTO 100
C
C5-------IF THE CELL IS INTERNAL GET THE DRAIN DATA.
        EL=DRTF(4,L)
        EEL=EL
C
C6------IF HEAD IS LOWER THAN DRAIN THEN SKIP THIS CELL.
        IF (HNEW(IC,IR,IL).LE.EEL) GOTO 100
C
C7------HEAD IS HIGHER THAN DRAIN. ADD TERMS TO RHS AND HCOF.
        C=DRTF(5,L)
        HCOF(IC,IR,IL)=HCOF(IC,IR,IL)-C
        RHS(IC,IR,IL)=RHS(IC,IR,IL)-C*EL
        IF (IDRTFL.GT.0) THEN
          ILR = DRTF(6,L)
          IF (ILR.NE.0) THEN
            IRR = DRTF(7,L)
            ICR = DRTF(8,L)
            RFPROP = DRTF(9,L)
            H = HNEW(IC,IR,IL)
            RHS(ICR,IRR,ILR) = RHS(ICR,IRR,ILR)
     &                         - RFPROP*C*(H-EL)
          ENDIF
        ENDIF
  100 CONTINUE
C
C8------RETURN.
      RETURN
      END
```

List of Variables for Module GWF1DRT1FM

Variable	Range	Definition
C	Module	Hydraulic conductance of drain for a drain-return cell
DRTF	Package	Drain-return cell data
EEL	Module	Drain elevation for a drain-return cell
EL	Module	Drain elevation for a drain-return cell
H	Module	Hydraulic head at a drain-return cell
HCOF	Global	Head-coefficient array
HNEW	Global	Head
IBOUND	Global	Boundary-status indicator
IC	Module	Cell index of a drain-return cell
ICR	Module	Cell index of a recipient cell
IDRTFL	Package	Indicator for return-flow option
IL	Module	Layer index of a drain-return cell
ILR	Module	Layer index of a recipient cell
IR	Module	Row index of a drain-return cell
IRR	Module	Row index of a recipient cell
L	Module	Index for drain-return cells
MXDRT	Package	Dimensioning variable for DRTF
NCOL	Global	Number of columns in model grid
NDRTCL	Package	Number of drain-return cells used in a stress period
NDRTVL	Package	Dimensioning variable for DRTF
NLAY	Global	Number of layers in model grid
NROW	Global	Number of rows in model grid
RFPROP	Package	Return-flow proportion
RHS	Global	Right-hand side

Module GWF1DRT1BD

Narrative for Module GWF1DRT1BD

This primary module calculates rates and volumes of water removed from drain-return cells and returned to recipient cells. Output is written to the LIST file and, optionally, to the unformatted file associated with unit IDRTCB.

1. If cell-by-cell flows will be saved as a list, write a header to the cell-by-cell output file.

2. Initialize a buffer of all cell locations to zero.

3. For each drain-return cell, do steps 4 through 11.

4. If the cell is inactive, skip steps 5 through 11.

5. If the head in the cell is at or below the drain elevation, skip steps 6 through 11.
6. Accumulate flow volume and rate out of the drain-return cell.
7. Determine if a recipient cell is specified to receive return flow. If not, skip step 8.
8. Accumulate flow volume and rate returned to the recipient cell.
9. Write cell-by-cell flow rates to the LIST file, if requested.
10. Add rates to buffer at drain-return cell location and, if applicable, at recipient cell location.
11. Copy rates to DTRF array, if requested.
12. If requested, save cell-by-cell flow rates to the unformatted file associated with unit IDRTCB.
13. Move volumes, rates, and labels into arrays for printing budget.
14. Increment budget-term counter.

Listing for Module GWF1DRT1BD

```
      SUBROUTINE GWF1DRT1BD(NDRTCL,MXDRT,VBNM,VBVL,MSUM,DRTF,DELT,HNEW,
     &                      NCOL,NROW,NLAY,IBOUND,KSTP,KPER,IDRTCB,
     &                      ICBCFL,BUFF,IOUT,PERTIM,TOTIM,NDRTVL,IDRTAL,
     &                      IDRTFL,NRFLOW,IAUXSV)
C-----VERSION 20000620 ERB
C     ******************************************************************
C     CALCULATE VOLUMETRIC BUDGET FOR DRAIN-RETURN CELLS
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      COMMON /DRTCOM/DRTAUX(5)
      CHARACTER*16 DRTAUX
      CHARACTER*16 VBNM(MSUM),TEXT
      DOUBLE PRECISION HNEW,HHNEW,EEL,CC,CEL,RATIN,RATOUT,QQ
C
      DIMENSION VBVL(4,MSUM),DRTF(NDRTVL,MXDRT),HNEW(NCOL,NROW,NLAY),
     &          IBOUND(NCOL,NROW,NLAY),BUFF(NCOL,NROW,NLAY)
C
      DATA TEXT /'    DRAINS (DRT)'/
C     ------------------------------------------------------------------
C
C1------INITIALIZE CELL-BY-CELL FLOW TERM FLAG (IBD) AND
C1------ACCUMULATORS (RATIN AND RATOUT).
      ZERO=0.
      RATIN=ZERO
      RATOUT=ZERO
      IBD=0
      IF (IDRTCB.LT.0 .AND. ICBCFL.NE.0) IBD=-1
      IF (IDRTCB.GT.0) IBD=ICBCFL
      IBDLBL=0
C
C2------IF CELL-BY-CELL FLOWS WILL BE SAVED AS A LIST, WRITE HEADER.
      IF (IBD.EQ.2) THEN
        NAUX = NDRTVL - 5 - IDRTAL
        IF (IAUXSV.EQ.0) NAUX = 0
        CALL UBDSV4(KSTP,KPER,TEXT,NAUX,DRTAUX,IDRTCB,NCOL,NROW,NLAY,
     &          NDRTCL+NRFLOW,IOUT,DELT,PERTIM,TOTIM,IBOUND)
      ENDIF
C
C3------CLEAR THE BUFFER.
```

```
      DO 30 IL=1,NLAY
        DO 20 IR=1,NROW
          DO 10 IC=1,NCOL
            BUFF(IC,IR,IL)=ZERO
   10     CONTINUE
   20   CONTINUE
   30 CONTINUE
C
C4------IF THERE ARE NO DRAIN-RETURN CELLS THEN DO NOT ACCUMULATE FLOW.
      IF (NDRTCL.LE.0) GOTO 200
C
C5------LOOP THROUGH EACH DRAIN-RETURN CELL, CALCULATING FLOW.
      DO 100 L=1,NDRTCL
C
C5A-----GET LAYER, ROW & COLUMN OF CELL CONTAINING DRAIN.
        IL=DRTF(1,L)
        IR=DRTF(2,L)
        IC=DRTF(3,L)
        Q=ZERO
C
C5B-----IF CELL IS NO-FLOW OR CONSTANT-HEAD, IGNORE IT.
        IF (IBOUND(IC,IR,IL).LE.0) GOTO 99
C
C5C-----GET DRAIN PARAMETERS FROM DRAIN-RETURN LIST.
        EL=DRTF(4,L)
        EEL=EL
        C=DRTF(5,L)
        HHNEW=HNEW(IC,IR,IL)
C
C5D-----IF HEAD HIGHER THAN DRAIN, CALCULATE Q=C*(EL-HHNEW).
C5D-----SUBTRACT Q FROM RATOUT.
        IF (HHNEW.GT.EEL) THEN
          CC=C
          CEL=C*EL
          QQ=CEL - CC*HHNEW
          Q=QQ
          RATOUT=RATOUT-QQ
          ILR=0
          IF (IDRTFL.GT.0) THEN
            ILR = DRTF(6,L)
            IF (ILR.NE.0) THEN
              IRR = DRTF(7,L)
              ICR = DRTF(8,L)
              RFPROP = DRTF(9,L)
              QQIN = RFPROP*(CC*HHNEW-CEL)
              QIN = QQIN
              RATIN = RATIN + QQIN
            ENDIF
          ENDIF
        ENDIF
C
C5E-----PRINT THE INDIVIDUAL RATES IF REQUESTED(IDRTCB<0).
        IF (IBD.LT.0) THEN
          IF (IBDLBL.EQ.0) WRITE(IOUT,61) TEXT,KPER,KSTP
   61     FORMAT(1X,/1X,A,'   PERIOD',I3,'   STEP',I3)
          WRITE(IOUT,62) L,IL,IR,IC,Q
   62     FORMAT(1X,'DRAIN ',I4,'   LAYER ',I3,'   ROW ',I4,
     &       '   COL ',I4,'   RATE ',1PG15.6)
          IF (ILR.NE.0) THEN
            WRITE(IOUT,550) L,ILR,IRR,ICR,QIN
  550       FORMAT(1X,'DRAIN ',I4,' RETURN:  LAYER ',I3,'   ROW ',I4,
     &       '   COL ',I4,'   RATE ',1PG15.6)
          ENDIF
          IBDLBL=1
        ENDIF
C
C5F-----ADD Q TO BUFFER.
        BUFF(IC,IR,IL) = BUFF(IC,IR,IL) + Q
```

```
        IF (IDRTFL.GT.0 .AND. ILR.GT.0)
     &      BUFF(ICR,IRR,ILR) = BUFF(ICR,IRR,ILR) + QIN
C
C5G-----IF SAVING CELL-BY-CELL FLOWS IN A LIST, WRITE FLOW.  OR IF
C5G-----RETURNING THE FLOW IN THE DRTF ARRAY, COPY FLOW TO DRTF.
   99   IF (IBD.EQ.2) THEN
          CALL UBDSVB(IDRTCB,NCOL,NROW,IC,IR,IL,Q,DRTF(1,L),NDRTVL,NAUX,
     &                10,IBOUND,NLAY)
          IF (IDRTFL.NE.0 .AND. ILR.GT.0)
     &      CALL UBDSVB(IDRTCB,NCOL,NROW,ICR,IRR,ILR,QIN,DRTF(1,L),
     &                  NDRTVL,NAUX,10,IBOUND,NLAY)
        ENDIF
        IF (IDRTAL.NE.0) DRTF(NDRTVL,L) = Q
        IF (IDRTAL.GT.1) DRTF(NDRTVL-1,L) = QIN
  100 CONTINUE
C
C6------IF CELL-BY-CELL FLOW WILL BE SAVED AS A 3-D ARRAY,
C6------CALL UBUDSV TO SAVE THEM.
      IF (IBD.EQ.1) CALL UBUDSV(KSTP,KPER,TEXT,IDRTCB,BUFF,NCOL,NROW,
     &                          NLAY,IOUT)
C
C7------MOVE RATES,VOLUMES & LABELS INTO ARRAYS FOR PRINTING.
  200 CONTINUE
      RIN = RATIN
      ROUT=RATOUT
      VBVL(3,MSUM)=RIN
      VBVL(1,MSUM)=VBVL(1,MSUM)+RIN*DELT
      VBVL(4,MSUM)=ROUT
      VBVL(2,MSUM)=VBVL(2,MSUM)+ROUT*DELT
      VBNM(MSUM)=TEXT
C
C8------INCREMENT BUDGET TERM COUNTER.
      MSUM=MSUM+1
C
C9------RETURN.
      RETURN
      END
```

List of Variables for Module GWF1DRT1BD

Variable	Range	Definition
BUFF	Global	Buffer used to accumulate information before printing or recording it
C	Module	Hydraulic conductance of drain for a drain-return cell
CC	Module	Hydraulic conductance of drain for a drain-return cell
CEL	Module	Product of C times EL
DELT	Global	Length of the current time step
DRTAUX	Package	Auxiliary-variable names
DRTF	Package	Drain-return cell data
EEL	Module	Drain elevation for a drain-return cell
EL	Module	Drain elevation for a drain-return cell
HHNEW	Module	Head at a drain-return cell
HNEW	Global	Head
IBD	Module	Cell-by-cell budget save flag
IBDLBL	Module	Indicator for printing table heading
IBOUND	Global	Boundary-status indicator

Variable	Range	Definition
IC	Module	Cell index for a drain-return cell
ICBCFL	Global	Cell-by-cell flow-term write flag
ICR	Module	Cell index for a recipient cell
IDRTAL	Package	Indicator for saving cell-by-cell budget terms
IDRTCB	Package	Indicator and unit number for writing cell-by-cell flows
IDRTFL	Package	Indicator for return-flow option
IL	Module	Layer index for a drain-return cell
ILR	Module	Layer index for a recipient cell
IOUT	Global	Unit number of LIST output file
IR	Module	Row index for a drain-return cell
IRR	Module	Row index for a recipient cell
KPER	Global	Stress period counter
KSTP	Global	Time step counter
L	Module	Index for drain-return cells
MSUM	Global	Counter for budget entries and labels in VBVL and VBNM
MXDRT	Package	Dimensioning variable for DRTF
NAUX	Module	Number of auxiliary variables
NCOL	Global	Number of columns in model grid
NDRTCL	Package	Number of drain-return cells used in a stress period
NDRTVL	Package	Dimensioning variable for DRTF
NLAY	Global	Number of layers in model grid
NRFLOW	Package	Number of drain-return cells with a positive return-flow proportion
NROW	Global	Number of rows in model grid
PERTIM	Global	Elapsed time since beginning of stress period
Q	Module	Drain-flow rate
QIN	Module	Return-flow rate at a recipient cell
QQ	Module	Drain-flow rate
QQIN	Module	Return-flow rate at a recipient cell
RATIN	Module	Cumulative return-flow rate at all recipient cells
RATOUT	Module	Cumulative drain-flow rate at all drain-return cells
RFPROP	Package	Return-flow proportion
RIN	Module	Cumulative return-flow rate at all recipient cells
ROUT	Module	Cumulative drain-flow rate at all drain-return cells
TEXT	Module	Heading label
TOTIM	Global	Elapsed time since beginning of simulation
VBNM	Global	Labels for entries in the volumetric budget
VBVL	Global	Entries for the volumetric budget
ZERO	Module	0.0

Module SGWF1DRT1LR

Narrative for Module SGWF1DRT1LR

This secondary module reads and writes a list of drain-return cell entries. Output is written to the GLOBAL file.

1. Determine from which file list is to be read.

2. Determine if a scaling factor is to be used. If so, read it and print the value.

3. Print a label for the list.

4. For each entry in the list, read drain-return cell layer, row, column, drain elevation, and other variables, as required by options. Write values related to the drain-return cell and check validity of drain-cell location.

5. If the RETURNFLOW option has been specified, for each entry in the list, do steps 6 and 7.

6. Print values related to the recipient cell and check validity of recipient-cell location and return-flow proportion.

7. For the recipient cell, if the layer index or return-flow proportion equals zero, set all cell indices and proportion to zero.

8. If data came from a file specified with the “OPEN/CLOSE” option (Harbaugh and others, 2000), close the file.

Listing for Module SGWF1DRT1LR

```
      SUBROUTINE SGWF1DRT1LR(NLIST,DRTF,LSTBEG,NDRTVL,MXDRT,IDRTAL,
     &                       INPACK,IOUT,DRTAUX,NCAUX,NAUX,IFREFM,
     &                       NCOL,NROW,NLAY,ITERP,IDRTFL)
C
C-----VERSION 20000620 ERB
C     ******************************************************************
C     Read and print a list of drain and optional associated
C     return-flow recipient cells.  NAUX of the values in the list are
C     optional -- auxiliary data.
C     ******************************************************************
      CHARACTER*57 LABEL1, LABEL2, LABEL3
      CHARACTER*16 DRTAUX(NCAUX)
      DIMENSION DRTF(NDRTVL,MXDRT)
      CHARACTER*200 LINE,FNAME
      DATA NUNOPN/99/
C     ------------------------------------------------------------------
C
      IERR = 0
      ISCLOC1 = 5
      ISCLOC2 = 5
      IN=INPACK
      ICLOSE=0
      LABEL1='DRAIN NO.  LAYER   ROW   COL     DRAIN EL.  STRESS FACTOR'
      LABEL2='          ----DRAIN CELL----  --RECIPIENT CELL--   RETURN'
      LABEL3='DRAIN NO.  LAYER   ROW   COL   LAYER   ROW   COL    PROP.'
C
C  Check for and decode EXTERNAL and SFAC records.
      READ(IN,'(A)') LINE
      SFAC=1.
      LLOC=1
      CALL URWORD(LINE,LLOC,ISTART,ISTOP,1,I,R,IOUT,IN)
      IF (LINE(ISTART:ISTOP).EQ.'EXTERNAL') THEN
```

```
        CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,I,R,IOUT,IN)
        IN=I
        IF (ITERP.EQ.1) WRITE(IOUT,510) IN
  510   FORMAT(1X,'Reading list on unit',I4)
        READ(IN,'(A)') LINE
      ELSEIF (LINE(ISTART:ISTOP).EQ.'OPEN/CLOSE') THEN
        CALL URWORD(LINE,LLOC,ISTART,ISTOP,0,N,R,IOUT,IN)
        FNAME=LINE(ISTART:ISTOP)
        IN=NUNOPN
        IF (ITERP.EQ.1) WRITE(IOUT,520) IN,FNAME
  520   FORMAT(1X,/1X,'OPENING FILE ON UNIT',I4,':',/1X,A)
        OPEN(UNIT=IN,FILE=FNAME)
        ICLOSE=1
        READ(IN,'(A)') LINE
      ENDIF
      LLOC=1
      CALL URWORD(LINE,LLOC,ISTART,ISTOP,1,I,R,IOUT,IN)
      IF (LINE(ISTART:ISTOP).EQ.'SFAC') THEN
        CALL URWORD(LINE,LLOC,ISTART,ISTOP,3,I,SFAC,IOUT,IN)
        IF (ITERP.EQ.1) THEN
          WRITE(IOUT,530) SFAC
  530     FORMAT(1X,'LIST SCALING FACTOR=',1PG12.5)
          IF (ISCLOC1.EQ.ISCLOC2) THEN
            WRITE(IOUT,540) ISCLOC1
  540       FORMAT(1X,'(THE SCALE FACTOR WAS APPLIED TO FIELD',I2,')')
          ELSE
            WRITE(IOUT,550) ISCLOC1,ISCLOC2
  550       FORMAT(1X,'(THE SCALE FACTOR WAS APPLIED TO FIELDS',
     &             I2,'-',I2,')')
          ENDIF
        ENDIF
        READ(IN,'(A)') LINE
      ENDIF
C
C  Write a label for the list.
      IF (ITERP.EQ.1) THEN
        WRITE(IOUT,'(1X)')
        CALL ULSTLB(IOUT,LABEL1,DRTAUX,NCAUX,NAUX)
      ENDIF
C
C  Read the list
      NREAD2=NDRTVL-IDRTAL
      NREAD1=NREAD2-NAUX
      N=NLIST+LSTBEG-1
      DO 100 II=LSTBEG,N
C  Read a line into the buffer.  (The first line has already been read
C  in order to scan for EXTERNAL and SFAC records.)
        IF (II.NE.LSTBEG) READ(IN,'(A)') LINE
C
C  Read the non-optional values from the line.
        IF (IDRTFL.EQ.0) THEN
          IF (IFREFM.EQ.0) THEN
            READ(LINE,'(3I10,9F10.0)') K,I,J,(DRTF(JJ,II),JJ=4,NREAD1)
            LLOC=10*NREAD1+1
          ELSE
            LLOC=1
            CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,K,R,IOUT,IN)
            CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,I,R,IOUT,IN)
            CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,J,R,IOUT,IN)
            DO 10 JJ=4,NREAD1
              CALL URWORD(LINE,LLOC,ISTART,ISTOP,3,IDUM,DRTF(JJ,II),
     &                    IOUT,IN)
   10       CONTINUE
```

```
          ENDIF
        ELSE
          IF (IFREFM.EQ.0) THEN
            READ(LINE,'(3I10,2F10.0,3I10,9F10.0)') K,I,J,
     &          (DRTF(JJ,II),JJ=4,5),KR,IR,JR,(DRTF(JJ,II),JJ=9,NREAD1)
            LLOC=10*NREAD1+1
          ELSE
            LLOC=1
            CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,K,R,IOUT,IN)
            CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,I,R,IOUT,IN)
            CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,J,R,IOUT,IN)
            CALL URWORD(LINE,LLOC,ISTART,ISTOP,3,IDUM,DRTF(4,II),IOUT,
     &                  IN)
            CALL URWORD(LINE,LLOC,ISTART,ISTOP,3,IDUM,DRTF(5,II),IOUT,
     &                  IN)
            CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,KR,R,IOUT,IN)
            IF (KR.EQ.0 .AND. NREAD1.EQ.9 .AND. NAUX.EQ.0) THEN
              IR = 0
              JR = 0
              DRTF(9,II) = 0.0
            ELSE
              CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,IR,R,IOUT,IN)
              CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,JR,R,IOUT,IN)
              DO 20 JJ=9,NREAD1
                CALL URWORD(LINE,LLOC,ISTART,ISTOP,3,IDUM,DRTF(JJ,II),
     &                      IOUT,IN)
   20         CONTINUE
            ENDIF
            DRTF(6,II) = KR
            DRTF(7,II) = IR
            DRTF(8,II) = JR
          ENDIF
        ENDIF
        DRTF(1,II)=K
        DRTF(2,II)=I
        DRTF(3,II)=J
        DO 50 ILOC=ISCLOC1,ISCLOC2
          DRTF(ILOC,II)=DRTF(ILOC,II)*SFAC
   50   CONTINUE
C
C  Read the optional values from the line
        IF (NAUX.GT.0) THEN
          DO 60 JJ=NREAD1+1,NREAD2
            CALL URWORD(LINE,LLOC,ISTART,ISTOP,3,IDUM,DRTF(JJ,II),IOUT,
     &                  IN)
   60     CONTINUE
        ENDIF
C
C  Write the values that were read and that are not related to
C  return flow.
        NN=II-LSTBEG+1
        IF (ITERP.EQ.1) THEN
          IF (IDRTFL.EQ.0) THEN
            WRITE(IOUT,570) NN,K,I,J,(DRTF(JJ,II),JJ=4,NREAD2)
  570       FORMAT(1X,I6,I7,I7,I7,14G16.4)
          ELSE
            IF (NREAD2.GE.10) THEN
              WRITE(IOUT,570) NN,K,I,J,(DRTF(JJ,II),JJ=4,5),
     &                        (DRTF(JJ,II),JJ=10,NREAD2)
            ELSE
              WRITE(IOUT,570) NN,K,I,J,(DRTF(JJ,II),JJ=4,5)
            ENDIF
          ENDIF
```

```
        ENDIF
C
C  Check for illegal grid location
        IF (K.LT.1 .OR. K.GT.NLAY) THEN
          WRITE(IOUT,*) ' ERROR: Layer number is outside of the grid'
          IERR = 1
        ENDIF
        IF (I.LT.1 .OR. I.GT.NROW) THEN
          WRITE(IOUT,*) ' ERROR: Row number is outside of the grid'
          IERR = 1
        ENDIF
        IF (J.LT.1 .OR. J.GT.NCOL) THEN
          WRITE(IOUT,*) ' ERROR: Column number is outside of the grid'
          IERR = 1
        ENDIF
        IF (IERR.NE.0) STOP
  100 CONTINUE
C
C     Check and write data related to return-flow recipient cells
      IF (IDRTFL.GT.0) THEN
        IF (ITERP.EQ.1) WRITE(IOUT,'(/,1X,A,/,1X,A)') LABEL2,LABEL3
        NN = 0
        DO 110 II=LSTBEG,N
          NN = NN + 1
          K = DRTF(1,II)
          I = DRTF(2,II)
          J = DRTF(3,II)
          KR = DRTF(6,II)
          IR = DRTF(7,II)
          JR = DRTF(8,II)
          RFP = DRTF(9,II)
          IF (ITERP.EQ.1) WRITE(IOUT,600) NN,K,I,J,KR,IR,JR,RFP
  600     FORMAT(1X,I6,3I7,3I7,2X,F8.6)
C
C  Check for illegal grid location
          IF (KR.NE.0) THEN
            IF (KR.LT.0 .OR. KR.GT.NLAY) THEN
              WRITE(IOUT,*) ' ERROR: Layer number is outside of the',
     &                      ' grid'
              IERR = 1
            ENDIF
            IF (IR.LT.1 .OR. IR.GT.NROW) THEN
              WRITE(IOUT,*) ' ERROR: Row number is outside of the grid'
              IERR = 1
            ENDIF
            IF (JR.LT.1 .OR. JR.GT.NCOL) THEN
              WRITE(IOUT,*) ' ERROR: Column number is outside of the',
     &                      ' grid'
              IERR = 1
            ENDIF
C
C  Check for invalid return-flow proportion
            IF (RFP.LT.0.0 .OR. RFP.GT.1.0) THEN
              WRITE(IOUT,590)
  590         FORMAT(' ERROR: Proportion must be between 0.0 and 1.0')
              IERR = 1
            ENDIF
          ENDIF
C
C  If the proportion = 0 or KR = 0, set all indices and proportion to 0
          IF (KR.EQ.0 .OR. RFP.EQ.0.0) THEN
            DRTF(6,II) = 0.0
            DRTF(7,II) = 0.0
```

```
            DRTF(8,II) = 0.0
            DRTF(9,II) = 0.0
          ENDIF
          IF (IERR.NE.0) STOP
  110   CONTINUE
      ENDIF
C
      IF (ICLOSE.NE.0) CLOSE(UNIT=IN)
C
      RETURN
      END
```

List of Variables for Module SGWF1DRT1LR

Variable	Range	Definition
DRTAUX	Package	Auxiliary-variable names
DRTF	Package	Drain-return cell data
FNAME	Module	Input file name for OPEN/CLOSE type file
I	Module	Row index for a drain-return cell
ICLOSE	Module	Indicator for use of OPEN/CLOSE type file
IDRTAL	Package	Indicator for saving cell-by-cell budget terms
IDRTFL	Package	Indicator for return-flow option
IDUM	Module	Dummy integer variable
IERR	Module	Error flag
IFREFM	Global	Flag indicating if variables are to be read in free format
II	Module	List-entry index
ILOC	Module	Variable in DRTF to which SFAC applies
IN	Module	Unit number of input file
INPACK	Module	Unit number of input file
IOUT	Global	Unit number of GLOBAL output file
IR	Module	Row index for a recipient cell
ISCLOC1	Module	First variable in DRTF to which SFAC applies
ISCLOC2	Module	Last variable in DRTF to which SFAC applies
ISTART	Module	Starting position of parsed word
ISTOP	Module	Ending position of parsed word
ITERP	Global	Parameter-estimation iteration number
J	Module	Column index for a drain-return cell
JJ	Module	DO-loop counter
JR	Module	Column index for a recipient cell
K	Module	Layer index for a drain-return cell
KR	Module	Layer index for a recipient cell
LABEL1	Module	Table heading

Variable	Range	Definition
LABEL2	Module	Table heading
LABEL3	Module	Table heading
LINE	Module	Contents of one line read from input file
LLOC	Module	Pointer used to keep track of position in LINE
LSTBEG	Module	First position in DRTF of a list of parameter-controlled drain-return cells
MXDRT	Package	Dimensioning variable for DRTF
N	Module	Last position in DRTF of a list of parameter-controlled drain-return cells
NAUX	Module	Number of auxiliary variables
NCAUX	Module	Maximum number of auxiliary variables
NCOL	Global	Number of columns in model grid
NDRTVL	Package	Dimensioning variable for DRTF
NLAY	Global	Number of layers in model grid
NLIST	Module	Number of entries in a list of drain-return cells
NN	Module	Drain-return cell number
NREAD1	Module	First index in DRTF for auxiliary variables
NREAD2	Module	Last index in DRTF for auxiliary variables
NROW	Global	Number of rows in model grid
NUNOPN	Module	Unit number for OPEN/CLOSE type file
R	Module	Dummy real variable
RFP	Module	Return-flow proportion
SFAC	Module	Multiplier for list entries

Module SGWF1DRT1LS

Narrative for Module SGWF1DRT1LS

This secondary module reads a DRT1 parameter name then activates that parameter by performing substitution, using the current parameter value. Output is written to the LIST file.

1. Read the line containing the parameter name (item 6 of the DRT1 file) and print a message with the name.

2. Search through the list of parameter names to find a match. When a match is found, check that parameter type is “DRT.” Stop with error message if parameter name is not found or if parameter type is incorrect.

3. Determine number of list entries associated with the parameter.

4. Print label for list values.

5. For each entry in list, perform substitution by copying data into the part of the DRTF array that is used in formulating the finite-difference equations. Use current parameter value to calculate the drain conductance.

6. If the RETURNFLOW option has been specified, write recipient-cell data associated with the parameter.

Listing for Module SGWF1DRT1LS

```
      SUBROUTINE SGWF1DRT1LS(IN,IOUT,DRTF,NDRTVL,MXDRT,NREAD,MXADRT,
     &                       NDRTCL,DRTAUX,NCAUX,NAUX,IDRTFL)
C
C-----VERSION 20000620 ERB
C     ******************************************************************
C     Read a list parameter name and look it up in the list of
C     parameters.
C     ******************************************************************
C
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      INCLUDE 'param.inc'
      CHARACTER*3 PACK, PTYP
      DIMENSION DRTF(NDRTVL,MXDRT)
      CHARACTER*57 LABEL1, LABEL2, LABEL3
      CHARACTER*16 DRTAUX(NCAUX)
      CHARACTER*200 LINE
      CHARACTER*10 CTMP1, CTMP2
C     ------------------------------------------------------------------
      PACK = 'DRT'
      PTYP = 'DRT'
      IPVL1 = 5
      IPVL2 = 5
      LABEL1='DRAIN NO.  LAYER   ROW   COL     DRAIN EL.  CONDUCTANCE  '
      LABEL2='          ----DRAIN CELL----  --RECIPIENT CELL--   RETURN'
      LABEL3='DRAIN NO.  LAYER   ROW   COL   LAYER   ROW   COL    PROP.'
C
      READ(IN,'(A)') LINE
      LLOC=1
      CALL URWORD(LINE,LLOC,ISTART,ISTOP,0,IDUM,RDUM,IOUT,IN)
      WRITE(IOUT,500) LINE(ISTART:ISTOP)
  500 FORMAT(/,' Parameter:  ',A)
      IF(LINE(ISTART:ISTOP).EQ.' ') THEN
        WRITE(IOUT,*) ' Blank parameter name in the ',PACK,' file.'
        STOP
      END IF
C
      CTMP1=LINE(ISTART:ISTOP)
      CALL UPCASE(CTMP1)
      DO 100 IP=1,MXPAR
        CTMP2=PARNAM(IP)
        CALL UPCASE(CTMP2)
        IF(CTMP1.EQ.CTMP2) THEN
          IF(PARTYP(IP).NE.PTYP) THEN
            WRITE(IOUT,510) PARNAM(IP),PARTYP(IP),PACK,PTYP
  510       FORMAT(1X,'Parameter type conflict:',/
     &        1X,'Named parameter:',A,' was defined as type:',A,/
     &        1X,'However, this parameter is used in the ',A,
     &          ' file, so it should be type:',A)
            STOP
          ENDIF
          NLST=IPLOC(2,IP)-IPLOC(1,IP)+1
          IACTIVE(IP)=1
          NDRTCL=NDRTCL+NLST
          IF(NDRTCL.GT.MXADRT) THEN
            WRITE(IOUT,520) NDRTCL,MXADRT
  520       FORMAT(1X,/1X,'THE NUMBER OF ACTIVE LIST ENTRIES (',I4,
     &       ')',/1X,'IS GREATER THAN THE MAXIMUM ALLOWED (',I4,')')
            STOP
          ENDIF
C
```

```
C  Write label for list values
          CALL ULSTLB(IOUT,LABEL1,DRTAUX,NCAUX,NAUX)
C
C  Substitute values
          DO 60 I=1,NLST
            II=NDRTCL-NLST+I
            III=I-1+IPLOC(1,IP)
            DO 20 J=1,NREAD
              DRTF(J,II)=DRTF(J,III)
   20       CONTINUE
            DO 40 IPVL=IPVL1,IPVL2
              DRTF(IPVL,II)=DRTF(IPVL,II)*B(IP)
   40       CONTINUE
            IL=DRTF(1,II)
            IR=DRTF(2,II)
            IC=DRTF(3,II)
            IF (IDRTFL.EQ.0) THEN
              WRITE(IOUT,530) II,IL,IR,IC,(DRTF(JJ,II),JJ=4,NREAD)
  530         FORMAT(1X,I6,I7,I7,I7,14G16.4)
            ELSE
              IF (NREAD.GE.10) THEN
                WRITE(IOUT,530) II,IL,IR,IC,(DRTF(JJ,II),JJ=4,5),
     &                          (DRTF(JJ,II),JJ=10,NREAD)
              ELSE
                WRITE(IOUT,530) II,IL,IR,IC,(DRTF(JJ,II),JJ=4,5)
              ENDIF
            ENDIF
   60     CONTINUE
          GOTO 120
        ENDIF
  100 CONTINUE
C
      WRITE(IOUT,*) ' The ',PACK,
     &   ' file specifies an undefined parameter:',LINE(ISTART:ISTOP)
      STOP
C
  120 CONTINUE
C
C     WRITE DATA RELATED TO RETURN-FLOW RECIPIENT CELLS
      IF (IDRTFL.GT.0) THEN
        WRITE(IOUT,'(/,1X,A,/,1X,A)') LABEL2,LABEL3
        NN = 0
        DO 140 II=NDRTCL-NLST+1,NDRTCL
          NN = NN + 1
          K = DRTF(1,II)
          I = DRTF(2,II)
          J = DRTF(3,II)
          KR = DRTF(6,II)
          IR = DRTF(7,II)
          JR = DRTF(8,II)
          RFP = DRTF(9,II)
          WRITE(IOUT,600) NN,K,I,J,KR,IR,JR,RFP
  600     FORMAT(1X,I6,3I7,3I7,2X,F8.6)
  140   CONTINUE
      ENDIF
C
      RETURN
      END
```

List of Variables for Module SGWF1DRT1LS

Variable	Range	Definition
B	Global	Parameter values
CTMP1	Module	Name of active parameter listed in input file for the stress period
CTMP2	Module	Parameter name listed in parameter definition
DRTAUX	Package	Auxiliary-variable names
DRTF	Package	Drain-return cell data
I	Module	Counter for entries for a list of parameter-controlled drain-return cells
IACTIVE	Global	Flag indicating if a parameter is active
IC	Module	Column index for a drain-return cell
IDRTFL	Package	Indicator for return-flow option
IDUM	Module	Dummy integer variable
II	Module	List-entry index for an active drain-return cell
III	Module	List-entry index for a parameter-controlled drain-return cell
IL	Module	Layer index for a drain-return cell
IN	Module	Unit number for input file
IOUT	Global	Unit number of LIST output file
IP	Module	Parameter number
IPLOC	Global	First and last locations in DRTF of cell-list entries for each parameter
IPVL	Module	Index of DRTF for elements controlled by parameter value
IPVL1	Module	Index of DRTF for first element controlled by parameter value
IPVL2	Module	Index of DRTF for last element controlled by parameter value
IR	Module	Row index for a drain-return cell
ISTART	Module	Starting position of parsed word
ISTOP	Module	Ending position of parsed word
J	Module	Column index for a drain-return cell
JJ	Module	DO-loop counter
JR	Module	Column index for a recipient cell
K	Module	Layer index for a drain-return cell
KR	Module	Layer index for a recipient cell
LABEL1	Module	Table heading
LABEL2	Module	Table heading
LABEL3	Module	Table heading
LINE	Module	Contents of one line read from input file
LLOC	Module	Pointer used to keep track of position in LINE
MXADRT	Package	Maximum number of drain-return cells that can be active in a stress period
MXDRT	Package	Dimensioning variable for DRTF

Variable	Range	Definition
MXPAR	Global	Maximum number of parameters
NAUX	Module	Number of auxiliary variables
NCAUX	Module	Maximum number of auxiliary variables
NDRTCL	Package	Number of drain-return cells used in a stress period
NDRTVL	Package	Dimensioning variable for DRTF
NLST	Module	Number of drain-return cells in list
NN	Module	Drain-return cell number
NREAD	Module	Number of values to be substituted for each drain-return cell
PACK	Module	Package abbreviation
PARNAM	Global	Parameter names
PARTYP	Global	Parameter type
PTYP	Module	Expected parameter type
RDUM	Module	Dummy real variable
RFP	Module	Return flow proportion

Module OBS1DRT1AL

Narrative for Module OBS1DRT1AL

This primary module reads item 1 of the DTOB file and allocates space for flow observations for the DRT1 Package. Output is written to the GLOBAL file.

1. Write a message identifying the process, the package, and the unit number used for input.
2. If an OBS file (Hill and others, 2000) has not been listed in the name file, print a warning message, turn off DRT1 flow observations, and return.
3. Read and print comment lines introduced with the “#” character.
4. Read the number of cell groups, total number of cells, and number of flow observations from item 1 of the DTOB file. Print message showing these values.
5. Allocate space in the X array for the DRTF array.

Listing for Module OBS1DRT1AL

```
      SUBROUTINE OBS1DRT1AL(IUDTOB,NQ,NQC,NQT,IOUT,NQDT,NQTDT,IOBSUM,
     &                      LCOBDRT,ITMXP,LCSSDT,ISUM,IOBS)
C     VERSION 20000620 ERB
C     ******************************************************************
C     ALLOCATE ARRAY STORAGE FOR FLOW OBSERVATIONS AT DRAIN-RETURN CELLS
C     ******************************************************************
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      INTEGER IOUT, IUDTOB, NQ, NQC, NQT, NQDT, NQCDT, NQTDT
      CHARACTER*200 LINE
C     ------------------------------------------------------------------
C     IDENTIFY PROCESS
```

```
      WRITE(IOUT,490) IUDTOB
  490 FORMAT(/,' OBS1DRT1 -- OBSERVATION PROCESS (DRAIN FLOW ',
     &'OBSERVATIONS: DRAIN RETURN PACKAGE)',/,' VERSION 1.0, 5/2/2000',
     &/,' INPUT READ FROM UNIT ',I3)
C
C  Turn off observation package if OBS is not active
      IF (IOBS.LE.0) THEN
        WRITE(IOUT,610)
610     FORMAT(/,1X,'WARNING: OBSERVATION (OBS) FILE IS NOT LISTED BUT',
     &      ' THE DRT OBSERVATION',/,' FILE (DTOB) IS',
     &     ' LISTED -- TURNING OFF DRT OBSERVATIONS (OBS1DRT1AL)')
        IUDTOB = 0
        RETURN
      ENDIF
C
C  Read data
C     READ COMMENTS (ITEM 0)
      CALL URDCOM(IUDTOB,IOUT,LINE)
      LLOC = 1
C     READ ITEM 1
      CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,NQDT,DUM,IOUT,IUDTOB)
      CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,NQCDT,DUM,IOUT,IUDTOB)
      CALL URWORD(LINE,LLOC,ISTART,ISTOP,2,NQTDT,DUM,IOUT,IUDTOB)
      WRITE (IOUT,500) NQDT, NQCDT, NQTDT
   10 FORMAT(15I5)
  500 FORMAT (/,
     &     ' FOR DRAIN RETURN PACKAGE:',/,
     &     ' NUMBER OF FLOW-OBSERVATION DRAIN-CELL GROUPS.......:',I5,/,
     &     '   NUMBER OF CELLS IN DRAIN-CELL GROUPS.............:',I5,/,
     &     '   NUMBER OF DRAIN-CELL FLOWS.......................:',I5)
C
      NQ = NQ + NQDT
      NQC = NQC + NQCDT
      NQT = NQT + NQTDT
      LCSSDT = ISUM
      ISUM = ISUM + ITMXP + 1
C     POINTER TO OBSERVATION ARRAYS
      LCOBDRT = IOBSUM
      IOBSUM = IOBSUM + NQTDT
C
      RETURN
      END
```

List of Variables for Module OBS1DRT1AL

Variable	Range	Definition
DUM	Module	Dummy real variable
IOBS	Global	Indicator that Observation Process is active
IOBSUM	Global	Pointer used to keep track of position in OBSNAM and HOBS
IOUT	Global	Unit number of GLOBAL output file
ISTART	Module	Starting position of parsed word
ISTOP	Module	Ending position of parsed word
ISUM	Global	Pointer used to keep track of position in X
ITMXP	Global	Maximum number of parameter-estimation iterations
IUDTOB	Package	Unit number for DRT observations

Variable	Range	Definition
LCOBDRT	Package	Position in OBSNAM and HOBS of first DRT observation
LCSSDT	Package	Position in X of first element of SSDT
LINE	Module	Contents of one line read from input file
LLOC	Module	Pointer used to keep track of position in LINE
NQ	Global	Number of cell groups used for all flow observations
NQC	Global	Number of cells in all cell groups
NQCDT	Package	Number of cells in used for all DRT observations
NQDT	Package	Number of cell groups used for DRT observations
NQT	Global	Total number of flow observations
NQTDT	Package	Number of DRT flow observations

Module OBS1DRT1RP

Narrative for Module OBS1DRT1RP

This primary module reads items 2 through 7 of the DTOB file and prepares data for DRT1 flow observations. Output is written to the GLOBAL file.

6. Read the time-offset multiplier, error variance, and variance-covariance matrix flag for DRT1 observations from item 2.

7. Initialize some variables.

8. Write messages showing error variance and time-offset multiplier.

9. For each cell group, do steps 5 through 13.

10. Read the number of times at which flows are observed for the cell group and the number of cells in the group.

11. Set a flag identifying the cell group as being associated with the DRT1 Package.

12. Print a message showing the number of observations and the number of cells in the group, and print a table heading for the list of cells.

13. For each observation time, do steps 9 through 12.

14. Read and print the observation name, reference stress period, time offset, observation, data related to the observation weight, and a plot symbol.

15. Call a utility to convert the observation time to a time-step number and offset within a time step.

16. Advance the variable that indicates the time step required for the latest observation, if appropriate.

17. Check that DRT1 Package is active. If not, print error message and stop.

18. For each cell in the group, read and print layer, row, column, and factor for the cell. Check validity of cell location.

19. If flag indicates variance-covariance matrix for weighting DRT1 flow observations is to be read, do steps 15 and 16.

20. Read input format and print flag for variance-covariance matrix on DRT1 flow observations.

21. If requested, print the variance-covariance matrix.

22. Set pointer for the variance-covariance matrix for the next flow-observation package.

Listing for Module OBS1DRT1RP

```
      SUBROUTINE OBS1DRT1RP(NCOL,NROW,NPER,IUDTOB,IOUT,OBSNAM,NH,JT,NQT,
     &                      IBT,NQOB,NQCL,IQOB,QCLS,IERR,HOBS,TOFF,WTQ,
     &                      IOWTQ,IPRN,NDMH,NSTPA,PERLNA,TSMLTA,ISSA,
     &                      ITRSS,NQAR,NQCAR,NQTAR,IQ1,NQT1,NDD,IUDT,
     &                      NQDT,NQTDT,NT,NC,IPLOT,NAMES,ND,IPR,MPR,
     &                      IOWTQDT)
C     VERSION 20000620 ERB
C     ******************************************************************
C     READ, CHECK AND STORE FLOW-OBSERVATION DATA FOR DRAIN-RETURN
C     BOUNDARIES.
C     ******************************************************************
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      REAL BLANK, EVFDT, HOBS, PERLNA, QCLS, TOFF, TOFFSET, TOMULTDT,
     &     TSMLTA, WTQ
      INTEGER I, I4, IBT, IERR, IOUT, IOWTQ, IPRN, IQ, IQOB, IUDTOB,
     &        IWT, J, JT, L, N, NC, NC1, NC2, NCOL, NDMH, NH, NPER,
     &        NQCL, NQOB, NQT, NROW, NSTPA, NT, NT1, NT2, IUDT, ISSA
      INTEGER IPLOT(ND+IPR+MPR)
      CHARACTER*12 OBSNAM(NDD), NAMES(ND+IPR+MPR)
      CHARACTER*20 FMTIN*20, ANAME*50
      DIMENSION IBT(2,NQAR), NQOB(NQAR), NQCL(NQAR), IQOB(NQTAR),
     &          QCLS(5,NQCAR), HOBS(NH+NQT), TOFF(NH+NQT), NSTPA(NPER),
     &          PERLNA(NPER), TSMLTA(NPER), ISSA(NPER)
      DIMENSION WTQ(NDMH,NDMH)
      CHARACTER*10 STATYP(0:2)
      DATA (STATYP(I),I=0,2)/'VARIANCE','STD. DEV.','COEF. VAR.'/
      DATA ANAME/'COVARIANCE OF DRT-PACKAGE FLOW OBSERVATIONS '/
C     ------------------------------------------------------------------
  500 FORMAT (15X,2F5.0,F10.0)
  505 FORMAT (8F10.0)
  510 FORMAT (A4,6X,I5,3F10.0,I5)
  515 FORMAT (A3,2X,2I5)
  517 FORMAT (/,' DRT-PACKAGE FLOW OBSERVATION VARIANCES ARE',
     &        ' MULTIPLIED BY: ',G15.4)
  520 FORMAT (/,' OBSERVED DRT-PACKAGE FLOW DATA',/,' -- TIME OFFSETS',
     &        ' ARE MULTIPLIED BY: ',G12.5)
  525 FORMAT (/,' GROUP NUMBER: ',I3,'     BOUNDARY TYPE: ',A,
     &'     NUMBER OF CELLS IN GROUP: ',I5,/,
     &' NUMBER OF FLOW OBSERVATIONS: ',I5,//,
     &20X,'REFER.',14X,'OBSERVED',/,
     &7X,'OBSERVATION',2X,'STRESS',4X,'TIME',5X,'DRAIN FLOW',15X,
     &'STATISTIC   PLOT',/,
     &2X,'OBS#    NAME',6X,'PERIOD   OFFSET',5X,'GAIN (-)',
     &4X,'STATISTIC     TYPE      SYM.')
  535 FORMAT (1X,I5,1X,A12,2X,I4,2X,G11.4,1X,G11.4,1X,G11.4,2X,A10,
     &1X,I5)
  540 FORMAT (/,'       LAYER  ROW  COLUMN    FACTOR')
  550 FORMAT (4X,F8.0,F6.0,F7.0,F9.2)
  555 FORMAT (4X,F8.0,F6.0,F9.2)
  560 FORMAT (/,' FOR OBS',I5,' STATISTIC RELATED TO WEIGHT < OR =0 -- '
     &        ,'STOP EXECUTION (OBS1DRT1RP)',/)
```

```
  565 FORMAT (/,' DRAIN RETURN (DRT) PACKAGE',
     &        ' IS NOT OPEN -- STOP EXECUTION (OBS1DRT1RP)')
  570 FORMAT (/,' LARGEST OBS TIME STEP (',I5,') LARGER THAN NPER (',I5,
     &        ') OF BASIC PACKAGE INPUT FILE',/,
     &        ' -- STOP EXECUTION (OBS1DRT1RP)',/)
  590 FORMAT (/,' ROW OR COLUMN NUMBER INVALID',
     &        ' -- STOP EXECUTION (OBS1DRT1RP)',/)
  605 FORMAT (/,' OBSERVATION',I5,' EQUALS ZERO, THE STATISTIC ',
     &        'CAN NOT BE A',/,' COEFFICIENT OF VARIATION (ISTAT=2)',
     &        ' -- STOP EXECUTION(OBS1DRT1RP)')
  615 FORMAT (//,1X,A,/,1X,42('-'))
  620 FORMAT (/,1X,'ERROR: SEARCH ABOVE FOR ERROR MESSAGE(S)',/,
     &' -- STOP EXECUTION (OBS1DRT1RP)')
C
C-----READ TIME-OFFSET MULTIPLIER FOR FLOW-OBSERVATION TIMES AND INPUT
C     ERROR VARIANCE FOR FLOW OBSERVATIONS (ITEM 2)
      READ(IUDTOB,*) TOMULTDT, EVFDT, IOWTQDT
      IF (IOWTQDT.GT.0) IOWTQ = 1
C
C-------INITIALIZE VARIABLES
      IQ2 = IQ1 + NQDT - 1
      DO 20 IQ = IQ1,IQ2
        IBT(2,IQ) = 0
   20 CONTINUE
C-------WRITE TITLE AND LOOP THROUGH CELL GROUPS (READ ITEMS 3, 4, AND 5)
      WRITE (IOUT,517) EVFDT
      WRITE (IOUT,520) TOMULTDT
      DO 120 IQ = IQ1,IQ2
C       READ ITEM 3
        READ (IUDTOB,*) NQOB(IQ), NQCL(IQ)
        IBT(1,IQ) = 6
        WRITE (IOUT,525) IQ, 'DRT', NQCL(IQ), NQOB(IQ)
C----------SET FLAG FOR SETTING ALL FACTORS TO 1
        I4 = 0
        IF (NQCL(IQ).LT.0) THEN
          I4 = 1
          NQCL(IQ) = -NQCL(IQ)
        ENDIF
C----------READ TIME STEPS, MEASURED FLOWS, AND WEIGHTS.
        NT1 = NT + 1
        NT2 = NT + NQOB(IQ)
        DO 30 J = NT1, NT2
          N = NH + J
C---------READ ITEM 4
          IF (IOWTQDT.GT.0) THEN
            READ (IUDTOB,*) OBSNAM(N), IREFSP, TOFFSET, HOBS(N), STAT,
     &                      IST, IPLOT(N)
            NAMES(N) = OBSNAM(N)
            WRITE (IOUT,535) N,OBSNAM(N),IREFSP,TOFFSET,HOBS(N),
     &          STATYP(IST),IPLOT(N)
          ELSE
            READ (IUDTOB,*) OBSNAM(N), IREFSP, TOFFSET, HOBS(N),
     &                      WTQ(J,J), IWT, IPLOT(N)
            NAMES(N) = OBSNAM(N)
            WRITE (IOUT,535) N, OBSNAM(N), IREFSP, TOFFSET, HOBS(N),
     &          WTQ(J,J), STATYP(IWT), IPLOT(N)
            IF (HOBS(N).EQ.0 .AND. IWT.EQ.2) THEN
              WRITE (IOUT,605) N
              IERR = 1
            ENDIF
            IF (IWT.EQ.2) WTQ(J,J) = WTQ(J,J)*HOBS(N)
            IF (IWT.GT.0) WTQ(J,J) = WTQ(J,J)*WTQ(J,J)
            WTQ(J,J) = WTQ(J,J)*EVFDT
            IF (WTQ(J,J).LE.0.) THEN
              WRITE (IOUT,560) N
              IERR = 1
```

```
            ENDIF
          ENDIF
          CALL UOBSTI(OBSNAM(N),IOUT,ISSA,ITRSS,NPER,NSTPA,IREFSP,
     &                IQOB(J),PERLNA,TOFF(N),TOFFSET,TOMULTDT,TSMLTA,1)
C----------ERROR CHECKING
          IF (IQOB(J).GT.JT) JT = IQOB(J)
          IF (IUDT.EQ.0) THEN
            WRITE (IOUT,565)
            IERR = 1
          ENDIF
   30   CONTINUE
C----------READ LAYER, ROW, COLUMN, AND FACTOR (ITEM 5)
        NC1 = NC + 1
        NC2 = NC + NQCL(IQ)
        WRITE (IOUT,540)
        DO 40 L = NC1, NC2
          READ (IUDTOB,*) (QCLS(I,L),I=1,4)
          IF (I4.EQ.1) QCLS(4,L) = 1.
          WRITE (IOUT,550) (QCLS(I,L),I=1,4)
          I = QCLS(2,L)
          J = QCLS(3,L)
          IF (J.LE.0 .OR. J.GT.NCOL .OR. I.LE.0 .OR. I.GT.NROW) THEN
            WRITE (IOUT,590)
            IERR = 1
          ENDIF
   40   CONTINUE
C-------UPDATE COUNTERS
        NC = NC2
        NT = NT2
  120 CONTINUE
      IQ1 = IQ2 + 1
C
C-------READ FULL COVARIANCE MATRIX ON DRAIN-RETURN-CELL
C       FLOW-OBSERVATION DATA
      IPRN = 0
      NQT2 = NQT1 + NQTDT - 1
      IF (IOWTQDT.GT.0 .AND. NQTDT.GT.0) THEN
C       READ ITEM 6
        READ (IUDTOB,*) FMTIN, IPRN
C       READ ITEM 7
        DO 140 I = NQT1,NQT2
          READ (IUDTOB,FMTIN) (BLANK,J=NQT1,I-1), (WTQ(I,J),J=I,NQT2)
          DO 130 J = I, NQT2
            WTQ(I,J) = WTQ(I,J)*EVFDT
            IF (I.EQ.J) THEN
              IF (WTQ(I,J).LT.0.) WTQ(I,J) = -WTQ(I,J)
            ELSE
              WTQ(J,I) = WTQ(I,J)
            ENDIF
  130     CONTINUE
  140   CONTINUE
        IF (IPRN.GE.0) THEN
          WRITE (IOUT,615) ANAME
          CALL UARRSUBPRW(WTQ,NDMH,NDMH,NQT1,NQT2,NQT1,NQT2,IPRN,IOUT,
     &                    OBSNAM(NH+1),NDMH)
        ENDIF
      ENDIF
      NQT1 = NQT2 + 1
C
      IF (IERR.GT.0) THEN
        WRITE(IOUT,620)
        STOP
      ENDIF
C
      RETURN
      END
```

List of Variables for Module OBS1DRT1RP

Variable	Range	Definition
ANAME	Module	Header for printed WTQ matrix
BLANK	Module	Dummy real variable
EVFDT	Package	Error variance multiplier for DRT observations
FMTIN	Module	Fortran format for reading WTQ
HOBS	Global	Observed values
I	Module	Index for WTQ
I4	Module	Flag for setting all observation-cell contribution factors to 1.0
IBT	Process	Indicator identifying package used for flow observation
IERR	Global	Error flag
IOUT	Global	Unit number of GLOBAL output file
IOWTQ	Global	Indicator of use of variance-covariance matrix for flow observations
IOWTQDT	Package	Indicator of use of variance-covariance matrix for DRT flow observations
IPLOT	Global	Plot symbols
IPR	Global	Number of parameters involved in variance-covariance matrix for weighting prior information (Hill and others, 2000)
IPRN	Module	Print code for WTQ
IQ	Module	Index for cell groups
IQ1	Module	Pointer for first cell group of DRT observations
IQ2	Module	Pointer for last cell group of DRT observations
IQOB	Process	Time step of each observation
IREFSP	Module	Reference stress period
ISSA	Global	Indicator of steady or transient state for each stress period
IST	Module	Indicator of statistic type
ITRSS	Global	Indicator that simulation is steady, transient, or a combination of the two
IUDT	Package	Unit number for DRT input file
IUDTOB	Package	Unit number for DRT observations input file
IWT	Module	Statistic type
J	Module	DO-loop counter for DRT observations
JT	Global	Number of final required time step
L	Module	Index for flow-observation cells
MPR	Global	Number of prior-information equations (Hill and others, 2000)
N	Module	Index for observations
NAMES	Global	Observation names

Variable	Range	Definition
NC	Module	Counter for flow-observation cells
NC1	Module	Pointer for first cell in group
NC2	Module	Pointer for last cell in group
NCOL	Global	Number of columns in model grid
ND	Global	Number of observations
NDD	Process	Dimensioning variable for observation arrays
NDMH	Process	Number of observations minus number of head observations
NH	Process	Number of head observations
NPER	Global	Number of stress periods
NQAR	Process	Dimensioning variable for flow-observation cell-group arrays
NQCAR	Process	Dimensioning variable for flow-observation cell arrays
NQCL	Process	Number of cells in each group
NQDT	Package	Number of cell groups for DRT observations
NQOB	Process	Number of flow observations for each group
NQT	Process	Total number of flow observations
NQT1	Process	Counter for number of flow observations
NQT2	Module	Pointer for last DRT flow observation
NQTAR	Process	Dimensioning variable for IQOB
NQTDT	Package	Number of DRT flow observations
NROW	Global	Number of rows in model grid
NSTPA	Global	Number of time steps in each stress period
NT	Process	Pointer for flow observations
NT1	Module	Pointer for first cell in group
NT2	Module	Pointer for last cell in group
OBSNAM	Global	Observation names
PERLNA	Global	Length of each stress period
QCLS	Global	Cell data for flow observations
STAT	Module	Statistic
STATYP	Module	Statistic type
TOFF	Process	Normalized observation-time offset within a time step
TOFFSET	Module	Observation-time offset from beginning of reference stress period
TOMULTDT	Package	Time-offset multiplier for DRT observations
TSMLTA	Global	Time-step multiplier for each stress period
WTQ	Global	Variance-covariance matrix for weighting flow observations

Module OBS1DRT1FM

Narrative for Module OBS1DRT1FM

This primary module calculates simulated equivalents for flow observations at features simulated using the DRT1 Package. Output is written to the LIST file.

1. Initialize some variables.

2. For each flow-observation cell group in the simulation, do steps 3 through 9.

3. If the cell group is associated with the DRT1 Package, do steps 4 through 9.

4. For each observation time specified for the cell group, do steps 5 through 9.

5. If the observation time is in the current time step, do steps 6 through 9.

6. For each cell in the cell group, do steps 7 and 8.

7. Loop through the DRTF array to find a matching cell, based on layer, row, column, and position in the DRTF array. When a match is found, calculate the flow for the cell. If the head in the cell is below the drain elevation, increment count of disconnected cells.

8. Add flow from the cell to the variable that accumulates flow for the cell group to calculate the simulated equivalent for the observation.

9. If any cells in the group are disconnected, print message listing them. Check for disconnected observation (heads at all cells in group below corresponding drain elevations). Print message if observation is disconnected.

Listing for Module OBS1DRT1FM

```
      SUBROUTINE OBS1DRT1FM(NQ,NQT,NQOB,NQCL,IQOB,QCLS,IBT,HNEW,NCOL,
     &                      NROW,NLAY,IOUT,IBOUND,NH,OBSNAM,H,TOFF,
     &                      MXDRT,NDRTCL,DRTF,WTQ,NDMH,ITS,NQAR,NQCAR,
     &                      NQTAR,NDRTVL)
C     VERSION 20000620 ERB
C     ******************************************************************
C     CALCULATE SIMULATED EQUIVALENTS TO OBSERVED FLOWS FOR THE DRAIN
C     RETURN PACKAGE
C     ******************************************************************
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      REAL C, DRTF, FACT, H, HB, HH, HHNEW, QCLS, TOFF, WTQ, ZERO
      INTEGER I, IBOUND, IBT, IBT1, IFLAG, II, IOUT, IQ, IQOB, IRBOT,
     &        ITS, J, JJ, JRBOT, K, KK, KRBOT, MXDRT, N, NB, NBN, NC,
     &        NC1, NC2, NCOL, NDMH, NDRTCL, NH, NLAY, NQ, NQCL, NQOB,
     &        NQT, NROW, NT, NT1, NT2
      CHARACTER*12 OBSNAM(NH+NQT)
      DOUBLE PRECISION HNEW(NCOL,NROW,NLAY)
      DIMENSION IBOUND(NCOL,NROW,NLAY), IBT(2,NQAR), NQOB(NQAR),
     &          NQCL(NQAR), IQOB(NQTAR), QCLS(5,NQCAR), H(NH+NQT),
     &          TOFF(NH+NQT), DRTF(NDRTVL,MXDRT), WTQ(NDMH,NDMH)
      INCLUDE 'param.inc'
C     ------------------------------------------------------------------
  500 FORMAT (/,
     &' HEADS AT DRAIN-RETURN CELLS ARE BELOW THE',
```

```
     &' BOTTOM OF THE DRAIN AT THE CELLS LISTED',/,
     &' BELOW.  THESE CONDITIONS DIMINISH THE IMPACT',
     &' OF THE OBSERVATION ON ALL',/,
     &' PARAMETERS EXCEPT, IN SOME CASES, THE HYDRAULIC CONDUCTIVITY',
     &' OF THE DRAIN',/,
     &' (SEE TEXT FOR MORE INFORMATION).')
  505 FORMAT (/,' OBS#',I5,', ID ',A,', TIME STEP ',I5)
  510 FORMAT ('    LAYER   ROW  COLUMN')
  520 FORMAT (3I7)
  525 FORMAT (' *',I5,I7)
  530 FORMAT (I7,' OF THE',I7,' REACHES OR CELLS USED TO SIMULATE THE',
     &        ' GAIN OR LOSS ARE',/,22X,'AFFECTED.')
  535 FORMAT (' THIS OBSERVATION NO LONGER IMPACTS PARAMETER ',
     &        'ESTIMATION AND WILL BE ELIMINATED FROM THIS PARAMETER ',
     &        /,'ESTIMATION ITERATION')
  540 FORMAT (' CELL #',I5,
     &        ' OF HEAD-DEP. BOUNDARY GAIN OR LOSS OBS#',I5,' ID=',A,/,
     &        ' NOT FOUND IN CELLS LISTED FOR DRAIN RETURN PACKAGE',/,
     &        ' -- STOP EXECUTION (OBS1DRT1FM)')
C
C-------INITIALIZE VARIABLES
      ZERO = 0.0
      NC = 0
      NT1 = 1
      JRBOT = 0
C-------LOOP THROUGH BOUNDARY FLOWS
      DO 60 IQ = 1, NQ
        IBT1 = IBT(1,IQ)
        NT2 = NT1 + NQOB(IQ) - 1
        IF (IBT1.NE.6) GOTO 50
C----------WAS THERE A MEASUREMENT AT THIS BOUNDARY THIS TIME STEP?
        DO 40 NT = NT1, NT2
          IF (IQOB(NT).EQ.ITS .OR.
     &        (IQOB(NT).EQ.ITS-1.AND.TOFF(NH+NT).GT.ZERO)) THEN
C----------ASSIGN VARIABLES ACCORDING TO BOUNDARY TYPE
            IRBOT = 0
            KRBOT = 0
            NBN = NDRTCL
C----------LOOP THROUGH CELLS.
            NC1 = NC + 1
            NC2 = NC + NQCL(IQ)
            NB = 0
            DO 30 N = NC1, NC2
              K = QCLS(1,N)
              I = QCLS(2,N)
              J = QCLS(3,N)
C----------LOOP THROUGH DATA FILE TO FIND A MATCH.
              IFLAG = 0
              DO 10 MNB = 1, NBN
                NB = NB + 1
                IF (NB.GT.NBN) NB = 1
                KK = DRTF(1,NB)
                II = DRTF(2,NB)
                JJ = DRTF(3,NB)
C----------DO CALCULATIONS IF THIS IS A MATCH
                IF (I.EQ.II.AND.J.EQ.JJ.AND.K.EQ.KK) THEN
                  IF (IBOUND(J,I,K).LT.1) GOTO 30
                  IFLAG = 1
C-------------ASSIGN VARIABLE VALUES
                  HHNEW = HNEW(J,I,K)
                  HB = DRTF(4,NB)
                  C = DRTF(5,NB)
C-------------CALCULATE FLOWS
```

```
                  HH = C*(HB-HHNEW)
                  IF (HHNEW.LE.HB) THEN
                    HH = 0.0
                    IF (JRBOT.EQ.0) WRITE (IOUT,500)
                    JRBOT = 1
                    IF (IRBOT.EQ.0) THEN
                      WRITE (IOUT,505) NH + NT, OBSNAM(NH+NT), ITS
                      WRITE (IOUT,510)
                    ENDIF
                    IRBOT = IRBOT + 1
                    IF (IBT(2,IQ).EQ.0) KRBOT = KRBOT + 1
                    WRITE (IOUT,520) K, I, J
                  ENDIF
                  GOTO 20
                ENDIF
   10         CONTINUE
              IF (IFLAG.EQ.0) THEN
                WRITE (IOUT,540) N, NH + NT, OBSNAM(NH+NT)
                STOP
              ENDIF
C-------------SUM VALUES FROM INDIVIDUAL CELLS.
C----------------CALCULATE FACTOR FOR TEMPORAL INTERPOLATION
   20         FACT = 1.0
              IF (TOFF(NH+NT).GT.ZERO) THEN
                IF (IQOB(NT).EQ.ITS) FACT = 1. - TOFF(NH+NT)
                IF (IQOB(NT).EQ.ITS-1) FACT = TOFF(NH+NT)
              ENDIF
C--------------FLOWS
              H(NH+NT) = H(NH+NT) + HH*FACT*QCLS(4,N)
   30       CONTINUE
C-------PRINT NUMBER OF CELLS AT WHICH HEAD IS BELOW THE BOTTOM OF THE
C-------DRAIN; CHECK FOR DISCONNECTED OBSERVATIONS.
            IF (IRBOT.GT.0) WRITE (IOUT,530) IRBOT, NQCL(IQ)
            IF (KRBOT.EQ.NQCL(IQ)) THEN
              WTQ(NT,NT) = -WTQ(NT,NT)
              WRITE (IOUT,535)
            ENDIF
          ENDIF
   40   CONTINUE
C-------UPDATE COUNTERS
   50   NC = NC + NQCL(IQ)
        NT1 = NT2 + 1
C
   60 CONTINUE
      RETURN
      END
```

List of Variables for Module OBS1DRT1FM

Variable	Range	Definition
C	Module	Hydraulic conductance of drain for a drain-return cell
DRTF	Package	Drain-return cell data
FACT	Module	Factor for temporal interpolation
H	Module	Simulated equivalents to observations
HB	Module	Drain elevation for a drain-return cell
HH	Module	Drain flow at a drain-return cell

Variable	Range	Definition
HHNEW	Module	Head at a drain-return cell
HNEW	Global	Head
I	Module	Implied-DO-loop counter
IBOUND	Global	Boundary-status indicator
IBT	Process	Indicator identifying package used for flow observation
IBT1	Module	Observation-type indicator for a flow-observation cell group
IFLAG	Module	Indicator that cell in observation cell group is a drain-return cell
II	Module	Row index for a drain-return cell
IOUT	Global	Unit number of LIST output file
IQ	Module	Index for cell groups
IQOB	Process	Time step of each observation
IRBOT	Module	Counter for observation cells where head is below drain elevation
ITS	Global	Time-step number
J	Module	Column index for a DRT observation cell
JJ	Module	Column index for a drain-return cell
JRBOT	Module	Indicator that head is below drain elevation for at least one cell
K	Module	Layer index for a DRT observation cell
KK	Module	Layer index for a drain-return cell
KRBOT	Module	Counter for cells where head is below drain elevation and cell is not controlled by any DRT parameter
MNB	Module	DO-loop counter for drain-return cells
MXDRT	Package	Dimensioning variable for DRTF
N	Module	Cell index in QCLS
NB	Module	Cell index in DRTF
NBN	Module	Number of drain-return cells used in a stress period
NC	Module	Place marker for position in QCLS
NC1	Module	Position in QCLS of first cell in group
NC2	Module	Position in QCLS of last cell in group
NCOL	Global	Number of columns in model grid
NDMH	Process	Number of observations minus number of head observations
NDRTCL	Package	Number of drain-return cells used in a stress period
NDRTVL	Package	Dimensioning variable for DRTF
NH	Process	Number of head observations
NLAY	Global	Number of layers in model grid
NQ	Process	Number of flow-observation cell groups

Variable	Range	Definition
NQAR	Process	Dimensioning variable for flow-observation cell-group arrays
NQCAR	Process	Dimensioning variable for flow-observation cell arrays
NQCL	Process	Number of cells in each group
NQOB	Process	Number of flow observations for each group
NQT	Process	Total number of flow observations
NQTAR	Process	Dimensioning variable for IQOB
NROW	Global	Number of rows in model grid
NT	Module	Pointer for flow observations
NT1	Module	Pointer for first cell in group
NT2	Module	Pointer for last cell in group
OBSNAM	Global	Observation names
QCLS	Global	Cell data for flow observations
TOFF	Process	Normalized observation-time offset within a time step
WTQ	Global	Variance-covariance matrix for weighting flow observations
ZERO	Module	0.0

Module OBS1DRT1DR

Narrative for Module OBS1DRT1DR

This primary module calculates observation sensitivities for flow observations at features simulated using the DRT1 Package for one DRT1 parameter. Output, if any, is written to the GLOBAL file.

1. Initialize some variables.

2. If the current parameter is a DRT parameter, call a secondary module to populate an element in the QCLS array with Condfact from the parameter definition.

3. For each flow-observation cell group in the simulation, do steps 4 through 10.

4. If the cell group is associated with the DRT1 Package, do steps 5 through 9.

5. For each observation time specified for the cell group, do steps 6 through 9.

6. If the observation time is in the current time step, do steps 7 through 9.

7. For each cell in the cell group, do steps 8 and 9.

8. Loop through the DRTF array to find a matching cell, based on layer, row, column, and position in the DRTF array. When a match is found, calculate contribution for the cell at this time step to observation sensitivity.

9. Sum contributions from individual cells to sensitivity for the group.

10. Update pointers for the next cell group.

Listing for Module OBS1DRT1DR

```
      SUBROUTINE OBS1DRT1DR(NQ,NQT,NQOB,NQCL,IQOB,QCLS,IBT,HNEW,IP,SNEW,
     &                      NCOL,NROW,NLAY,IOUT,IBOUND,NH,X,OBSNAM,NPE,
     &                      LN,TOFF,MXDRT,NDRTCL,DRTF,NPLIST,ITS,NQAR,
     &                      NQCAR,NQTAR,NDRTVL,IERR,IERRU,NDRTNP,IDRTPB)
C     VERSION 20000619 ERB
C     ******************************************************************
C     CALCULATE SENSITIVITIES FOR FLOW OBSERVATIONS FOR THE DRAIN RETURN
C     PACKAGE
C     ******************************************************************
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      REAL C, DRTF, FACT, HB, HHNEW, QCLS, TOFF, X, XX, ZERO
      INTEGER I, IBOUND, IBT, IBT1, IFLAG, II, IOUT, IP, IQ, IQOB, ITS,
     &        J, JJ, K, KK, LN, MXDRT, N, NB, NBN, NC, NC1, NC2, NCOL,
     &        NDRTCL, NH, NLAY, NPE, NQ, NQCL, NQOB, NQT, NROW, NT, NT1,
     &        NT2
      CHARACTER*4 PIDTMP
      CHARACTER*12 OBSNAM(NH+NQT)
      DOUBLE PRECISION HNEW(NCOL,NROW,NLAY), SNEW(NCOL,NROW,NLAY)
      DIMENSION IBOUND(NCOL,NROW,NLAY), X(NPE,NH+NQT), IBT(2,NQAR),
     &          LN(NPLIST), NQOB(NQAR), NQCL(NQAR), IQOB(NQTAR),
     &          QCLS(5,NQCAR), TOFF(NH+NQT), DRTF(NDRTVL,MXDRT)
      INCLUDE 'param.inc'
C     ------------------------------------------------------------------
  500 FORMAT (/,
     &' FOR THE DRAIN RETURN PACKAGE:,',/,
     &' HEADS AT DRAIN CELLS ARE BELOW THE',
     &' BOTTOM OF THE DRAIN AT THE CELLS LISTED',/,
     &' BELOW.  THESE CONDITIONS DIMINISH THE IMPACT',
     &' OF THE OBSERVATION ON ALL',/,
     &' PARAMETERS EXCEPT, IN SOME CASES, THE HYDRAULIC CONDUCTIVITY',
     &' OF THE DRAIN',/,
     &' (SEE TEXT FOR MORE INFORMATION).')
  505 FORMAT (/,' OBS#',I5,', ID ',A4,', TIME STEP ',I5)
  510 FORMAT ('    LAYER   ROW  COLUMN')
  520 FORMAT (3I7)
  525 FORMAT (' *',I5,I7)
  530 FORMAT (I7,' OF THE',I7,' REACHES OR CELLS USED TO SIMULATE THE',
     &        ' GAIN OR LOSS ARE',/,22X,'AFFECTED.')
  535 FORMAT (' THIS OBSERVATION NO LONGER IMPACTS PARAMETER ',
     &        'ESTIMATION AND WILL BE ELIMINATED FROM THIS PARAMETER ',
     &        /,'ESTIMATION ITERATION')
  540 FORMAT (' CELL #',I5,
     &        ' OF HEAD-DEP. BOUNDARY GAIN OR LOSS OBS#',I5,' ID=',A,
     &        ' NOT FOUND IN CELLS LISTED FOR',/,'DRAIN RETURN PACKAGE',
     &        ' -- STOP EXECUTION (OBS1DRT1DR)')
C
C-------INITIALIZE VARIABLES
      ZERO = 0.0
      NC = 0
      NT1 = 1
      IIPP = IPPTR(IP)
      PIDTMP = PARTYP(IIPP)
      IF (PIDTMP.EQ.'DRT ')
     &    CALL SOBS1DRT1QC(IBT,IIPP,NDRTVL,MXDRT,NQ,NQCL,DRTF,QCLS,
     &                     NQAR,NQCAR,NDRTNP,IDRTPB)
C-------LOOP THROUGH BOUNDARY FLOWS
      DO 60 IQ = 1, NQ
        IBT1 = IBT(1,IQ)
        NT2 = NT1 + NQOB(IQ) - 1
        IF (IBT1.NE.6) GOTO 50
C----------WAS THERE A MEASUREMENT AT THIS BOUNDARY THIS TIME STEP?
```

```
        DO 40 NT = NT1, NT2
          IF (IQOB(NT).EQ.ITS .OR.
     &        (IQOB(NT).EQ.ITS-1.AND.TOFF(NH+NT).GT.ZERO)) THEN
C----------ASSIGN VARIABLES ACCORDING TO BOUNDARY TYPE
            NBN = NDRTCL
C----------LOOP THROUGH CELLS.
            NC1 = NC + 1
            NC2 = NC + NQCL(IQ)
            NB = 0
            DO 30 N = NC1, NC2
              K = QCLS(1,N)
              I = QCLS(2,N)
              J = QCLS(3,N)
C----------LOOP THROUGH DATA FILE TO FIND A MATCH.
              IFLAG = 0
              DO 10 MNB = 1, NBN
                NB = NB + 1
                IF (NB.GT.NBN) NB = 1
                KK = DRTF(1,NB)
                II = DRTF(2,NB)
                JJ = DRTF(3,NB)
C----------DO CALCULATIONS IF THIS IS A MATCH
                IF (I.EQ.II.AND.J.EQ.JJ.AND.K.EQ.KK) THEN
                  IF (IBOUND(J,I,K).LT.1) GOTO 30
                  IFLAG = 1
C-------------ASSIGN VARIABLE VALUES
                  HHNEW = HNEW(J,I,K)
                  HB = DRTF(4,NB)
                  C = DRTF(5,NB)
C-------------CALCULATE SENSITIVITIES
                  XX = ZERO
                  IF (HHNEW.LE.HB) GOTO 30
                  IF (HHNEW.GT.HB) XX = -C*SNEW(J,I,K)
                  IF (IIPP.EQ.IBT(2,IQ) .AND. HHNEW.GT.HB)
     &                XX = XX + QCLS(5,N)*(HB-HHNEW)
                  GOTO 20
                ENDIF
   10         CONTINUE
              IF (IFLAG.EQ.0) THEN
                WRITE (IOUT,540) N, NH + NT, OBSNAM(NH+NT)
                WRITE (IERRU,540) N, NH + NT, OBSNAM(NH+NT)
                IERR = 1
                RETURN
              ENDIF
C-------------SUM VALUES FROM INDIVIDUAL CELLS.
C----------------CALCULATE FACTOR FOR TEMPORAL INTERPOLATION
   20         FACT = 1.0
              IF (TOFF(NH+NT).GT.ZERO) THEN
                IF (IQOB(NT).EQ.ITS) FACT = 1. - TOFF(NH+NT)
                IF (IQOB(NT).EQ.ITS-1) FACT = TOFF(NH+NT)
              ENDIF
C----------------SENSITIVITY-EQUATION SENSITIVITIES
              IF (LN(IIPP).GT.0) XX = XX*B(IIPP)
              X(IP,NH+NT) = X(IP,NH+NT) + XX*FACT*QCLS(4,N)
   30       CONTINUE
          ENDIF
   40   CONTINUE
C-------UPDATE COUNTERS
   50   NC = NC + NQCL(IQ)
        NT1 = NT2 + 1
C
   60 CONTINUE
      RETURN
      END
```

List of Variables for Module OBS1DRT1DR

Variable	Range	Definition
B	Global	Parameter values
C	Module	Hydraulic conductance of drain for a drain-return cell
DRTF	Package	Drain-return cell data
FACT	Module	Factor for temporal interpolation
HB	Module	Drain elevation for a drain-return cell
HHNEW	Module	Head at a drain-return cell
HNEW	Global	Head
I	Module	Row index for a flow-observation cell
IBOUND	Global	Boundary-status indicator
IBT	Process	Indicator identifying package used for flow observations and parameter controlling drain conductance of cells in flow-observation cell group
IBT1	Module	Indicator identifying package used for a flow observation
IDRTPB	Package	Index of first cell of first parameter definition in DRTF
IERR	Global	Error flag
IERRU	Global	Unit for writing warnings and error messages
IFLAG	Module	Indicator that cell in observation cell group is a drain-return cell
II	Module	Row index for a drain-return cell
IIPP	Module	Parameter number
IOUT	Global	Unit number of GLOBAL output file
IP	Module	Index for pointer to parameter number
IPPTR	Global	Pointer to parameter number
IQ	Module	Index for cell groups
IQOB	Process	Time step of each observation
ITS	Global	Time-step number
J	Module	Column index for a DRT observation cell
JJ	Module	Column index for a drain-return cell
K	Module	Layer index for a DRT observation cell
KK	Module	Layer index for a drain-return cell
LN	Global	Indicator for log-transforming parameter values
MNB	Module	DO-loop counter for drain-return cells
MXDRT	Package	Dimensioning variable for DRTF
N	Module	Cell index in QCLS
NB	Module	Cell index in DRTF
NBN	Module	Number of drain-return cells used in a stress period
NC	Module	Place marker for position in QCLS
NC1	Module	Position in QCLS of first cell in group

Variable	Range	Definition
NC2	Module	Position in QCLS of last cell in group
NCOL	Global	Number of columns in model grid
NDRTCL	Package	Number of drain-return cells used in a stress period
NDRTNP	Package	Number of non-parameter drain-return cells in use during current stress period
NDRTVL	Package	Dimensioning variable for DRTF
NH	Process	Number of head observations
NLAY	Global	Number of layers in model grid
NPE	Global	Number of parameters being estimated or analyzed for sensitivity
NPLIST	Global	Number of parameters listed in Sensitivity Process input file (Hill and others, 2000)
NQ	Process	Number of flow-observation cell groups
NQAR	Process	Dimensioning variable for flow-observation cell-group arrays
NQCAR	Process	Dimensioning variable for flow-observation cell arrays
NQCL	Process	Number of cells in each group
NQOB	Process	Number of flow observations for each group
NQT	Process	Total number of flow observations
NQTAR	Process	Dimensioning variable for IQOB
NROW	Global	Number of rows in model grid
NT	Module	Pointer for flow observations
NT1	Module	Pointer for first cell in group
NT2	Module	Pointer for last cell in group
OBSNAM	Global	Observation names
PARTYP	Global	Parameter type
PIDTMP	Module	Parameter type of current parameter
QCLS	Global	Cell data for flow observations
SNEW	Global	Parameter sensitivity at each cell
TOFF	Process	Normalized observation-time offset within a time step
X	Global	Observation sensitivities
XX	Module	Temporary variable for calculation of observation sensitivity
ZERO	Module	0.0

Module SOBS1DRT1OH

Narrative for Module SOBS1DRT1OH

This secondary module calculates and prints weighted residuals for flow observations at features simulated using the DRT1 Package. Output is written to the LIST file and, optionally, to files generated by the Observation Process.

1. Write table heading.

2. Initialize some variables.

3. For each flow observation specified using the DRT1 Package, do steps 4 through 9.

4. If the observation has not been deactivated, do steps 5 through 9.

5. Calculate the unweighted residual.

6. Calculate the weighted residual.

7. If required, write data to output files named using OUTNAM of the Observation Process input file (Hill and others, 2000).

8. Add weighted residual to variables that accumulate the sum of squared, weighted residuals.

9. Determine the effect of the weighted residual on descriptive statistics.

10. Store the sum of squared, weighted residuals due to DRT1-Package flow observations.

11. Calculate and print statistics for DRT1-Package residuals.

Listing for Module SOBS1DRT1OH

```
      SUBROUTINE SOBS1DRT1OH(IO,IOWTQDT,IOUT,NH,NQTDT,HOBS,H,WTQ,OBSNAM,
     &                       IDIS,WTQS,D,AVET,NPOST,NNEGT,NRUNS,RSQ,ND,
     &                       MPR,IPR,NDMH,WTRL,NRES,IUGDO,OUTNAM,IPLOT,
     &                       IPLPTR,LCOBDRT,ISSWR,SSDT,ITMXP)
C     VERSION 20000510 ERB
C     ******************************************************************
C     CALCULATE AND PRINT WEIGHTED RESIDUALS FOR DRAIN-RETURN FLOW
C     OBSERVATIONS
C     ******************************************************************
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      REAL AVE, AVET, D, H, HOBS, RES, RSQ, SWH, VMAX, VMIN, WT2, WTQ,
     &     WTQS, WTR, WTRL
      INTEGER IDIS, IO, IOUT, IOWTQDT, IPR, J, MPR, N, ND, NDMH, NH,
     &        NMAX, NMIN, NNEG, NNEGT, NPOS, NPOST, NQ1, NQ2, NQTDT,
     &        NRES, NRUNS
      INTEGER IUGDO(6), IPLOT(ND+IPR+MPR), IPLPTR(ND+IPR+MPR)
      CHARACTER*12 OBSNAM(ND)
      CHARACTER*200 OUTNAM
      DIMENSION H(ND), HOBS(ND), D(ND+MPR+IPR), WTQ(NDMH,NDMH),
     &          WTQS(NDMH,NDMH), SSDT(ITMXP+1)
C     ------------------------------------------------------------------
C
  500 FORMAT (/,
     &' DATA FOR FLOWS REPRESENTED USING THE DRAIN RETURN PACKAGE',//
     &7X,'OBSERVATION      MEAS.      CALC.',14X,'WEIGHTED',/,
     &'  OBS#    NAME',10X,'FLOW',7X,'FLOW',4X,'RESIDUAL',3X,
     &        'RESIDUAL',/)
  505 FORMAT (/,
     &' DATA FOR FLOWS REPRESENTED USING THE DRAIN RETURN PACKAGE',//
     &7X,'OBSERVATION',6X,'MEAS.      CALC.',26X,'WEIGHTED',/,
     &2X,'OBS#    NAME',10X,'FLOW',7X,'FLOW',5X,'RESIDUAL',2X,
     &'WEIGHT**.5',2X,'RESIDUAL',/)
  510 FORMAT (1X,I5,1X,A12,1X,5(1X,G10.3))
  515 FORMAT (1X,I5,1X,A12,2X,G10.3,'   DISCONNECTED')
  520 FORMAT (/,' SUM OF SQUARED WEIGHTED RESIDUALS (DRT FLOWS ONLY)',
     &        2X,G11.5)
  525 FORMAT (/,' STATISTICS FOR DRT PACKAGE FLOW RESIDUALS :',/,
     &        ' MAXIMUM WEIGHTED RESIDUAL  :',G10.3,' OBS#',I7,/,
     &        ' MINIMUM WEIGHTED RESIDUAL  :',G10.3,' OBS#',I7,/,
     &        ' AVERAGE WEIGHTED RESIDUAL  :',G10.3,/,
     &        ' # RESIDUALS >= 0. :',I7,/,' # RESIDUALS < 0.  :',I7,/,
```

```
     &        ' NUMBER OF RUNS  :',I5,'  IN',I5,' OBSERVATIONS')
  530 FORMAT (2G20.7)
  535 FORMAT (' ')
  540 FORMAT (2(G15.7,1X),I5,2X,A)
  550 FORMAT (G15.7,1X,I5,2X,A)
C
      IF (IO.EQ.1) THEN
        IF (IOWTQDT.GT.0) THEN
          WRITE (IOUT,500)
        ELSE
          WRITE (IOUT,505)
        ENDIF
      ENDIF
      IDISDT = 0
      NRESDT = 0
      NRUNSDT = 1
      RSQDT = 0.0
      NNEG = 0
      NPOS = 0
      VMAX = -1.E20
      VMIN = 1.E20
      AVE = 0.
      DO 20 N = LCOBDRT, LCOBDRT+NQTDT-1
        NQ1 = N - NH
        IF (WTQ(NQ1,NQ1).LT.0.) THEN
          WRITE (IOUT,515) N, OBSNAM(N), HOBS(N)
          IDIS = IDIS + 1
          IDISDT = IDISDT + 1
          GOTO 20
        ENDIF
        NRES = NRES + 1
        NRESDT = NRESDT + 1
        IPLPTR(NRES) = N
        RES = HOBS(N) - H(N)
        IF (IOWTQDT.GT.0) THEN
          WTR = 0.0
          SWH = 0.0
          OWH = 0.0
          DO 10 J = 1, NQTDT
            NQ2 = LCOBDRT + J - 1
            WTR = WTR + WTQS(NQ1,J)*(HOBS(NQ2)-H(NQ2))
            SWH = SWH + WTQS(NQ1,J)*H(NQ2)
            OWH = OWH + WTQS(NQ1,J)*HOBS(NQ2)
   10     CONTINUE
          IF (IO.EQ.1) WRITE (IOUT,510) N, OBSNAM(N),
     &                                  HOBS(N), H(N), RES, WTR
        ELSE
          WT2 = WTQS(NQ1,NQ1)
          WTR = RES*WT2
          OWH = HOBS(NQ1)*WT2
          SWH = H(NQ1)*WT2
          IF (IO.EQ.1) WRITE (IOUT,510) N, OBSNAM(N),
     &                                  HOBS(N), H(N), RES, WT2, WTR
        ENDIF
        IF (IO.EQ.1) THEN
          IF (OUTNAM.NE.'NONE') THEN
            WRITE (IUGDO(1),540) H(N), HOBS(N), IPLOT(N), OBSNAM(N)
            WRITE (IUGDO(2),540) SWH, OWH, IPLOT(N), OBSNAM(N)
            WRITE (IUGDO(3),540) SWH, WTR, IPLOT(N), OBSNAM(N)
            WRITE (IUGDO(4),550) RES, IPLOT(N), OBSNAM(N)
            WRITE (IUGDO(5),550) WTR, IPLOT(N), OBSNAM(N)
            D(NRES) = WTR
          ENDIF
        ENDIF
        RSQ = RSQ + (WTR**2)
```

```
        RSQDT = RSQDT + (WTR**2)
        IF (WTR.GT.VMAX) THEN
          VMAX = WTR
          NMAX = N
        ENDIF
        IF (WTR.LT.VMIN) THEN
          VMIN = WTR
          NMIN = N
        ENDIF
        IF (WTR.GE.0.) NPOS = NPOS + 1
        IF (WTR.LT.0.) NNEG = NNEG + 1
        IF (N.GT.1) THEN
          IF (WTRL*WTR.LT.0.) NRUNS = NRUNS + 1
        ENDIF
        IF (N.GT.LCOBDRT) THEN
          IF (WTRL*WTR.LT.0.) NRUNSDT = NRUNSDT + 1
        ENDIF
        WTRL = WTR
        AVE = AVE + WTR
   20 CONTINUE
      IF (ISSWR.GT.0) SSDT(ISSWR) = RSQDT
      IF (NQTDT.NE.IDISDT) THEN
        AVET = AVET + AVE
        NPOST = NPOST + NPOS
        NNEGT = NNEGT + NNEG
        AVE = AVE/REAL(NQTDT-IDISDT)
        IF (IO.EQ.1) THEN
          WRITE (IOUT,525) VMAX, NMAX, VMIN, NMIN, AVE, NPOS, NNEG,
     &                     NRUNSDT, NRESDT
          WRITE (IOUT,520) RSQDT
        ENDIF
      ENDIF
      RETURN
      END
```

List of Variables for Module SOBS1DRT1OH

Variable	Range	Definition
AVE	Module	Average weighted residual for DRT observations
AVET	Process	Cumulative weighted residual for all observations
D	Process	Weighted residuals
H	Process	Simulated equivalents to observations
HOBS	Global	Observed values
IDIS	Process	Counter for deactivated observations
IDISDT	Module	Counter for deactivated DRT observations
IO	Process	Printing flag
IOUT	Global	Unit number of LIST output file
IOWTQDT	Package	Variance-covariance matrix for weighting flow observations
IPLOT	Global	Plot symbols
IPLPTR	Global	Pointer to IPLOT elements
IPR	Global	Number of parameters involved in variance-covariance matrix for weighting prior information
ISSWR	Global	Number of times parameter-estimation loop has been executed

Variable	Range	Definition
ITMXP	Global	Maximum number of parameter-estimation iterations
IUGDO	Global	Unit numbers for automatically generated output files
J	Module	Counter for DRT observations
LCOBDRT	Package	Position in OBSNAM and HOBS of first DRT observation
MPR	Global	Number of prior-information equations
N	Module	Counter for DRT observations
ND	Global	Number of observations
NDMH	Process	Number of observations minus number of head observations
NH	Process	Number of head observations
NMAX	Module	Number of observation having largest weighted residual
NMIN	Module	Number of observation having smallest weighted residual
NNEG	Module	Number of residuals for DRT observations that are less than zero
NNEGT	Process	Number of residuals that are less than zero
NPOS	Module	Number of residuals for DRT observations that are greater than or equal to zero
NPOST	Process	Number of residuals that are greater than or equal to zero
NQ1	Module	Index for flow observations
NQ2	Module	Index for observations
NQTDT	Package	Number of DRT flow observations
NRES	Process	Number of residuals
NRESDT	Package	Number of residuals for DRT observations
NRUNS	Process	Number of runs
NRUNSDT	Package	Number of runs in DRT observations
OBSNAM	Global	Observation names
OUTNAM	Global	File name base for automatically generated output files
OWH	Module	Weighted observation
RES	Module	Residual
RSQ	Process	Cumulative sum of squared, weighted residuals
RSQDT	Module	Sum of squared, weighted residuals for DRT observations
SSDT	Package	Sum of squared, weighted residuals for DRT observations for each iteration
SWH	Module	Weighted simulated equivalent
VMAX	Module	Maximum weighted residual
VMIN	Module	Minimum weighted residual
WT2	Module	Square root of the weight
WTQ	Global	Variance-covariance matrix for weighting flow observations
WTQS	Global	Square root of the weight matrix
WTR	Module	Weighted residual
WTRL	Process	Weighted residual of previous observation

Module SOBS1DRT1QC

Narrative for Module SOBS1DRT1QC

Where one or more drain-return cells in an observation cell group are controlled by a DRT parameter, this secondary module copies Condfact from the parameter definition into the QCLS array.

1. Initialize some variables.

2. For each flow-observation cell group do steps 3 through 12.

3. Increment pointers to starting and ending cells in the cell group.

4. If the current parameter is active this stress period, do steps 5 through 12.

5. If this cell group is for DRT1 flow observations, do steps 6 through 12.

6. Set pointers that keep place in the DRTF array.

7. Do steps 8 through 12 for each cell in the cell group.

8. Identify the layer, row, and column of the flow-observation cell.

9. If the flow-observation cell is a non-parameter drain-return cell, skip steps 10 through 12 and go to the next cell in the cell group.

10. If the flow-observation cell is associated with an active DRT1 parameter preceding the parameter of interest, skip steps 11 and 12 and go to the next cell in the cell group.

11. Do step 12 for each parameter-controlled drain-return cell.

12. If the flow-observation cell is a drain-return cell controlled by the parameter of interest, populate the appropriate element for the flow-observation cell in the QCLS array with Condfact from the parameter definition.

Listing for Module SOBS1DRT1QC

```
      SUBROUTINE SOBS1DRT1QC(IBT,IIPP,NDRTVL,MXDRT,NQ,NQCL,DRTF,QCLS,
     &                       NQAR,NQCAR,NDRTNP,IDRTPB)
C     VERSION 20000518 ERB
C     ******************************************************************
C     POPULATE QCLS ARRAY ELEMENT 5 FOR DRT FLOW-OBSERVATION CELLS ON
C     ONE DRT-PARAMETER-CONTROLLED HEAD-DEPENDENT BOUNDARY IF IT IS
C     ACTIVE THIS STRESS PERIOD
C     ******************************************************************
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      DIMENSION IBT(2,NQAR), NQCL(NQAR), DRTF(NDRTVL,MXDRT),
     &          QCLS(5,NQCAR)
      CHARACTER*4 PTYP
      INCLUDE 'param.inc'
C     ------------------------------------------------------------------
      PTYP = 'DRT '
      MCOLFAC = 5
      NC = 0
C-------LOOP THROUGH CELL GROUPS
      DO 120 IQ=1,NQ
```

```
        IFLAG = 0
C---------DETERMINE STARTING AND ENDING CELLS IN THIS CELL GROUP
        NC1 = NC + 1
        NC2 = NC + NQCL(IQ)
        IF (IACTIVE(IIPP).EQ.1) THEN
C---------IF PID FOR THIS PARAMETER MATCHES BOUNDARY TYPE SPECIFIED
C         FOR THIS CELL GROUP
          IF (IBT(1,IQ).EQ.6) THEN
C           RESET POINTERS
            NB = 0
            NBOP = IDRTPB - 1
            NBP = IPLOC(1,IIPP) - 1
            IP1 = 1
C-----------LOOP THROUGH CELLS IN THIS GROUP
            DO 100 JJ = NC1,NC2
              KO = QCLS(1,JJ)
              IO = QCLS(2,JJ)
              JO = QCLS(3,JJ)
C
C             SKIP OVER CELLS IN OBSERVATION CELL GROUP ASSOCIATED WITH
C             NON-PARAMETER CELLS IN THE SAME LAYER, ROW AND COLUMN
              IF(NDRTNP.GT.0) THEN
                DO 20 MNB = 1, NDRTNP
                  NB = NB + 1
                  IF (NB.GT.NDRTNP) GOTO 30
                  KNP = DRTF(1,NB)
                  INP = DRTF(2,NB)
                  JNP = DRTF(3,NB)
                  IF (KO.EQ.KNP .AND. IO.EQ.INP .AND. JO.EQ.JNP)
     &                GOTO 100
   20           CONTINUE
   30           CONTINUE
              ENDIF
C
C             SKIP OVER CELLS IN OBSERVATION CELL GROUP ASSOCIATED WITH
C             ACTIVE DRAIN-RETURN PARAMETERS PRECEDING PARAMETER OF
C             INTEREST IN PARAMETER SECTION OF ARRAY WHERE LAYER, ROW,
C             AND COLUMN MATCH
              IF (IIPP.GT.1 .AND. NBP.EQ.IPLOC(1,IIPP)-1) THEN
                KIP1 = IP1
                DO 60 KIP = KIP1, IIPP-1
                  IP1 = KIP
                  IF (PARTYP(KIP).EQ.PTYP) THEN
                    IF (IACTIVE(KIP).GT.0) THEN
                      DO 40 II = IPLOC(1,KIP),IPLOC(2,KIP)
                        NBOP = NBOP + 1
                        IF (NBOP.GT.IPLOC(2,KIP)) GOTO 50
                        KOP = DRTF(1,NBOP)
                        IOP = DRTF(2,NBOP)
                        JOP = DRTF(3,NBOP)
                        IF (KO.EQ.KOP .AND. IO.EQ.IOP .AND. JO.EQ.JOP)
     &                      GOTO 100
   40                 CONTINUE
   50                 CONTINUE
                    ENDIF
                    NBOP = IPLOC(2,KIP)
                  ENDIF
   60           CONTINUE
              ENDIF
C
C-------------LOOP THROUGH PARAMETER CELLS IN PACKAGE DATA FILE
              DO 80 II = IPLOC(1,IIPP),IPLOC(2,IIPP)
                NBP = NBP + 1
```

```
                IF (NBP.GT.IPLOC(2,IIPP)) GOTO 90
                K = DRTF(1,NBP)
                I = DRTF(2,NBP)
                J = DRTF(3,NBP)
C---------------IF OBSERVATION CELL IS ON THE PARAMETER-CONTROLLED
C               BOUNDARY, PUT PARAMETER FACTOR IN QCLS(5)
                IF (KO.EQ.K .AND. IO.EQ.I .AND. JO.EQ.J) THEN
                  IBT(2,IQ) = IIPP
                  IFLAG = 1
                  QCLS(5,JJ) = DRTF(MCOLFAC,NBP)
                  GOTO 100
                ENDIF
   80         CONTINUE
   90         CONTINUE
  100       CONTINUE
          ENDIF
        ENDIF
        IF (IFLAG.EQ.0 .AND. IBT(2,IQ).EQ.IIPP) IBT(2,IQ) = 0
        NC = NC2
  120 CONTINUE
C
      RETURN
      END
```

List of Variables for Module SOBS1DRT1QC

Variable	Range	Definition
DRTF	Package	Drain-return cell data
I	Module	Row index of a drain-return cell
IACTIVE	Global	Flag indicating if a parameter is active
IBT	Process	Indicator identifying package used for flow observations and parameter controlling drain conductance of cells in flow-observation cell group
IDRTPB	Package	Index of first cell of first parameter definition in DRTF
IFLAG	Module	Indicator that cell in observation cell group is a drain-return cell
II	Module	Counter for cells controlled by a parameter
IIPP	Module	Parameter number
INP	Module	Row index for a non-parameter drain-return cell
IO	Module	Row index for a flow-observation cell
IOP	Module	Row index for a drain-return cell defined by a parameter other than the parameter of interest
IP1	Module	Place keeper for parameters other than the parameter of interest
IPLOC	Global	First and last locations in DRTF of cell-list entries for each parameter
IQ	Module	Index for cell groups
J	Module	Column index for a drain-return cell
JJ	Module	Counter for cells in group of flow-observation cells
JNP	Module	Column index for a non-parameter drain-return cell
JO	Module	Column index for a flow-observation cell

Variable	Range	Definition
JOP	Module	Column index for a drain-return cell defined by a parameter other than the parameter of interest
K	Module	Layer index for a drain-return cell
KIP	Module	Counter for parameters other than the parameter of interest
KIP1	Module	Starting parameter when looping through parameters other than the parameter of interest
KNP	Module	Layer index for a non-parameter drain-return cell
KO	Module	Layer index for a flow-observation cell
KOP	Module	Layer index for a drain-return cell defined by a parameter other than the parameter of interest
MCOLFAC	Module	Position in DRTF where factor used to calculate drain conductance from parameter value is stored
MNB	Module	Counter for non-parameter drain-return cells
MXDRT	Package	Dimensioning variable for DRTF
NB	Module	Entry index for non-parameter drain-return cells
NBOP	Module	Entry index for cells defined by parameters other than the parameter of interest
NBP	Module	Entry index for cells defined by parameter of interest
NC	Module	Place marker for position in QCLS
NC1	Module	Position in QCLS of first cell in group
NC2	Module	Position in QCLS of last cell in group
NDRTNP	Package	Number of non-parameter drain-return cells in use during current stress period
NDRTVL	Package	Dimensioning variable for DRTF
NQ	Process	Number of flow-observation cell groups
NQAR	Process	Dimensioning variable for flow-observation cell-group arrays
NQCAR	Process	Dimensioning variable for flow-observation cell arrays
NQCL	Process	Number of cells in each group
PARTYP	Global	Parameter type
PTYP	Module	Parameter type for drain-return parameters
QCLS	Global	Cell data for flow observations

Module SEN1DRT1FM

Narrative for Module SEN1DRT1FM

This primary module calculates the derivative of the drain flow with respect to one DRT1 parameter and subtracts it from the RHS array. If the RETURNFLOW option is specified, it also calculates the derivative of the return flow with respect to the parameter and subtracts it from the RHS array.

1. For each cell listed in the parameter definition, do steps 2 and 3.

2. If the cell is active, do step 3.

3. If the head in the cell is above the drain elevation, calculate the derivative of the drain flow with respect to the parameter. If the RETURNFLOW option has been selected, also calculate the derivative of the return flow with respect to the parameter. Subtract the derivative(s) from the appropriate RHS array element(s).

Listing for Module SEN1DRT1FM

```
      SUBROUTINE SEN1DRT1FM(MXDRT,DRTF,HNEW,NCOL,NROW,NLAY,IBOUND,RHS,
     &                      IP,NDRTVL,IDRTFL)
C-----VERSION 20000619 ERB
C     ******************************************************************
C     FOR DRAIN-RETURN AND RECIPIENT CELLS: CALCULATE MATRIX AND VECTOR
C     DERIVATIVES, MULTIPLY BY HEADS, AND ADD COMPONENTS TO RHS.
C     ******************************************************************
C        SPECIFICATIONS:
C     ------------------------------------------------------------------
      REAL DRTF, RHS
      INTEGER I, IBOUND, II, J, K, MXDRT, NCOL, NLAY, NROW
      DOUBLE PRECISION DF, HH, HNEW(NCOL,NROW,NLAY)
      DIMENSION DRTF(NDRTVL,MXDRT), IBOUND(NCOL,NROW,NLAY),
     &          RHS(NCOL,NROW,NLAY)
      INCLUDE 'param.inc'
C     ------------------------------------------------------------------
C
      IF (IACTIVE(IP).EQ.0) RETURN
      IPOS1 = IPLOC(1,IP)
      NPC = IPLOC(2,IP)-IPOS1+1
C-----LOOP THROUGH PARAMETER CELLS
      DO 20 II = 1, NPC
        ICP = IPOS1-1+II
        K = DRTF(1,ICP)
        I = DRTF(2,ICP)
        J = DRTF(3,ICP)
        IF (IBOUND(J,I,K).GT.0) THEN
C---------CALCULATE CONTRIBUTION TO SENSITIVITY
          ELEVD = DRTF(4,ICP)
          HH = HNEW(J,I,K)
          IF (HH.GT.ELEVD) THEN
            FACTOR = DRTF(5,ICP)
            DF = FACTOR*(ELEVD-HH)
            RHS(J,I,K) = RHS(J,I,K) - DF
C  CALCULATE CONTRIBUTION TO SENSITIVITY OF RETURN FLOW
            IF (IDRTFL.GT.0) THEN
              KR = DRTF(6,ICP)
              IF (KR.NE.0) THEN
                IR = DRTF(7,ICP)
                JR = DRTF(8,ICP)
                RFPROP = DRTF(9,ICP)
                DFR = RFPROP*FACTOR*(HH-ELEVD)
                RHS(JR,IR,KR) = RHS(JR,IR,KR) - DFR
              ENDIF
            ENDIF
          ENDIF
        ENDIF
   20 CONTINUE
C
      RETURN
      END
```

List of Variables for Module SEN1DRT1FM

Variable	Range	Definition
DF	Module	Contribution to RHS of derivative of drain flow with respect to the parameter
DFR	Module	Contribution to RHS of derivative of return flow with respect to the parameter
DRTF	Package	Drain-return cell data
ELEVD	Module	Drain elevation for an active drain-return cell
FACTOR	Module	Multiplier (Condfact) in the parameter definition
HH	Module	Hydraulic head in a cell
HNEW	Global	Head
I	Module	Row index for a drain-return cell controlled by the parameter
IACTIVE	Global	Flag indicating if each parameter is active
IBOUND	Global	Boundary-status indicator
ICP	Module	List-entry index for a drain-return cell in the parameter definition
IDRTFL	Package	Indicator for return-flow option
II	Module	Counter for drain-return cells in the parameter definition
IP	Module	Parameter number
IPLOC	Global	First and last locations in DRTF of cell-list entries for each parameter
IPOS1	Module	Position in DRTF of first cell in the parameter definition
IR	Module	Row index of a recipient cell
J	Module	Column index for a drain-return cell controlled by the parameter
JR	Module	Column index of a recipient cell
K	Module	Layer index of a drain-return cell in the parameter definition
KR	Module	Layer index of a recipient cell
MXDRT	Package	Dimensioning variable for DRTF
NCOL	Global	Number of columns in model grid
NDRTVL	Package	Dimensioning variable for DRTF
NLAY	Global	Number of layers in model grid
NPC	Module	Number of cells controlled by the parameter
NROW	Global	Number of rows in model grid
RFPROP	Package	Return-flow proportion
RHS	Global	Right-hand side

PARAMETER-ESTIMATION EXAMPLE PROBLEM

This example problem demonstrates the use of the Sensitivity and Parameter-Estimation Processes with the ETS1 and DRT1 Packages. The example also demonstrates the use of observations with the DRT1 Package. For this problem, a grid of 11 rows by 11 columns in one layer was used to simulate an unconfined aquifer with a uniform base elevation of 0 ft. All row and column widths were 100 ft. All cells in column 1 had a specified head of 50 ft, all cells in column 11 had a specified head of 100 ft, and the system was modeled in steady state. The parameter “HydCond” was defined in the LPF Package (Harbaugh and others, 2000) to produce uniform hydraulic conductivity in the model domain. The parameter “Recharge” was defined to produce uniform recharge over the model area using the RCH Package (Harbaugh and others, 2000). Unique input and output files for this example problem are listed in Appendix C. Some of the required input files were the same as for either the ETS1 or the DRT1 example problem and are listed in Appendix A or B; these files are not repeated.

The ETS1 Package was used to simulate evapotranspiration with a uniform maximum evapotranspiration rate, but with a segmented function relating evapotranspiration rate to head. The two-segment function was the same as that described in the “ETS1 Example Problem” section. The parameter “ETS-Max” was defined to determine the maximum evapotranspiration rate. The input file for the ETS1 Package is listed in Appendix A.

The DRT1 package was used to simulate a drain-return feature in the cell in row 5, column 8. Forty percent of the discharge from the drain-return feature was assumed to recharge the ground-water system in the cell in row 7, column 3. The location of the drain-return and recipient cells are shown in figure 6. The parameter “DRT-Cond” was defined to determine the hydraulic conductance of the drain. The input file for the DRT1 Package is listed in Appendix B.

Twenty-two head observations were specified. One flow observation was specified at the drain-return feature. As described in Hill and others (2000), the Observation Process uses observed values and simulated equivalents to calculate the value of an objective function, which is used as a measure of model fit to the observations. MODFLOW-2000 was run in the “Forward with Observations” mode using “true” parameter values to generate a set of model-calculated values to be used as observations when the model was run in the “Parameter Estimation” mode.

To demonstrate the capability of the program to estimate parameter values, the starting values for the parameters “ETS-Max,” “DRT-Cond,” “Recharge,” and “HydCond” were changed in the Sensitivity-Process input file from the “true” values. MODFLOW-2000 was then run in the “Parameter Estimation” mode to estimate these four parameters. The GLOBAL and LIST output files for the run made in “Parameter Estimation” mode are listed in Appendix C. The Parameter-Estimation Process converged on a set of parameter values that minimized the objective function in five parameter-estimation iterations. The parameters and their starting, estimated, and “true” values are listed in table 1. The ability of the program to converge on the “true” set of parameter values indicates that the ETS1 and DRT1 Packages perform the functions of the Ground-Water Flow, Observation, Sensitivity, and Parameter-Estimation Processes as intended.

Table 1. Parameters defined by parameter-estimation example problem and starting, estimated, and true parameter values

[d, day; ft, foot]

Parameter name	Description	Starting value	Estimated value	True value
ETS-Max	Maximum evapotranspiration flux rate (ft/d)	0.005	1.000×10^{-2}	1.000×10^{-2}
DRT-Cond	Hydraulic conductance of drain-return cells (ft^2/d)	4.0	2.000	2.000
Recharge	Recharge rate (ft/d)	3.0×10^{-3}	1.000×10^{-3}	1.000×10^{-3}
HydCond	Hydraulic conductivity (ft/d)	9.0×10^{-2}	5.000×10^{-2}	5.000×10^{-2}

MODFLOW-2000 MODIFICATIONS NEEDED TO USE ETS1 AND DRT1

The ETS1 and DRT1 Packages are designed to be incorporated into the USGS modular, three-dimensional finite-difference ground-water flow model, MODFLOW-2000. Call statements to invoke the subroutines described in the preceding module-documentation sections and other code changes must be added to the main program unit and to modules of the Observation, Sensitivity, and Parameter-Estimation Processes for the ETS1 and DRT1 Packages to operate properly. The changes described in this section enable the use of both ETS1 and

DRT1. The changes are listed according to the file in which the changes are required. The files to be changed are: mf2k.f, obs1bas6.f, sen1bas6.f, pes1bas6.f, and pes1gau1.f. After the files are edited, the program will need to be recompiled. Versions of MODFLOW-2000 downloaded after publication of this report from the URL listed in the Preface of this report include the ETS1 and DRT1 Packages, and no modifications are required.

File mf2k.f

In the DATA statement where the CUNIT array is initialized, add "ETS " to initialize element 39, "DRT " for element 40, and "DTOB" for element 41. If these elements already have non-blank entries, other elements of the CUNIT array can be used. If other elements are used, the references to IUNIT elements 39 through 41 in the following code to be added need to be changed accordingly.

Insert variables LCOBDRT, LCSSDT, NQTDT, and IOWTQDT at the end of the argument list in the call to subroutine OBS1BAS6DF, after NDAR.

After the call to OBS1BAS6FAL, insert the following lines:

```
      IF (IUNIT(41).GT.0)
     &    CALL OBS1DRT1AL(IUNIT(41),NQ,NQC,NQT,IOUTG,NQDT,NQTDT,IOBSUM,
     &                    LCOBDRT,ITMXP,LCSSDT,ISUMX,IOBS)
```

After the call to OBS1BAS6FRP, insert the following lines:

```
      IF (IUNIT(41).GT.0)
     &    CALL OBS1DRT1RP(NCOL,NROW,NPER,IUNIT(41),IOUTG,OBSNAM,NH,JT,
     &                    NQT,IX(LCIBT),IX(LCNQOB),IX(LCNQCL),
     &                    IX(LCIQOB),X(LCQCLS),IERR,X(LCHOBS),X(LCTOFF),
     &                    X(LCWTQ),IOWTQ,IPRN,NDMH,NSTP,PERLEN,
     &                    TSMULT,ISSFLG,ITRSS,NQAR,NQCAR,
     &                    NQTAR,IQ1,NQT1,NDD,IUNIT(40),NQDT,NQTDT,NT,
     &                    NC,IX(LCIPLO),NAMES,ND,IPR,MPR,IOWTQDT)
```

After the call to GWF1HFB6AL, insert the following lines:

```
        IF(IUNIT(39).GT.0)
     &      CALL GWF1ETS1AL(ISUMRX,ISUMIR,LCIETS,LCETSR,LCETSX,LCETSS,
     &                      NCOL,NROW,NETSOP,IUNIT(39),IOUT,IETSCB,
     &                      IFREFM,NPETS,IETSPF,NETSEG,LCPXDP,LCPETM,
     &                      NSEGAR)
        IF(IUNIT(40).GT.0)
     &      CALL GWF1DRT1AL(ISUMRX,LCDRTF,MXDRT,NDRTCL,IUNIT(40),IOUT,
     &                      IDRTCB,NDRTVL,IDRTAL,IFREFM,NPDRT,IDRTPB,
     &                      NDRTNP,IDRTFL)
```

After the call to GWF1HFB6RP, insert the following lines:

```
        IF(IUNIT(39).GT.0) CALL GWF1ETS1RQ(IUNIT(39),IOUTG,NPETS,ITERPK)
        IF(IUNIT(40).GT.0)
     &      CALL GWF1DRT1RQ(IUNIT(40),IOUTG,NDRTVL,IDRTAL,NCOL,NROW,
     &                      NLAY,NPDRT,RX(LCDRTF),IDRTPB,MXDRT,IFREFM,
     &                      ITERPK,IDRTFL)
```

After the call to GWF1CHD6RP, insert the following lines:

```
          IF(IUNIT(39).GT.0)
     &        CALL GWF1ETS1RP(NETSOP,IR(LCIETS),RX(LCETSR),RX(LCETSX),
     &                        RX(LCETSS),GX(LCDELR),GX(LCDELC),NCOL,
     &                        NROW,IUNIT(39),IOUT,IFREFM,NPETS,
     &                        GX(LCRMLT),IG(LCIZON),NMLTAR,NZONAR,
     &                        IETSPF,NETSEG,RX(LCPXDP),RX(LCPETM),
     &                        NSEGAR)
```

```
      IF(IUNIT(40).GT.0)
     &        CALL GWF1DRT1RP(RX(LCDRTF),NDRTCL,MXDRT,IUNIT(40),
     &                        IOUT,NDRTVL,IDRTAL,IFREFM,NCOL,NROW,NLAY,
     &                        NDRTNP,NPDRT,IDRTPB,IDRTFL,NRFLOW)
```

After the call to GWF1RCH6FM, insert the following lines:

```
        IF (IUNIT(39).GT.0)
     &        CALL GWF1ETS1FM(NETSOP,IR(LCIETS),RX(LCETSR),
     &                        RX(LCETSX),RX(LCETSS),GX(LCRHS),
     &                        GX(LCHCOF),IG(LCIBOU),GZ(LCHNEW),NCOL,
     &                        NROW,NLAY,NETSEG,RX(LCPXDP),
     &                        RX(LCPETM),NSEGAR)
        IF (IUNIT(40).GT.0)
     &        CALL GWF1DRT1FM(NDRTCL,MXDRT,RX(LCDRTF),GZ(LCHNEW),
     &                        GX(LCHCOF),GX(LCRHS),IG(LCIBOU),NCOL,
     &                        NROW,NLAY,NDRTVL,IDRTFL)
```

Insert variables LCOBDRT, X(LCSSDT), NQTDT, and IOWTQDT at the end of the argument list in the call to subroutine SEN1BAS6NC. Note that SEN1BAS6NC is called twice from the main program unit, so this change needs to be made in two places.

After the call to GWF1RCH6BD, insert the following lines:

```
C--EVAPOTRANSPIRATION WITH SEGMENTED RATE FUNCTION
        IF (IUNIT(39).GT.0)
     &        CALL GWF1ETS1BD(NETSOP,IR(LCIETS),RX(LCETSR),RX(LCETSX),
     &                        RX(LCETSS),IG(LCIBOU),GZ(LCHNEW),NCOL,
     &                        NROW,NLAY,DELT,VBVL,VBNM,MSUM,KKSTP,
     &                        KKPER,IETSCB,ICBCFL,GX(LCBUFF),IOUT,
     &                        PERTIM,TOTIM,NETSEG,RX(LCPXDP),
     &                        RX(LCPETM),NSEGAR)
C--DRAINS WITH RETURN FLOW
        IF (IUNIT(40).GT.0)
     &        CALL GWF1DRT1BD(NDRTCL,MXDRT,VBNM,VBVL,MSUM,RX(LCDRTF),
     &                        DELT,GZ(LCHNEW),NCOL,NROW,NLAY,
     &                        IG(LCIBOU),KKSTP,KKPER,IDRTCB,ICBCFL,
     &                        GX(LCBUFF),IOUT,PERTIM,TOTIM,NDRTVL,
     &                        IDRTAL,IDRTFL,NRFLOW,IAUXSV)
```

After the call to OBS1BAS6FFM, insert the following lines:

```
          IF (IUNIT(40).NE.0)
     &        CALL OBS1DRT1FM(NQ,NQT,IX(LCNQOB),IX(LCNQCL),
     &                        IX(LCIQOB),X(LCQCLS),IX(LCIBT),
     &                        GZ(LCHNEW),NCOL,NROW,NLAY,IOUT,
     &                        IG(LCIBOU),NH,OBSNAM,X(LCH),
     &                        X(LCTOFF),MXDRT,NDRTCL,RX(LCDRTF),
     &                        X(LCWTQ),NDMH,ITS,NQAR,NQCAR,NQTAR,
     &                        NDRTVL)
```

Insert variables LCOBDRT, X(LCSSDT), NQTDT, and IOWTQDT at the end of the argument list in the call to subroutine OBS1BAS6SS, after X(LCRSPA).

After the call to SEN1CHD6FM, insert the following lines:

```
          IF (PIDTMP.EQ.'ETS ')
     &        CALL SEN1ETS1FM(NCOL,NROW,NLAY,GX(LCDELR),
     &                        GX(LCDELC),GX(LCRMLT),NETSOP,
     &                        IR(LCIETS),IG(LCIBOU),GX(LCRHS),
     &                        RX(LCETSS),RX(LCETSX),GZ(LCHNEW),
     &                        IG(LCIZON),NMLTAR,NZONAR,IIPP,
     &                        NETSEG,RX(LCPXDP),RX(LCPETM),NSEGAR)
```

```
              IF (PIDTMP.EQ.'DRT ')
     &            CALL SEN1DRT1FM(MXDRT,RX(LCDRTF),GZ(LCHNEW), NCOL,
     &                            NROW,NLAY,IG(LCIBOU),GX(LCRHS),
     &                            IIPP,NDRTVL,IDRTFL)
```

After the call to OBS1BAS6FDR, insert the following lines:

```
              IF (IUNIT(40).NE.0)
     &            CALL OBS1DRT1DR(NQ,NQT,IX(LCNQOB),IX(LCNQCL),
     &                            IX(LCIQOB),X(LCQCLS),IX(LCIBT),
     &                            GZ(LCHNEW),IP,Z(LCSNEW),NCOL,NROW,
     &                            NLAY,IOUTG,IG(LCIBOU),NH,X(LCX),
     &                            OBSNAM,NPE,IX(LCLN),X(LCTOFF),
     &                            MXDRT,NDRTCL,RX(LCDRTF),NPLIST,
     &                            ITS,NQAR,NQCAR,NQTAR,NDRTVL,IERR,
     &                            IERRU,NDRTNP,IDRTPB)
```

Insert variables LCOBDRT, X(LCSSDT), NQTDT, and IOWTQDT at the end of the argument list in the call to subroutine OBS1BAS6OS, after X(LCBSCA).

Insert variables LCOBDRT, X(LCSSDT), NQTDT, and IOWTQDT at the end of the argument list in the call to subroutine OBS1BAS6OH, after X(LCBPRI).

Insert variables X(LCSSDT) and NQTDT at the end of the argument list in the call to subroutine PES1BAS6OT, after ITERPK.

File obs1bas6.f

Insert variables LCOBDRT, LCSSDT, NQTDT, and IOWTQDT at the end of the argument list in the SUBROUTINE statement for subroutine OBS1BAS6DF, after NDAR.

In subroutine OBS1BAS6DF before the RETURN statement, insert the following lines:

```
  IOWTQDT = 0
  LCOBDRT = 1
  LCSSDT = 1
  NQTDT = 0
```

Insert variables LCOBDRT, SSDT, NQTDT, and IOWTQDT at the end of the argument list in the SUBROUTINE statement for subroutine OBS1BAS6SS, after RSPA.

In subroutine OBS1BAS6SS, insert after the existing DIMENSION statements the following line:

```
  DIMENSION SSDT(ITMXP+1)
```

In subroutine OBS1BAS6SS, insert variables LCOBDRT, SSDT, NQTDT, and IOWTQDT at the end of the argument list in the call to subroutine OBS1BAS6OH, after BPRI.

Insert variables LCOBDRT, SSDT, NQTDT, and IOWTQDT at the end of the argument list in the SUBROUTINE statement for subroutine OBS1BAS6OS, after BSCAL.

In subroutine OBS1BAS6OS, insert after the existing DIMENSION statements the following line:

```
  DIMENSION SSDT(ITMXP+1)
```

In subroutine OBS1BAS6OS, insert variables LCOBDRT, SSDT, NQTDT, and IOWTQDT at the end of the argument list in the call to subroutine OBS1BAS6OH, after BPRI.

Insert variables LCOBDRT, SSDT, NQTDT, and IOWTQDT at the end of the argument list in the SUBROUTINE statement for subroutine OBS1BAS6OH, after BPRI.

In subroutine OBS1BAS6OH, insert after the existing DIMENSION statements the following line:

```
  DIMENSION SSDT(ITMXP+1)
```

In subroutine OBS1BAS6OH, insert after the call to SOBS1BAS6FOH the following lines:

```
C-------DRAIN-RETURN FLOW OBSERVATIONS
```

```
      IF (NQTDT.GT.0) CALL SOBS1DRT1OH(IO,IOWTQDT,IOUT,NH,NQTDT,HOBS,H,
     &                                WTQ,OBSNAM,IDIS,WTQS,D,AVET,NPOST,
     &                                NNEGT,NRUNS,RSQ,ND,MPR,IPR,NDMH,
     &                                WTRL,NRES,IUGDO,OUTTMP,IPLOT,
     &                                IPLPTR,LCOBDRT,ISSWR,SSDT,ITMXP)
```

File sen1bas6.f

Insert variables LCOBDRT, SSDT, NQTDT, and IOWTQDT at the end of the argument list in the SUBROUTINE statement for subroutine SEN1BAS6NC, after IERRU.

In subroutine SEN1BAS6NC, insert after the existing DIMENSION statements the following line:

```
      DIMENSION SSDT(ITMXP+1)
```

In subroutine SEN1BAS6NC, insert variables LCOBDRT, SSDT, NQTDT, and IOWTQDT at the end of the argument list in the call to subroutine OBS1BAS6OH, after BPRI.

File pes1bas6.f

In subroutine PES1BAS6CN add “`.OR. PIDTMP.EQ.'DRT ' .OR. PIDTMP.EQ.'ETS '`” to the end of the logical expression in the first IF statement in DO loop 20.

In subroutine PES1BAS6CK add “`.OR. PIDTMP.EQ.'ETS '`” to the end of the logical expression in the IF statement in DO loop 60.

Insert variables SSDT and NQTDT at the end of the argument list in the SUBROUTINE statement for subroutine PES1BAS6OT, after ITERPK.

In subroutine PES1BAS6OT, insert after the existing DIMENSION statements the following line:

```
      DIMENSION SSDT(ITMXP+1)
```

In subroutine PES1BAS6OT, insert variables SSDT and NQTDT at the end of the argument list in the call to subroutine SPES1GAU1PR, after ITERPK.

File pes1gau1.f

Insert variables SSDT and NQTDT at the end of the argument list in the SUBROUTINE statement for subroutine SPES1GAU1PR, after ITERPK.

In subroutine SPES1GAU1PR, insert after the existing DIMENSION statement the following line:

```
      DIMENSION SSDT(ITMXP+1)
```

In subroutine SPES1GAU1PR, insert after the IF…THEN…ENDIF block that is contingent on the logical expression (NQTDR.GT.0) the following lines:

```
        IF (NQTDT.GT.0) THEN
          WRITE (IUOUT(2),660)
     &        'SSWR-(DRT-PACKAGE FLOW OBSERVATIONS ONLY)'
          DO 205 IT = 1, ITER
            WRITE (IUOUT(2),670) IT,SSDT(IT)
  205     CONTINUE
        ENDIF
```

REFERENCES

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Harbaugh, A.W., and McDonald, M.G., 1996a, User's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 96–485, 56 p.

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Hill, M.C., 1990, Preconditioned conjugate-gradient 2 (PCG2), a computer program for solving ground-water flow equations: U.S. Geological Survey Water-Resources Investigations Report 90–4048, 43 p.

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McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1, 586 p.

APPENDIXES

APPENDIX A—Input and Output File for the ETS1 Example Problem

The name file (Harbaugh and others, 2000) is:

```
# NAME file for ets1 test case
#
# Output file
list    12  ets1.lst
#
# Global input files
dis     21  ..\data\ets1.dis
mult    22  ..\data\ets1.mlt
zone    23  ..\data\ets1.zon
#
# Flow-Process input files
bas6    31  ..\data\ets1.bas
oc      32  ..\data\ets1.oc
lpf     33  ..\data\ets1.lpf
ets     37  ..\data\ets1.ets
# evt     38  ..\data\ets1.evt
pcg     39  ..\data\ets1.pcg
```

The discretization (DIS) input file (Harbaugh and others, 2000) is:

```
# DIS file for ets1, drt1, and etsdrt test cases.  Units: Days, Feet
 1 11 11 1 4 1        Item 1: NLAY NROW NCOL NPER ITMUNI LENUNI
 0                    Item 2: LAYCBD
constant  100.0       Item 3: DELR
constant  100.0       Item 4: DELC
constant  100.0       Item 5: Top
constant    0.0       Item 6: BOTM, layer 1
 0.0   1  1.0  SS     Item 7: PERLEN NSTP TSMULT SS/TR, period 1
```

The multiplier-array (MULT) input file (Harbaugh and others, 2000) is:

```
# MULT file for ets1 test case
#
  1                 Item 1: NML
TwoTenths           Item 2: MLTNAM
constant   0.2      Item 3: RMLT
```

The zone-array (ZONE) input file (Harbaugh and others, 2000) is:

```
# ZONE file for ets1 test case
 1                      Item 1: NZN
ET-zones                Item 2: ZONNAM
INTERNAL  1 (11I2)  -1  Item 3: IZON
 2 2 2 2 2 2 2 2 2 1 1
 2 2 2 2 2 2 2 2 2 1 1
 2 2 2 2 2 2 2 2 2 1 1
 2 2 2 2 2 2 2 2 2 1 1
 2 2 2 2 2 2 2 2 2 1 1
 2 2 2 2 2 2 2 2 2 1 1
 2 2 2 2 2 2 2 2 2 1 1
 2 2 2 2 2 2 2 2 2 1 1
 2 2 2 2 2 2 2 2 2 1 1
 2 2 2 2 2 2 2 2 2 1 1
 2 2 2 2 2 2 2 2 2 1 1
```

The input file for the Basic (BAS) Package (Harbaugh and others, 2000) is:

```
# BAS file for ets1, drt1, and etsdrt test cases
free
internal 1 (free) -1              Item 2: Ibound
 -1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1 -1
 -1  1  1  1  1  1  1  1  1  1 -1
```

```
-999.                            Item 3: HNOFLO
INTERNAL  1.0  (FREE)  -1        Item 4: STRT
50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0
50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0
50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0
50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0
50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0
50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0
50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0
50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0
50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0
50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0
50.0 55.0 60.0 65.0 70.0 75.0 80.0 85.0 90.0 95.0 100.0
```

The Output-Control input file (Harbaugh and others, 2000) is:

```
# OC file for ets1, drt1, and etsdrt test cases
head print format 8
period 1 step 1
  print head
```

The input file for the Layer Property Flow (LPF) Package (Harbaugh and others, 2000), is:

```
# LPF file for ets1 and drt1 test cases
 0  0  0          Item 1: ILPFCB HDRY NPLPF
 1                Item 2: LAYTYP
 0                Item 3: LAYAVG
 1.0              Item 4: CHANI
 0                Item 5: LAYVKA
 0                Item 6: LAYWET
constant 5.0E-2  Item 10: HK, layer 1
constant 1.0E-2  Item 12: VKA, layer 1
```

The input file for the ETS1 Package follows. Note that the ETS1 Package is not used for the simulation in which evapotranspiration is simulated with the EVT Package.

```
# ETS input file for ets1 and etsdrt test cases
#
  1  0  1  2            Item 1: NETSOP IETSCB NPETS NETSEG
ETS-Max  ETS  0.01  1  Item 2: PARNAM PARTYP PARVAL NCLU
none       all          Item 3: Mltarr Zonarr
  1  1  1  0  1         Item 4: INETSS INETSR INETSX INIETS INSGDF, period 1
CONSTANT  100.0         Item 5: ETSS
ETS-Max                 Item 7: Pname
constant  36.0          Item 8: ETSX
constant   0.5          Item 10: PXDP
constant   0.1          Item 11: PETM
```

The input file for the Evapotranspiration (EVT) package follows. Note that the EVT Package is not used for the simulation in which evapotranspiration is simulated with the ETS1 Package.

```
# EVT file for ets1 test case
PARAMETER  1                Item 1: NPEVT
 1   0                      Item 2: NEVTOP IEVTCB
EVT-Max  EVT  0.01  2      Item 3: PARNAM PARTYP Parval NCLU
NONE       ET-zones  1     Item 4: Mltarr Zonarr IZ
TwoTenths  ET-zones  2     Item 4: Mltarr Zonarr IZ
 1  1  1  0                 Item 5: INSURF INEVTR INEXDP INIEVT
CONSTANT  100.0             Item 6: SURF
EVT-Max  10                 Item 8: Pname
INTERNAL  1.0  (FREE)  -1  Item 9: EXDP
36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 20.0 20.0
36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 20.0 20.0
36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 20.0 20.0
36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 20.0 20.0
36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 20.0 20.0
36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 20.0 20.0
36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 20.0 20.0
36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 20.0 20.0
36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 20.0 20.0
36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 20.0 20.0
36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 36.0 20.0 20.0
```

The input file for the Preconditioned Conjugate-Gradient (PCG2) Package (Hill, 1990), is:

```
# PCG file for ets1, drt1, and etsdrt test cases
#
 60  8  1                     Item 1: MXITER ITER1 NPCOND
1.E-4  80.  1.  2  0  2  1.0  Item 2: HCLOSE RCLOSE RELAX NBPOL IPRPCG MUTPCG DAMP
```

The combined GLOBAL and LIST output file for the run using the ETS1 Package is:

```
                                  MODFLOW-2000
      U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
                             VERSION 1.0 07/20/2000


 This model run combines GLOBAL and LIST output into this single file.

 GLOBAL LISTING FILE: ets1.lst
                         UNIT  12
#
# Global input files

 OPENING ..\data\ets1.dis
 FILE TYPE:DIS   UNIT  21

 OPENING ..\data\ets1.mlt
 FILE TYPE:MULT   UNIT  22

 OPENING ..\data\ets1.zon
 FILE TYPE:ZONE   UNIT  23
#
# Flow-Process input files

 OPENING ..\data\ets1.bas
 FILE TYPE:BAS6   UNIT  31

 OPENING ..\data\ets1.oc
 FILE TYPE:OC   UNIT  32

 OPENING ..\data\ets1.lpf
 FILE TYPE:LPF   UNIT  33

 OPENING ..\data\ets1.ets
 FILE TYPE:ETS   UNIT  37
# evt  38 ..\data\ets1.evt

 OPENING ..\data\ets1.pcg
 FILE TYPE:PCG   UNIT  39

 DISCRETIZATION INPUT DATA READ FROM UNIT 21
 # DIS file for ets1, drt1, and etsdrt test cases.  Units: Days, Feet
    1 LAYERS        11 ROWS        11 COLUMNS
   1 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS DAYS
 MODEL LENGTH UNIT IS FEET

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

 MODE: FORWARD


 ZONE OPTION, INPUT READ FROM UNIT 23
 # ZONE file for ets1 test case
     1 ZONE ARRAYS

 MULTIPLIER OPTION, INPUT READ FROM UNIT 22
 # MULT file for ets1 test case
 #
   1 MULTIPLIER ARRAYS
  Confining bed flag for each layer:
   0
```

```
      1232  ELEMENTS OF GX ARRAY USED OUT OF       1232
       121  ELEMENTS OF GZ ARRAY USED OUT OF        121
       242  ELEMENTS OF IG ARRAY USED OUT OF        242

                    DELR =   100.000

                    DELC =   100.000

TOP ELEVATION OF LAYER 1 =   100.000

  MODEL LAYER BOTTOM EL. =   0.00000     FOR LAYER   1

STRESS PERIOD     LENGTH       TIME STEPS     MULTIPLIER FOR DELT    SS FLAG
----------------------------------------------------------------------------
       1        0.000000          1                    1.000         SS

STEADY-STATE SIMULATION



 MULT. ARRAY: TwoTenths  =  0.200000



            ZONE ARRAY: ET-zones
READING ON UNIT  23 WITH FORMAT: (11I2)

LPF1 -- LAYER PROPERTY FLOW PACKAGE, VERSION 1, 1/11/2000
        INPUT READ FROM UNIT 33
# LPF file for ets1 and drt1 test cases
HEAD AT CELLS THAT CONVERT TO DRY=   0.0000
No named parameters

  LAYER FLAGS:
LAYER       LAYTYP        LAYAVG         CHANI        LAYVKA        LAYWET
---------------------------------------------------------------------------
   1           1             0     1.000E+00            0             0

  INTERPRETATION OF LAYER FLAGS:
                        INTERBLOCK     HORIZONTAL    DATA IN
        LAYER TYPE   TRANSMISSIVITY   ANISOTROPY   ARRAY VKA   WETTABILITY
LAYER      (LAYTYP)      (LAYAVG)       (CHANI)      (LAYVKA)      (LAYWET)
---------------------------------------------------------------------------
   1   CONVERTIBLE      HARMONIC     1.000E+00    VERTICAL K  NON-WETTABLE

       242 ELEMENTS IN X ARRAY ARE USED BY LPF
         6 ELEMENTS IN IX ARRAY ARE USED BY LPF

PCG2 -- CONJUGATE GRADIENT SOLUTION PACKAGE, VERSION 2.4, 12/29/98
# PCG file for ets1, drt1, and etsdrt test cases
#
MAXIMUM OF     60 CALLS OF SOLUTION ROUTINE
MAXIMUM OF      8 INTERNAL ITERATIONS PER CALL TO SOLUTION ROUTINE
MATRIX PRECONDITIONING TYPE :    1
      1323 ELEMENTS IN X ARRAY ARE USED BY PCG
      3360 ELEMENTS IN IX ARRAY ARE USED BY PCG
       242 ELEMENTS IN Z ARRAY ARE USED BY PCG

      1565  ELEMENTS OF X ARRAY USED OUT OF       1565
       242  ELEMENTS OF Z ARRAY USED OUT OF        242
      3366  ELEMENTS OF IX ARRAY USED OUT OF       3366
         0  ELEMENTS OF XHS ARRAY USED OUT OF          1


                                   SOLUTION BY THE CONJUGATE-GRADIENT METHOD
                                  ------------------------------------------
                   MAXIMUM NUMBER OF CALLS TO PCG ROUTINE =       60
```

```
                       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) =        2
                                        DAMPING PARAMETER =    0.10000E+01

WETTING CAPABILITY IS NOT ACTIVE IN ANY LAYER

   HYD. COND. ALONG ROWS =  5.000000E-02 FOR LAYER   1

     VERTICAL HYD. COND. =  1.000000E-02 FOR LAYER   1

# BAS file for ets1, drt1, and etsdrt test cases
THE FREE FORMAT OPTION HAS BEEN SELECTED
   1 LAYERS        11 ROWS        11 COLUMNS
  1 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 31
         5 ELEMENTS IN IR ARRAY ARE USED BY BAS

ETS1 -- EVAPOTRANSPIRATION SEGMENTS PACKAGE, VERSION 1, 5/2/2000
        INPUT READ FROM UNIT 37
# ETS input file for ets1 and etsdrt test cases
#
OPTION 1 -- EVAPOTRANSPIRATION FROM TOP LAYER
    1 Named Parameters
    2 SEGMENTS DEFINE EVAPOTRANSPIRATION RATE FUNCTION
       605 ELEMENTS IN RX ARRAY ARE USED BY ETS
       121 ELEMENTS IN IR ARRAY ARE USED BY ETS

       605  ELEMENTS OF RX ARRAY USED OUT OF        605
       126  ELEMENTS OF IR ARRAY USED OUT OF        126

# BAS file for ets1, drt1, and etsdrt test cases



                    BOUNDARY ARRAY FOR LAYER   1
READING ON UNIT  31 WITH FORMAT: (FREE)

AQUIFER HEAD WILL BE SET TO -999.00     AT ALL NO-FLOW NODES (IBOUND=0).



                      INITIAL HEAD FOR LAYER   1
READING ON UNIT  31 WITH FORMAT: (FREE)
# OC file for ets1, drt1, and etsdrt test cases

OUTPUT CONTROL IS SPECIFIED ONLY AT TIME STEPS FOR WHICH OUTPUT IS DESIRED
HEAD PRINT FORMAT CODE IS   8    DRAWDOWN PRINT FORMAT CODE IS   0
HEADS WILL BE SAVED ON UNIT   0    DRAWDOWNS WILL BE SAVED ON UNIT   0


    1 Evapotranspiration segments parameters

PARAMETER NAME:ETS-Max      TYPE:ETS    CLUSTERS:   1
Parameter value from package file is:   1.00000E-02
               MULTIPLIER ARRAY: none    ZONE ARRAY: all

  1 PARAMETER HAS BEEN DEFINED IN ALL PACKAGES.
(SPACE IS ALLOCATED FOR  500 PARAMETERS.)

                           STRESS PERIOD NO.   1, LENGTH =   0.000000
                           ----------------------------------------------

                             NUMBER OF TIME STEPS =     1
```

```
                              MULTIPLIER FOR DELT =     1.000

                           INITIAL TIME STEP SIZE =   0.000000

       ET SURFACE (ETSS) =   100.000


 ETSR array defined by the following parameters:
  Parameter:  ETS-Max
  EVAPOTRANS. RATE (ETSR) =  1.000000E-02

  EXTINCTION DEPTH (ETSX) =   36.0000

 PXDP AND PETM ARRAYS FOR INTERSECTION    1 OF HEAD/ET RELATION:

 EXTINCT. DEP. PROPORTION =  0.500000

       ET RATE PROPORTION =  0.100000

 SOLVING FOR HEAD

 OUTPUT CONTROL FOR STRESS PERIOD  1   TIME STEP  1
    PRINT HEAD FOR ALL LAYERS

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

         1     2     3     4     5     6     7     8     9    10    11
 ......................................................................
   1   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   2   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   3   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   4   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   5   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   6   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   7   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   8   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   9   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
  10   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
  11   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0

  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 =           0.0000         CONSTANT HEAD =         683.8303
         ET SEGMENTS =           0.0000           ET SEGMENTS =           0.0000

            TOTAL IN =           0.0000              TOTAL IN =         683.8303

          OUT:                                     OUT:
          ----                                     ----
             STORAGE =           0.0000               STORAGE =           0.0000
       CONSTANT HEAD =           0.0000         CONSTANT HEAD =         107.9628
         ET SEGMENTS =           0.0000           ET SEGMENTS =         575.8674

           TOTAL OUT =           0.0000             TOTAL OUT =         683.8302

            IN - OUT =           0.0000              IN - OUT =       1.2207E-04

 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  0.0000      0.0000      0.0000      0.0000      0.0000
 STRESS PERIOD TIME  0.0000      0.0000      0.0000      0.0000      0.0000
         TOTAL TIME  0.0000      0.0000      0.0000      0.0000      0.0000
```

The following calculated head distribution and volumetric budget is from the combined GLOBAL and LIST output file for the run using the EVT Package.

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

        1     2     3     4     5     6     7     8     9    10    11
 ...................................................................
   1   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   2   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   3   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   4   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   5   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   6   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   7   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   8   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
   9   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
  10   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
  11   50.0  53.8  57.3  60.7  63.8  66.8  70.1  74.2  79.6  86.6 100.0
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 =           0.0000        CONSTANT HEAD =         683.8303
                  ET =           0.0000                   ET =           0.0000

            TOTAL IN =           0.0000             TOTAL IN =         683.8303

          OUT:                                     OUT:
          ----                                     ----
             STORAGE =           0.0000              STORAGE =           0.0000
       CONSTANT HEAD =           0.0000        CONSTANT HEAD =         107.9628
                  ET =           0.0000                   ET =         575.8674

           TOTAL OUT =           0.0000            TOTAL OUT =         683.8303

            IN - OUT =           0.0000             IN - OUT =       6.1035E-05

 PERCENT DISCREPANCY =           0.00     PERCENT DISCREPANCY =           0.00
```

APPENDIX B—Input and Output Files for the DRT1 Example Problem

The name file (Harbaugh and others, 2000) is:

```
# NAME file for drt1 test case
# Output file
list    12  drt1.lst
#
# Global input file
dis     21  ..\data\ets1.dis
#
# Flow process input files
bas6    31  ..\data\ets1.bas
oc      32  ..\data\ets1.oc
lpf     33  ..\data\ets1.lpf
drt     34  ..\data\drt1.drt
# drn     35  ..\data\drt1.drn
# wel     36  ..\data\drt1.wel
pcg     39  ..\data\ets1.pcg
```

The DIS, BAS, OC, LPF, and PCG2 input files are the same as for the ETS1 example problem and are listed in Appendix A.

The input file for the DRT1 Package follows. Note that the DRT1 Package is not used for the simulation in which the drain and return flow are simulated with the Drain (DRN) and Well (WEL) Packages (Harbaugh and others, 2000).

```
# DRT file for drt1 and etsdrt test cases
1  0  1  1  returnflow    Item 1: MXADRT IDRTCB NPDRT MXL
DRT-Cond   drt  2.0  1    Item 2: PARNAM PARTYP PARVAL NLST
1 5 8 60.0 1.0 1 7 3 0.4  Item 3: LAY ROW COL ELEV Condfact LayR RowR ColR Rfprop
0  1                      Item 4: ITMP NP, stress period 1
DRT-Cond                  Item 6: Pname
```

The input file for the DRN Package follows. Note that the DRN Package is not used for the simulation in which the drain and return flow are simulated with the DRT1 Package.

```
# DRN file for drt1 test case
PARAMETER  1  1            Item 1: NPDRN MXL
 1  0                      Item 2: MXACTD IDRNCB
DRN-Cond   drn  2.0  1     Item 3: PARNAM PARTYP PARVAL NLST
1  5  8  60.0  1.0         Item 4: LAY ROW COL ELEV CONDFACT
0  1                       Item 5: ITMP NP, stress period 1
DRN-Cond                   Item 7: Pname
```

The input file for the WEL Package follows. Note that the WEL Package is not used for the simulation in which the drain and return flow are simulated with the DRT1 Package.

```
# WEL file for drt1 test case
#
parameter  1  1       Item 1: NPWEL MXL
 1   0                Item 2: MXACTW IWELCB
Inject  Q  18.085  1  Item 3: PARNAM PARTYP Parval NLST
 1  7  3  1.0         Item 4: Layer Row Column Qfact
 0  1                 Item 5: ITMP NP
Inject                Item 7: Pname
```

The combined GLOBAL and LIST output file for the run using the DRT1 Package is:

```
                                  MODFLOW-2000
      U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
                             VERSION 1.0 07/20/2000


 This model run combines GLOBAL and LIST output into this single file.

 GLOBAL LISTING FILE: drt1.lst
                         UNIT  12
#
# Global input file

 OPENING ..\data\ets1.dis
```

```
 FILE TYPE:DIS   UNIT  21
#
# Flow process input files

 OPENING ..\data\ets1.bas
 FILE TYPE:BAS6   UNIT  31

 OPENING ..\data\ets1.oc
 FILE TYPE:OC   UNIT  32

 OPENING ..\data\ets1.lpf
 FILE TYPE:LPF   UNIT  33

 OPENING ..\data\drt1.drt
 FILE TYPE:DRT   UNIT  34
# drn  35 ..\data\drt1.drn
# wel  36 ..\data\drt1.wel

 OPENING ..\data\ets1.pcg
 FILE TYPE:PCG   UNIT  39

 DISCRETIZATION INPUT DATA READ FROM UNIT 21
 # DIS file for ets1, drt1, and etsdrt test cases.  Units: Days, Feet
    1 LAYERS        11 ROWS        11 COLUMNS
   1 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS DAYS
 MODEL LENGTH UNIT IS FEET

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

 MODE: FORWARD

  Confining bed flag for each layer:
   0

       1111  ELEMENTS OF GX ARRAY USED OUT OF       1111
        121  ELEMENTS OF GZ ARRAY USED OUT OF        121
        121  ELEMENTS OF IG ARRAY USED OUT OF        121

                     DELR =   100.000

                     DELC =   100.000

 TOP ELEVATION OF LAYER 1 =   100.000

   MODEL LAYER BOTTOM EL. =   0.00000     FOR LAYER   1


 STRESS PERIOD     LENGTH       TIME STEPS     MULTIPLIER FOR DELT    SS FLAG
 ----------------------------------------------------------------------------
       1        0.000000         1                    1.000         SS

 STEADY-STATE SIMULATION




 LPF1 -- LAYER PROPERTY FLOW PACKAGE, VERSION 1, 1/11/2000
         INPUT READ FROM UNIT 33
 # LPF file for ets1 and drt1 test cases
 HEAD AT CELLS THAT CONVERT TO DRY=   0.0000
 No named parameters

   LAYER FLAGS:
 LAYER       LAYTYP        LAYAVG         CHANI        LAYVKA        LAYWET
 ---------------------------------------------------------------------------
    1             1             0     1.000E+00             0             0
```

```
  INTERPRETATION OF LAYER FLAGS:
                        INTERBLOCK     HORIZONTAL    DATA IN
        LAYER TYPE   TRANSMISSIVITY   ANISOTROPY   ARRAY VKA   WETTABILITY
LAYER      (LAYTYP)      (LAYAVG)       (CHANI)      (LAYVKA)      (LAYWET)
---------------------------------------------------------------------------
   1   CONVERTIBLE      HARMONIC     1.000E+00    VERTICAL K  NON-WETTABLE

       242 ELEMENTS IN X ARRAY ARE USED BY LPF
         6 ELEMENTS IN IX ARRAY ARE USED BY LPF

PCG2 -- CONJUGATE GRADIENT SOLUTION PACKAGE, VERSION 2.4, 12/29/98
# PCG file for ets1, drt1, and etsdrt test cases
#
MAXIMUM OF     60 CALLS OF SOLUTION ROUTINE
MAXIMUM OF      8 INTERNAL ITERATIONS PER CALL TO SOLUTION ROUTINE
MATRIX PRECONDITIONING TYPE :    1
      1323 ELEMENTS IN X ARRAY ARE USED BY PCG
      3360 ELEMENTS IN IX ARRAY ARE USED BY PCG
       242 ELEMENTS IN Z ARRAY ARE USED BY PCG

      1565  ELEMENTS OF X ARRAY USED OUT OF       1565
       242  ELEMENTS OF Z ARRAY USED OUT OF        242
      3366  ELEMENTS OF IX ARRAY USED OUT OF       3366
         0  ELEMENTS OF XHS ARRAY USED OUT OF          1


                                   SOLUTION BY THE CONJUGATE-GRADIENT METHOD
                                  -------------------------------------------
                   MAXIMUM NUMBER OF CALLS TO PCG ROUTINE =       60
                       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) =        2
                                        DAMPING PARAMETER =    0.10000E+01

WETTING CAPABILITY IS NOT ACTIVE IN ANY LAYER

   HYD. COND. ALONG ROWS =  5.000000E-02 FOR LAYER   1

     VERTICAL HYD. COND. =  1.000000E-02 FOR LAYER   1

# BAS file for ets1, drt1, and etsdrt test cases
THE FREE FORMAT OPTION HAS BEEN SELECTED
   1 LAYERS        11 ROWS        11 COLUMNS
  1 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 31
         5 ELEMENTS IN IR ARRAY ARE USED BY BAS

DRT1 -- DRAIN RETURN PACKAGE, VERSION 1, 5/2/2000
INPUT READ FROM UNIT 34
# DRT file for drt1 and etsdrt test cases
MAXIMUM OF    1 ACTIVE DRAINS WITH RETURN FLOW AT ONE TIME
    1 Named Parameters         1 List entries
RETURN FLOW OPTION IS SELECTED
        18 ELEMENTS IN RX ARRAY ARE USED BY DRT

        18  ELEMENTS OF RX ARRAY USED OUT OF         18
         5  ELEMENTS OF IR ARRAY USED OUT OF          5

# BAS file for ets1, drt1, and etsdrt test cases
```

```
                    BOUNDARY ARRAY FOR LAYER   1
READING ON UNIT  31 WITH FORMAT: (FREE)

AQUIFER HEAD WILL BE SET TO -999.00     AT ALL NO-FLOW NODES (IBOUND=0).



                      INITIAL HEAD FOR LAYER   1
READING ON UNIT  31 WITH FORMAT: (FREE)
# OC file for ets1, drt1, and etsdrt test cases

OUTPUT CONTROL IS SPECIFIED ONLY AT TIME STEPS FOR WHICH OUTPUT IS DESIRED
HEAD PRINT FORMAT CODE IS   8    DRAWDOWN PRINT FORMAT CODE IS   0
HEADS WILL BE SAVED ON UNIT   0    DRAWDOWNS WILL BE SAVED ON UNIT   0


    1 Drain-return parameters

PARAMETER NAME:DRT-Cond     TYPE:DRT
Parameter value from package file is:    2.0000
  NUMBER OF ENTRIES:      1

DRAIN NO.  LAYER   ROW   COL     DRAIN EL.  STRESS FACTOR
------------------------------------------------------------
     1      1      5      8       60.00          1.000

          ----DRAIN CELL----  --RECIPIENT CELL--   RETURN
DRAIN NO.  LAYER   ROW   COL   LAYER   ROW   COL    PROP.
     1      1      5      8      1      7      3  0.400000

  1 PARAMETER HAS BEEN DEFINED IN ALL PACKAGES.
(SPACE IS ALLOCATED FOR  500 PARAMETERS.)

                           STRESS PERIOD NO.   1, LENGTH =   0.000000
                           ----------------------------------------------

                             NUMBER OF TIME STEPS =     1

                              MULTIPLIER FOR DELT =     1.000

                           INITIAL TIME STEP SIZE =   0.000000

Parameter:  DRT-Cond
DRAIN NO.  LAYER   ROW   COL     DRAIN EL.  CONDUCTANCE
------------------------------------------------------------
     1      1      5      8       60.00          2.000

          ----DRAIN CELL----  --RECIPIENT CELL--   RETURN
DRAIN NO.  LAYER   ROW   COL   LAYER   ROW   COL    PROP.
     1      1      5      8      1      7      3  0.400000

    1 DRAIN-RETURN CELLS

SOLVING FOR HEAD

OUTPUT CONTROL FOR STRESS PERIOD  1   TIME STEP  1
   PRINT HEAD FOR ALL LAYERS

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

        1     2     3     4     5     6     7     8     9    10    11
..................................................................
  1   50.0  56.7  62.6  68.1  73.1  77.8  82.4  86.9  91.4  95.7 100.0
  2   50.0  56.7  62.6  68.0  73.0  77.7  82.2  86.7  91.2  95.7 100.0
  3   50.0  56.7  62.7  68.0  73.0  77.5  81.9  86.2  90.9  95.5 100.0
  4   50.0  56.8  62.8  68.1  72.9  77.3  81.3  85.2  90.4  95.3 100.0
  5   50.0  57.0  63.1  68.3  73.0  77.2  80.7  82.6  89.8  95.2 100.0
  6   50.0  57.3  63.7  68.7  73.3  77.5  81.5  85.3  90.4  95.4 100.0
  7   50.0  57.7  65.2  69.2  73.6  78.0  82.2  86.5  91.1  95.6 100.0
```

```
  8   50.0  57.4  63.9  69.0  73.8  78.3  82.7  87.1  91.4  95.8 100.0
  9   50.0  57.2  63.4  68.9  73.8  78.5  83.0  87.4  91.7  95.9 100.0
 10   50.0  57.1  63.3  68.8  73.9  78.6  83.2  87.5  91.8  96.0 100.0
 11   50.0  57.0  63.2  68.8  73.9  78.7  83.2  87.6  91.9  96.0 100.0

 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 =           0.0000         CONSTANT HEAD =        233.9942
       DRAINS (DRT) =           0.0000          DRAINS (DRT) =         18.0850

           TOTAL IN =           0.0000              TOTAL IN =        252.0792

         OUT:                                     OUT:
         ----                                     ----
            STORAGE =           0.0000               STORAGE =          0.0000
      CONSTANT HEAD =           0.0000         CONSTANT HEAD =        206.8666
       DRAINS (DRT) =           0.0000          DRAINS (DRT) =         45.2126

          TOTAL OUT =           0.0000             TOTAL OUT =        252.0792

           IN - OUT =           0.0000              IN - OUT =      4.5776E-05

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  0.0000      0.0000      0.0000      0.0000      0.0000
 STRESS PERIOD TIME  0.0000      0.0000      0.0000      0.0000      0.0000
         TOTAL TIME  0.0000      0.0000      0.0000      0.0000      0.0000
```

The following calculated head distribution and volumetric budget are from the combined GLOBAL and LIST output file for the run using the DRN and WEL Packages.

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

        1     2     3     4     5     6     7     8     9    10    11
 ....................................................................
  1   50.0  56.7  62.6  68.1  73.1  77.8  82.4  86.9  91.4  95.7 100.0
  2   50.0  56.7  62.6  68.0  73.0  77.7  82.2  86.7  91.2  95.7 100.0
  3   50.0  56.7  62.7  68.0  73.0  77.5  81.9  86.2  90.9  95.5 100.0
  4   50.0  56.8  62.8  68.1  72.9  77.3  81.3  85.2  90.4  95.3 100.0
  5   50.0  57.0  63.1  68.3  73.0  77.2  80.7  82.6  89.8  95.2 100.0
  6   50.0  57.3  63.7  68.7  73.3  77.5  81.5  85.3  90.4  95.4 100.0
  7   50.0  57.7  65.2  69.2  73.6  78.0  82.2  86.5  91.1  95.6 100.0
  8   50.0  57.4  63.9  69.0  73.8  78.3  82.7  87.1  91.4  95.8 100.0
  9   50.0  57.2  63.4  68.9  73.8  78.5  83.0  87.4  91.7  95.9 100.0
 10   50.0  57.1  63.3  68.8  73.9  78.6  83.2  87.5  91.8  96.0 100.0
 11   50.0  57.0  63.2  68.8  73.9  78.7  83.2  87.6  91.9  96.0 100.0
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 =           0.0000         CONSTANT HEAD =         233.9942
             WELLS =           0.0000                 WELLS =          18.0850
            DRAINS =           0.0000                DRAINS =           0.0000

          TOTAL IN =           0.0000              TOTAL IN =         252.0792

        OUT:                                     OUT:
        ----                                     ----
           STORAGE =           0.0000               STORAGE =           0.0000
     CONSTANT HEAD =           0.0000         CONSTANT HEAD =         206.8666
             WELLS =           0.0000                 WELLS =           0.0000
            DRAINS =           0.0000                DRAINS =          45.2125

         TOTAL OUT =           0.0000             TOTAL OUT =         252.0792

          IN - OUT =           0.0000              IN - OUT =       6.1035E-05

PERCENT DISCREPANCY =          0.00     PERCENT DISCREPANCY =           0.00
```

APPENDIX C—Input and Output Files for the Parameter-Estimation Problem

The name file (Harbaugh and others, 2000) is:

```
# NAME file for etsdrt test case
# Output files
global  11  etsdrt.glo
list    12  etsdrt.lst
#
# Global input files
dis     21  ..\data\ets1.dis
#
# Flow process input files
bas6    31  ..\data\ets1.bas
oc      32  ..\data\ets1.oc
lpf     33  ..\data\etsdrt.lpf
drt     34  ..\data\drt1.drt
rch     36  ..\data\etsdrt.rch
ets     37  ..\data\ets1.ets
pcg     39  ..\data\ets1.pcg
#
# O-S-P processes input files
obs     41  ..\data\etsdrt.obs
hob     42  ..\data\etsdrt.ohd
dtob    43  ..\data\etsdrt.odt
sen     45  ..\data\etsdrt.sen
pes     46  ..\data\etsdrt.pes
```

The DIS, BAS, OC, ETS1, and PCG2 input files are the same as for the ETS1 example problem and are listed in Appendix A. The DRT1 input file is the same as for the DRT1 example problem and is listed in Appendix B.

The input file for the LPF Package is:

```
# LPF file for etsdrt test case
  0  0  1                Item 1: ILPFCB HDRY NPLPF
 1                       Item 2: LAYTYP
 0                       Item 3: LAYAVG
 1.0                     Item 4: CHANI
 0                       Item 5: LAYVKA
 0                       Item 6: LAYWET
HydCond  HK  5.0E-2  1   Item 8: PARNAM PARTYP Parval NCLU
 1  NONE  ALL            Item 9: Layer Mltarr Zonarr [IZ]
-1                       Item 10: HK layer 1 print code
constant 1.0E-2          Item 12: VKA, layer 1
```

The input file for the Recharge (RCH) Package (Harbaugh and others, 2000) is:

```
# RCH file for etsdrt test case
parameter 1              Item 1: NPRCH
1  0                     Item 2: NRCHOP IRCHCB
recharge  rch  1.e-3  1  Item 3: PARNAM PARTYP PARVAL NCLU
none      all            Item 4: MLTARR ZONARR [IZ]
 1                       Item 5: INRECH, stress period 1
recharge                 Item 7: Pname
```

The OBS input file for all observations (Hill and others, 2000) is:

```
# OBS file for etsdrt test case
etsdrt  1  Item 1: OBSNAM ISCALS
```

The HOB input file specifying head observations (Hill and others, 2000) is:

```
# HOB file for etsdrt test case
 22    0  0                                                  Item 1: NH MOBS MAXM
1.0  1.0                                                     Item 2: TOMULTH EVH
h-1-8    1  1   8  1  0.0  0.0  0.0  82.26832  0.1  1  1   Item 3
h-2-3    1  2   3  1  0.0  0.0  0.0  69.13411  0.1  1  1   Item 3
h-3-5    1  3   5  1  0.0  0.0  0.0  76.62444  0.1  1  1   Item 3
h-4-9    1  4   9  1  0.0  0.0  0.0  83.85851  0.1  1  1   Item 3
```

```
h-5-6    1  5   6  1  0.0  0.0  0.0  78.47830  0.1  1  1   Item 3
h-6-10   1  6  10  1  0.0  0.0  0.0  88.60881  0.1  1  1   Item 3
h-7-2    1  7   2  1  0.0  0.0  0.0  62.68863  0.1  1  1   Item 3
h-8-4    1  8   4  1  0.0  0.0  0.0  74.06773  0.1  1  1   Item 3
h-9-10   1  9  10  1  0.0  0.0  0.0  88.72263  0.1  1  1   Item 3
h-10-7   1 10   7  1  0.0  0.0  0.0  80.77811  0.1  1  1   Item 3
h-11-5   1 11   5  1  0.0  0.0  0.0  76.84839  0.1  1  1   Item 3
h-1-10   1  1  10  1  0.0  0.0  0.0  88.71668  0.1  1  1   Item 3
h-2-7    1  2   7  1  0.0  0.0  0.0  80.58694  0.1  1  1   Item 3
h-3-6    1  3   6  1  0.0  0.0  0.0  78.74275  0.1  1  1   Item 3
h-4-4    1  4   4  1  0.0  0.0  0.0  73.66403  0.1  1  1   Item 3
h-5-8    1  5   8  1  0.0  0.0  0.0  79.12901  0.1  1  1   Item 3
h-6-3    1  6   3  1  0.0  0.0  0.0  69.76251  0.1  1  1   Item 3
h-7-8    1  7   8  1  0.0  0.0  0.0  82.03431  0.1  1  1   Item 3
h-8-9    1  8   9  1  0.0  0.0  0.0  84.20422  0.1  1  1   Item 3
h-9-2    1  9   2  1  0.0  0.0  0.0  62.24666  0.1  1  1   Item 3
h-10-3   1 10   3  1  0.0  0.0  0.0  69.31798  0.1  1  1   Item 3
h-11-9   1 11   9  1  0.0  0.0  0.0  84.25888  0.1  1  1   Item 3
```

The DROB input file specifying flow observations using the DRT1 Package is:

```
# DTOB file for etsdrt test case
   1    1    1               Item 1: NQDT NQCDT NQTDT
 1.0  1.0    0               Item 2: TOMULTDT EVFDT IOWTQDT
 1  1                        Item 3: NQOBDT NQCLDT
D-1 1 0.0 -38.25803 0.1 2 2  Item 4: OBSNAM IREFSP TOFFSET HOBS STAT STAT-FLAG PLOTSYM
 1  5  8  1.0                Item 5: LAY ROW COL FACTOR
```

The input file for the Sensitivity Process (Hill and others, 2000) is:

```
# SEN file for etsdrt test case
4  0  0  4                                           Item 1: NPLIST ISENALL IUHEAD MXSEN
1  0 12  1                                           Item 2: IPRINTS ISENSU ISENPU ISENFM
ETS-Max     1  0  .005    1.E-3  1.E-1  1.E-4  Item 3: PARNAM ISENS LN B BL BU BSCAL
DRT-Cond    1  1   4.0     0.1   100.0   0.01  Item 3: PARNAM ISENS LN B BL BU BSCAL
Recharge    1  0  3.E-3   1.E-5  1.E-1  1.E-5  Item 3: PARNAM ISENS LN B BL BU BSCAL
HydCond     1  1  9.E-2   1.E-4  1.E1   1.E-5  Item 3: PARNAM ISENS LN B BL BU BSCAL
```

The input file for the Parameter-Estimation Process (Hill and others, 2000) is:

```
# PES file for etsdrt test case
20  2.0  0.0001  0.0       Item 1: MAX-ITER MAX-CHANGE TOL SOSC
 0 0 0 0 0 0.0 0.001 1.5 0 Item 2: IBEFLG IYCFLG IOSTAR NOPT NFIT SOSR RMAR RMARM IAP
 6  0  0                   Item 3: IPRCOV IPRINT LPRINT
 0.08  0.0  0              Item 4: CSA FCONV LASTX
 0  0  0                   Item 5: NPNG IFPR MPR
```

The GLOBAL output file is:

```
                            MODFLOW-2000
      U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
                           VERSION 1.0 07/20/2000

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

 GLOBAL LISTING FILE: etsdrt.glo
                         UNIT  11

 OPENING etsdrt.lst
 FILE TYPE:LIST   UNIT  12
#
# Global input files

 OPENING ..\data\ets1.dis
 FILE TYPE:DIS   UNIT  21
#
# Flow process input files

 OPENING ..\data\ets1.bas
 FILE TYPE:BAS6   UNIT  31
```

```
 OPENING ..\data\ets1.oc
 FILE TYPE:OC   UNIT  32

 OPENING ..\data\etsdrt.lpf
 FILE TYPE:LPF   UNIT  33

 OPENING ..\data\drt1.drt
 FILE TYPE:DRT   UNIT  34

 OPENING ..\data\etsdrt.rch
 FILE TYPE:RCH   UNIT  36

 OPENING ..\data\ets1.ets
 FILE TYPE:ETS   UNIT  37

 OPENING ..\data\ets1.pcg
 FILE TYPE:PCG   UNIT  39
#
# O-S-P processes input files

 OPENING ..\data\etsdrt.obs
 FILE TYPE:OBS   UNIT  41

 OPENING ..\data\etsdrt.ohd
 FILE TYPE:HOB   UNIT  42

 OPENING ..\data\etsdrt.odt
 FILE TYPE:DTOB   UNIT  43

 OPENING ..\data\etsdrt.sen
 FILE TYPE:SEN   UNIT  45

 OPENING ..\data\etsdrt.pes
 FILE TYPE:PES   UNIT  46

 DISCRETIZATION INPUT DATA READ FROM UNIT 21
 # DIS file for ets1, drt1, and etsdrt test cases.  Units: Days, Feet
    1 LAYERS        11 ROWS        11 COLUMNS
   1 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS DAYS
 MODEL LENGTH UNIT IS FEET

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

 MODE: PARAMETER ESTIMATION

  Confining bed flag for each layer:
   0

       1111  ELEMENTS OF GX ARRAY USED OUT OF       1111
        121  ELEMENTS OF GZ ARRAY USED OUT OF        121
        121  ELEMENTS OF IG ARRAY USED OUT OF        121

                     DELR =   100.000

                     DELC =   100.000

 TOP ELEVATION OF LAYER 1 =   100.000

   MODEL LAYER BOTTOM EL. =   0.00000     FOR LAYER   1


 STRESS PERIOD     LENGTH       TIME STEPS     MULTIPLIER FOR DELT    SS FLAG
 ----------------------------------------------------------------------------
        1        0.000000          1                    1.000         SS

 STEADY-STATE SIMULATION
```

```
LPF1 -- LAYER PROPERTY FLOW PACKAGE, VERSION 1, 1/11/2000
        INPUT READ FROM UNIT 33
# LPF file for etsdrt test case
HEAD AT CELLS THAT CONVERT TO DRY=   0.0000
    1 Named Parameters

  LAYER FLAGS:
LAYER       LAYTYP        LAYAVG         CHANI        LAYVKA        LAYWET
---------------------------------------------------------------------------
   1            1             0     1.000E+00            0             0

  INTERPRETATION OF LAYER FLAGS:
                     INTERBLOCK     HORIZONTAL    DATA IN
        LAYER TYPE   TRANSMISSIVITY   ANISOTROPY   ARRAY VKA   WETTABILITY
LAYER      (LAYTYP)       (LAYAVG)       (CHANI)      (LAYVKA)       (LAYWET)
---------------------------------------------------------------------------
   1   CONVERTIBLE      HARMONIC     1.000E+00    VERTICAL K  NON-WETTABLE

       242 ELEMENTS IN X ARRAY ARE USED BY LPF
         6 ELEMENTS IN IX ARRAY ARE USED BY LPF

PCG2 -- CONJUGATE GRADIENT SOLUTION PACKAGE, VERSION 2.4, 12/29/98
# PCG file for ets1, drt1, and etsdrt test cases
#
MAXIMUM OF     60 CALLS OF SOLUTION ROUTINE
MAXIMUM OF      8 INTERNAL ITERATIONS PER CALL TO SOLUTION ROUTINE
MATRIX PRECONDITIONING TYPE :    1
      1323 ELEMENTS IN X ARRAY ARE USED BY PCG
      3360 ELEMENTS IN IX ARRAY ARE USED BY PCG
       242 ELEMENTS IN Z ARRAY ARE USED BY PCG

SEN1BAS6 -- SENSITIVITY PROCESS, VERSION 1.0, 10/15/98
INPUT READ FROM UNIT  45
# SEN file for etsdrt test case

NUMBER OF PARAMETER VALUES TO BE READ FROM SEN FILE:    4
ISENALL............................................:    0
SENSITIVITIES WILL BE STORED IN MEMORY
FOR UP TO   4 PARAMETERS

       149 ELEMENTS IN X ARRAY ARE USED FOR SENSITIVITIES
       121 ELEMENTS IN Z ARRAY ARE USED FOR SENSITIVITIES
         8 ELEMENTS IN IX ARRAY ARE USED FOR SENSITIVITIES

PES1BAS6 -- PARAMETER-ESTIMATION PROCESS, VERSION 1.0, 07/22/99
INPUT READ FROM UNIT  46
# PES file for etsdrt test case

MAXIMUM NUMBER OF PARAMETER-ESTIMATION ITERATIONS (MAX-ITER)  =    20
MAXIMUM PARAMETER CORRECTION (MAX-CHANGE) ------------------- =  2.0000
CLOSURE CRITERION (TOL) ------------------------------------- = 0.10000E-03
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)  =     6
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

   271 ELEMENTS IN X ARRAY ARE USED FOR PARAMETER ESTIMATION
    99 ELEMENTS IN Z ARRAY ARE USED FOR PARAMETER ESTIMATION
    22 ELEMENTS IN IX ARRAY ARE USED FOR PARAMETER ESTIMATION

OBS1BAS6 -- OBSERVATION PROCESS, VERSION 1.0, 4/27/99
INPUT READ FROM UNIT  41
# OBS file for etsdrt test case
OBSERVATION GRAPH-DATA OUTPUT FILES
WILL BE PRINTED AND NAMED USING THE BASE: etsdrt
DIMENSIONLESS SCALED OBSERVATION SENSITIVITIES WILL BE PRINTED

HEAD OBSERVATIONS -- INPUT READ FROM UNIT  42
# HOB file for etsdrt test case

NUMBER OF HEADS....................................:   22
  NUMBER OF MULTILAYER HEADS.......................:    0
  MAXIMUM NUMBER OF LAYERS FOR MULTILAYER HEADS....:    0

OBS1DRT1 -- OBSERVATION PROCESS (DRAIN FLOW OBSERVATIONS: DRAIN RETURN PACKAGE)
VERSION 1.0, 5/2/2000
INPUT READ FROM UNIT  43
# DTOB file for etsdrt test case

FOR DRAIN RETURN PACKAGE:
NUMBER OF FLOW-OBSERVATION DRAIN-CELL GROUPS.......:    1
  NUMBER OF CELLS IN DRAIN-CELL GROUPS.............:    1
  NUMBER OF DRAIN-CELL FLOWS.......................:    1

    628 ELEMENTS IN X ARRAY ARE USED FOR OBSERVATIONS
      6 ELEMENTS IN Z ARRAY ARE USED FOR OBSERVATIONS
    231 ELEMENTS IN IX ARRAY ARE USED FOR OBSERVATIONS

COMMON ERROR VARIANCE FOR ALL OBSERVATIONS SET TO:       1.000

      2613  ELEMENTS OF X ARRAY USED OUT OF       2613
       468  ELEMENTS OF Z ARRAY USED OUT OF        468
      3627  ELEMENTS OF IX ARRAY USED OUT OF       3627
       484  ELEMENTS OF XHS ARRAY USED OUT OF        484

INFORMATION ON PARAMETERS LISTED IN SEN FILE
                                              LOWER         UPPER       ALTERNATE
                          VALUE IN SEN   REASONABLE    REASONABLE     SCALING
   NAME     ISENS  LN    INPUT FILE      LIMIT         LIMIT        FACTOR
----------  -----  --  ------------  ------------  ------------  ------------
ETS-Max       1     0   0.50000E-02  0.10000E-02  0.10000       0.10000E-03
DRT-Cond      1     1    4.0000      0.10000       100.00       0.10000E-01
Recharge      1     0   0.30000E-02  0.10000E-04  0.10000       0.10000E-04
HydCond       1     1   0.90000E-01  0.10000E-03   10.000       0.10000E-04
-----------------------------------------------------------------------------
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

                     REFER.
      OBSERVATION  STRESS    TIME                                  STATISTIC   PLOT
 OBS#    NAME      PERIOD   OFFSET    OBSERVATION  STATISTIC     TYPE      SYM.
    1 h-1-8            1    0.000       82.27      0.1000      STD. DEV.      1
    2 h-2-3            1    0.000       69.13      0.1000      STD. DEV.      1
    3 h-3-5            1    0.000       76.62      0.1000      STD. DEV.      1
    4 h-4-9            1    0.000       83.86      0.1000      STD. DEV.      1
    5 h-5-6            1    0.000       78.48      0.1000      STD. DEV.      1
```

6	h-6-10	1	0.000	88.61	0.1000	STD. DEV.	1
7	h-7-2	1	0.000	62.69	0.1000	STD. DEV.	1
8	h-8-4	1	0.000	74.07	0.1000	STD. DEV.	1
9	h-9-10	1	0.000	88.72	0.1000	STD. DEV.	1
10	h-10-7	1	0.000	80.78	0.1000	STD. DEV.	1
11	h-11-5	1	0.000	76.85	0.1000	STD. DEV.	1
12	h-1-10	1	0.000	88.72	0.1000	STD. DEV.	1
13	h-2-7	1	0.000	80.59	0.1000	STD. DEV.	1
14	h-3-6	1	0.000	78.74	0.1000	STD. DEV.	1
15	h-4-4	1	0.000	73.66	0.1000	STD. DEV.	1
16	h-5-8	1	0.000	79.13	0.1000	STD. DEV.	1
17	h-6-3	1	0.000	69.76	0.1000	STD. DEV.	1
18	h-7-8	1	0.000	82.03	0.1000	STD. DEV.	1
19	h-8-9	1	0.000	84.20	0.1000	STD. DEV.	1
20	h-9-2	1	0.000	62.25	0.1000	STD. DEV.	1
21	h-10-3	1	0.000	69.32	0.1000	STD. DEV.	1
22	h-11-9	1	0.000	84.26	0.1000	STD. DEV.	1

OBS#	OBSERVATION NAME	LAY	ROW	COL	ROW OFFSET	COL OFFSET	HEAD CHANGE REFERENCE OBSERVATION (IF > 0)
1	h-1-8	1	1	8	0.000	0.000	0
2	h-2-3	1	2	3	0.000	0.000	0
3	h-3-5	1	3	5	0.000	0.000	0
4	h-4-9	1	4	9	0.000	0.000	0
5	h-5-6	1	5	6	0.000	0.000	0
6	h-6-10	1	6	10	0.000	0.000	0
7	h-7-2	1	7	2	0.000	0.000	0
8	h-8-4	1	8	4	0.000	0.000	0
9	h-9-10	1	9	10	0.000	0.000	0
10	h-10-7	1	10	7	0.000	0.000	0
11	h-11-5	1	11	5	0.000	0.000	0
12	h-1-10	1	1	10	0.000	0.000	0
13	h-2-7	1	2	7	0.000	0.000	0
14	h-3-6	1	3	6	0.000	0.000	0
15	h-4-4	1	4	4	0.000	0.000	0
16	h-5-8	1	5	8	0.000	0.000	0
17	h-6-3	1	6	3	0.000	0.000	0
18	h-7-8	1	7	8	0.000	0.000	0
19	h-8-9	1	8	9	0.000	0.000	0
20	h-9-2	1	9	2	0.000	0.000	0
21	h-10-3	1	10	3	0.000	0.000	0
22	h-11-9	1	11	9	0.000	0.000	0

DRT-PACKAGE FLOW OBSERVATION VARIANCES ARE MULTIPLIED BY: 1.000

OBSERVED DRT-PACKAGE FLOW DATA
-- TIME OFFSETS ARE MULTIPLIED BY: 1.0000

GROUP NUMBER: 1 BOUNDARY TYPE: DRT NUMBER OF CELLS IN GROUP: 1
NUMBER OF FLOW OBSERVATIONS: 1

OBS#	OBSERVATION NAME	REFER. STRESS PERIOD	TIME OFFSET	OBSERVED DRAIN FLOW GAIN (-)	STATISTIC	STATISTIC TYPE	PLOT SYM.
23	D-1	1	0.000	-38.26	0.1000	COEF. VAR.	2

LAYER	ROW	COLUMN	FACTOR
1.	5.	8.	1.00

```
                    SOLUTION BY THE CONJUGATE-GRADIENT METHOD
                   ------------------------------------------
                MAXIMUM NUMBER OF CALLS TO PCG ROUTINE =      60
                    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) =        2
                                        DAMPING PARAMETER =    0.10000E+01

CONVERGENCE CRITERIA FOR SENSITIVITIES
PARAMETER      HCLOSE        RCLOSE
----------  ------------  ------------
ETS-Max      0.20000E-03    160.00
DRT-Cond     0.25000E-06   0.20000
Recharge     0.33333E-03    266.67
HydCond      0.11111E-04    8.8889
--------------------------------------

WETTING CAPABILITY IS NOT ACTIVE IN ANY LAYER

PARAMETERS DEFINED IN THE LPF PACKAGE

PARAMETER NAME:HydCond      TYPE:HK     CLUSTERS:   1
Parameter value from package file is:   5.00000E-02
This value has been changed to:         9.00000E-02, as read from
the Sensitivity Process file
               LAYER:  1    MULTIPLIER ARRAY: NONE    ZONE ARRAY: ALL

   HYD. COND. ALONG ROWS FOR LAYER   1 WILL BE DEFINED BY PARAMETERS
(PRINT FLAG=  -1)

     VERTICAL HYD. COND. =  1.000000E-02 FOR LAYER   1


    1 Recharge parameters

PARAMETER NAME:Recharge     TYPE:RCH    CLUSTERS:   1
Parameter value from package file is:   1.00000E-03
This value has been changed to:         3.00000E-03, as read from
the Sensitivity Process file
               MULTIPLIER ARRAY: none    ZONE ARRAY: all


    1 Evapotranspiration segments parameters

PARAMETER NAME:ETS-Max      TYPE:ETS    CLUSTERS:   1
Parameter value from package file is:   1.00000E-02
This value has been changed to:         5.00000E-03, as read from
the Sensitivity Process file
               MULTIPLIER ARRAY: none    ZONE ARRAY: all


    1 Drain-return parameters

PARAMETER NAME:DRT-Cond     TYPE:DRT
Parameter value from package file is:    2.0000
This value has been changed to:          4.0000    , as read from
the Sensitivity Process file
  NUMBER OF ENTRIES:      1

DRAIN NO.  LAYER   ROW   COL     DRAIN EL.  STRESS FACTOR
------------------------------------------------------------
     1      1      5      8       60.00           1.000

          ----DRAIN CELL----  --RECIPIENT CELL--   RETURN
DRAIN NO.  LAYER   ROW   COL   LAYER   ROW   COL    PROP.
     1      1      5      8      1      7      3  0.400000

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

***SUGGESTION FOR CONVERTIBLE LAYERS:
PERFORM INITIAL PARAMETER ESTIMATION RUNS WITH THE LAYERS
DESIGNATED AS CONFINED WITH ASSIGNED APPROXIMATE THICKNESSES
TO AVOID LONG EXECUTION TIMES AND EXCESSIVE FRUSTRATION.
CONVERT TO UNCONFINED AND CONVERTIBLE FOR FINAL PARAMETER
ESTIMATION RUNS WHEN PARAMETERS ARE ALREADY CLOSE TO
```

```
 OPTIMAL.

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

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

         PARAMETER:   ETS-Max     DRT-Cond    Recharge    HydCond
 OBS #  OBSERVATION
     1  h-1-8          -90.2       -2.87        94.0       -4.09
     2  h-2-3          -43.2      -0.180        123.       -191.
     3  h-3-5          -69.5       -2.06        113.       -101.
     4  h-4-9          -75.9       -12.2        74.7        24.0
     5  h-5-6          -78.5       -8.06        108.       -57.1
     6  h-6-10         -52.9       -5.02        46.9        23.0
     7  h-7-2          -26.8        13.9        94.5       -187.
     8  h-8-4          -57.5        6.93        116.       -153.
     9  h-9-10         -55.8      -0.753        48.0        20.2
    10  h-10-7         -92.1      -0.374        104.       -28.8
    11  h-11-5         -72.7       0.873        113.       -99.6
    12  h-1-10         -55.2       -1.23        47.9        19.8
    13  h-2-7          -88.5       -3.93        104.       -29.3
    14  h-3-6          -80.6       -4.24        109.       -61.0
    15  h-4-4          -55.2       0.126        116.       -147.
    16  h-5-8          -73.9       -58.6        83.9        77.8
    17  h-6-3          -43.9        13.0        121.       -209.
    18  h-7-8          -87.4       -8.43        92.7        1.80
    19  h-8-9          -81.1       -2.92        76.7        15.5
    20  h-9-2          -27.1        4.56        95.4       -172.
    21  h-10-3         -44.8        3.15        123.       -193.
    22  h-11-9         -83.3      -0.378        77.4        15.0
    23  D-1             7.72       -34.5       -8.77       -8.13

        COMPOSITE SCALED SENSITIVITIES ((SUM OF THE SQUARED VALUES)/ND)**.5
                        66.7        15.4        95.4        107.

  PARAMETER    COMPOSITE SCALED SENSITIVITY
  ----------   ----------------------------
  ETS-Max        6.66611E+01
  DRT-Cond       1.53726E+01
  Recharge       9.54185E+01
  HydCond        1.07280E+02

 STARTING VALUES OF REGRESSION PARAMETERS :

   ETS-Max      DRT-Cond     Recharge     HydCond

   5.0000E-03    4.000       3.0000E-03   9.0000E-02

 SUMS OF SQUARED, WEIGHTED RESIDUALS:
   ALL DEPENDENT VARIABLES:  0.21552E+06
   DEP. VARIABLES PLUS PARAMETERS:  0.21552E+06

 ------------------------------------------------------------------------
 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-03) = -.71375
        OCCURRED FOR PARAMETER  "Recharge  " 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 "Recharge  " TYPE U

UPDATED ESTIMATES OF REGRESSION PARAMETERS :

  ETS-Max      DRT-Cond     Recharge     HydCond

  7.6013E-03    2.838       8.5875E-04   7.8182E-02

SUMS OF SQUARED, WEIGHTED RESIDUALS:
  ALL DEPENDENT VARIABLES:   6107.9
  DEP. VARIABLES PLUS PARAMETERS:   6107.9

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-03) = 0.34440
       OCCURRED FOR PARAMETER  "ETS-Max   " 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 "ETS-Max   " TYPE U

UPDATED ESTIMATES OF REGRESSION PARAMETERS :

  ETS-Max      DRT-Cond     Recharge     HydCond

  1.0219E-02    2.153       1.0591E-03   5.2408E-02

SUMS OF SQUARED, WEIGHTED RESIDUALS:
  ALL DEPENDENT VARIABLES:   96.352
  DEP. VARIABLES PLUS PARAMETERS:   96.352

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-03) = -.68346E-01
       OCCURRED FOR PARAMETER  "DRT-Cond  " TYPE N

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 "DRT-Cond  " TYPE N

UPDATED ESTIMATES OF REGRESSION PARAMETERS :

  ETS-Max      DRT-Cond     Recharge     HydCond

  1.0024E-02    2.006       1.0012E-03   5.0150E-02

SUMS OF SQUARED, WEIGHTED RESIDUALS:
  ALL DEPENDENT VARIABLES:  0.21220
  DEP. VARIABLES PLUS PARAMETERS:  0.21220

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-03) = -.30231E-02
       OCCURRED FOR PARAMETER  "DRT-Cond  " TYPE N

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 "DRT-Cond  " TYPE N

UPDATED ESTIMATES OF REGRESSION PARAMETERS :
```

```
   ETS-Max      DRT-Cond     Recharge     HydCond

   9.9999E-03    2.000       9.9999E-04   4.9999E-02

 SUMS OF SQUARED, WEIGHTED RESIDUALS:
   ALL DEPENDENT VARIABLES:  0.11610E-04
   DEP. VARIABLES PLUS PARAMETERS:  0.11610E-04

 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-03) = 0.21498E-04
        OCCURRED FOR PARAMETER  "HydCond    " TYPE P

 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 "HydCond    " TYPE P

 UPDATED ESTIMATES OF REGRESSION PARAMETERS :

   ETS-Max      DRT-Cond     Recharge     HydCond

   1.0000E-02    2.000       1.0000E-03   5.0000E-02

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


OBSERVATION SENSITIVITY TABLE(S) FOR PARAMETER-ESTIMATION ITERATION     5

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

         PARAMETER:   ETS-Max     DRT-Cond    Recharge    HydCond
 OBS #  OBSERVATION
    1  h-1-8           -42.3      -0.441        37.8        15.2
    2  h-2-3           -44.0      -0.199        93.6       -148.
    3  h-3-5           -71.4       -1.04        105.       -96.7
    4  h-4-9           -46.2       -2.69        28.7        64.0
    5  h-5-6           -76.4       -3.45        98.8       -52.3
    6  h-6-10          -45.1      -0.807        15.8        91.3
    7  h-7-2           -25.5        4.52        68.7       -149.
    8  h-8-4           -61.4        2.55        103.       -137.
    9  h-9-10          -44.9      -0.578E-01    14.5        91.1
   10  h-10-7          -64.5       0.251E-01    72.2       -23.0
   11  h-11-5          -70.8       0.450        103.       -98.4
   12  h-1-10          -44.8      -0.981E-01    14.6        90.9
   13  h-2-7           -65.2       -1.26        74.3       -21.6
   14  h-3-6           -74.4       -1.80        96.4       -58.3
   15  h-4-4           -61.1      -0.212        105.       -130.
   16  h-5-8           -56.3       -20.5        54.4        94.3
   17  h-6-3           -45.1        4.16        93.2       -162.
   18  h-7-8           -45.6       -2.06        42.1        19.3
   19  h-8-9           -43.8      -0.378        24.4        59.8
   20  h-9-2           -25.3        1.47        68.9       -137.
   21  h-10-3          -44.5        1.06        92.9       -150.
   22  h-11-9          -43.7      -0.826E-02    23.6        60.2
   23  D-1              2.94       -5.86       -2.84       -4.93

        COMPOSITE SCALED SENSITIVITIES ((SUM OF THE SQUARED VALUES)/ND)**.5
                    52.6        4.81        71.5        97.6

  PARAMETER    COMPOSITE SCALED SENSITIVITY
  ----------   ----------------------------
  ETS-Max        5.26259E+01
  DRT-Cond       4.81191E+00
  Recharge       7.14750E+01
  HydCond        9.75598E+01

 FINAL PARAMETER VALUES AND STATISTICS:

 PARAMETER NAME(S) AND VALUE(S):
```

```
  ETS-Max      DRT-Cond     Recharge     HydCond

  1.0000E-02    2.000       1.0000E-03   5.0000E-02

SUMS OF SQUARED WEIGHTED RESIDUALS:
  OBSERVATIONS   PRIOR INFO.    TOTAL
   0.349E-07      0.00         0.349E-07

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

SELECTED STATISTICS FROM MODIFIED GAUSS-NEWTON ITERATIONS

       MAX. PARAMETER CALC. CHANGE   MAX. CHANGE     DAMPING
ITER.     PARNAM     MAX. CHANGE       ALLOWED      PARAMETER
-----   ----------  -------------   -------------  ------------
   1    Recharge    -0.713749         2.00000        1.0000
   2    ETS-Max      0.344404         2.00000        1.0000
   3    DRT-Cond    -0.683463E-01     2.00000        1.0000
   4    DRT-Cond    -0.302312E-02     2.00000        1.0000
   5    HydCond      0.214979E-04     2.00000        1.0000

SUMS OF SQUARED WEIGHTED RESIDUALS FOR EACH ITERATION

        SUMS OF SQUARED WEIGHTED RESIDUALS
ITER.  OBSERVATIONS  PRIOR INFO.      TOTAL
    1   0.21552E+06    0.0000       0.21552E+06
    2    6107.9        0.0000        6107.9
    3    96.352        0.0000        96.352
    4   0.21220        0.0000       0.21220
    5   0.11610E-04    0.0000       0.11610E-04
FINAL   0.34926E-07    0.0000       0.34926E-07

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

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

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

           ETS-Max    DRT-Cond   Recharge   HydCond
......................................................
ETS-Max     2.071E-15  1.811E-13  2.053E-16  2.022E-13
DRT-Cond    1.811E-13  1.843E-11  1.812E-14  1.813E-11
Recharge    2.053E-16  1.812E-14  2.039E-17  2.012E-14
HydCond     2.022E-13  1.813E-11  2.012E-14  1.997E-11


_________________

PARAMETER SUMMARY
_________________

________________________________________________________________________

PARAMETER VALUES IN "REGRESSION" SPACE --- LOG TRANSFORMED AS APPLICABLE
________________________________________________________________________

PARAMETER:        ETS-Max    DRT-Cond   Recharge   HydCond
* = LOG TRNS:                    *                     *


UPPER 95% C.I.     1.00E-02   3.01E-01   1.00E-03  -1.30E+00
FINAL VALUES       1.00E-02   3.01E-01   1.00E-03  -1.30E+00
LOWER 95% C.I.     1.00E-02   3.01E-01   1.00E-03  -1.30E+00

STD. DEV.          4.55E-08   1.86E-06   4.51E-09   1.94E-06

COEF. OF VAR. (STD. DEV. / FINAL VALUE); "--" IF FINAL VALUE = 0.0
                   4.55E-06   6.19E-06   4.51E-06   1.49E-06

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```

```
PHYSICAL PARAMETER VALUES --- EXP10 OF LOG TRANSFORMED PARAMETERS

PARAMETER:        ETS-Max    DRT-Cond   Recharge   HydCond
* = LOG TRNS:                  *                     *

UPPER 95% C.I.     1.00E-02   2.00E+00   1.00E-03   5.00E-02
FINAL VALUES       1.00E-02   2.00E+00   1.00E-03   5.00E-02
LOWER 95% C.I.     1.00E-02   2.00E+00   1.00E-03   5.00E-02

    REASONABLE
   UPPER LIMIT     1.00E-01   1.00E+02   1.00E-01   1.00E+01
    REASONABLE
   LOWER LIMIT     1.00E-03   1.00E-01   1.00E-05   1.00E-04

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


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

           ETS-Max    DRT-Cond   Recharge   HydCond
...................................................
ETS-Max      1.00      0.927      0.999      0.995
DRT-Cond    0.927       1.00      0.935      0.945
Recharge    0.999      0.935       1.00      0.997
HydCond     0.995      0.945      0.997       1.00

THE CORRELATION OF THE FOLLOWING PARAMETER PAIRS >= .95
    PARAMETER   PARAMETER   CORRELATION
    ETS-Max     Recharge        1.00
    ETS-Max     HydCond         0.99
    Recharge    HydCond         1.00

THE CORRELATION OF THE FOLLOWING PARAMETER PAIRS IS BETWEEN .90 AND .95
    PARAMETER   PARAMETER   CORRELATION
    ETS-Max     DRT-Cond        0.93
    DRT-Cond    Recharge        0.93
    DRT-Cond    HydCond         0.95

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

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)- = 0.34926E-07
 LEAST-SQUARES OBJ FUNC (W/PARAMETERS)-- = 0.34926E-07
 CALCULATED ERROR VARIANCE-------------- = 0.18382E-08
 STANDARD ERROR OF THE REGRESSION------- = 0.42874E-04
 CORRELATION COEFFICIENT---------------- =  1.0000
      W/PARAMETERS---------------------- =  1.0000
 ITERATIONS----------------------------- =       5

 MAX LIKE OBJ FUNC = -56.359
 AIC STATISTIC---- = -48.359
 BIC STATISTIC---- = -43.817
```

```
ORDERED DEPENDENT-VARIABLE WEIGHTED RESIDUALS
NUMBER OF RESIDUALS INCLUDED:        23
   -0.763E-04 -0.763E-04   0.00       0.00       0.00       0.00       0.00
     0.00       0.00       0.00       0.00       0.00       0.00       0.00
     0.00       0.00       0.00       0.00      0.997E-06  0.763E-04  0.763E-04
    0.763E-04  0.763E-04

SMALLEST AND LARGEST DEPENDENT-VARIABLE WEIGHTED RESIDUALS

    SMALLEST WEIGHTED RESIDUALS                LARGEST WEIGHTED RESIDUALS
       OBSERVATION     WEIGHTED                   OBSERVATION     WEIGHTED
 OBS#     NAME         RESIDUAL            OBS#     NAME         RESIDUAL
   13  h-2-7         -0.76294E-04             3  h-3-5          0.76294E-04
   10  h-10-7        -0.76294E-04             9  h-9-10         0.76294E-04
   22  h-11-9          0.0000                17  h-6-3          0.76294E-04
   21  h-10-3          0.0000                19  h-8-9          0.76294E-04
    4  h-4-9           0.0000                23  D-1            0.99710E-06

CORRELATION BETWEEN ORDERED WEIGHTED RESIDUALS AND
NORMAL ORDER STATISTICS (EQ.38 OF TEXT) =    0.687

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

Generally, IF the reported CORRELATION is LESS than the critical value,
at the selected significance level (usually 5 or 10%), the hypothesis
that the weighted residuals are INDEPENDENT AND NORMALLY DISTRIBUTED
would be REJECTED.  HOWEVER, in this case, conditions are outside of
the range of published critical values as discussed below.

The sum of the number of observations and prior information items is    23
which is less than 35, the minimum value for which critical values are
published.  Therefore, the critical values for the 5 and 10% significance
levels are less than 0.943 and 0.952, respectively.

CORRELATIONS GREATER than these critical values indicate that, probably, the
weighted residuals ARE INDEPENDENT AND NORMALLY DISTRIBUTED.

Correlations LESS than these critical values MAY BE ACCEPTABLE, and
rejection of the hypothesis is not necessarily warranted.

The Kolmogorov-Smirnov test can be used to further evaluate the residuals.
---------------------------------------------------------------------------


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

The LIST output file is:

```
                                 MODFLOW-2000
     U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER FLOW MODEL
                             VERSION 1.0 07/20/2000


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
----------  ---------  ------------  -----
ETS-Max        ETS      1.00000E-02    *
DRT-Cond       DRT       2.0000        *
Recharge       RCH      1.00000E-03    *
HydCond        HK       5.00000E-02    *
------------------------------------------
```

```
* INDICATES VALUE ADJUSTABLE BY PARAMETER-
  ESTIMATION PROCESS


REWOUND etsdrt.lst
FILE TYPE:LIST   UNIT  12

REWOUND ..\data\ets1.dis
FILE TYPE:DIS   UNIT  21

REWOUND ..\data\ets1.bas
FILE TYPE:BAS6   UNIT  31

REWOUND ..\data\ets1.oc
FILE TYPE:OC   UNIT  32

REWOUND ..\data\drt1.drt
FILE TYPE:DRT   UNIT  34

REWOUND ..\data\etsdrt.rch
FILE TYPE:RCH   UNIT  36

REWOUND ..\data\ets1.ets
FILE TYPE:ETS   UNIT  37

REWOUND ..\data\etsdrt.obs
FILE TYPE:OBS   UNIT  41

REWOUND ..\data\etsdrt.ohd
FILE TYPE:HOB   UNIT  42

REWOUND ..\data\etsdrt.odt
FILE TYPE:DTOB   UNIT  43

# BAS file for ets1, drt1, and etsdrt test cases
THE FREE FORMAT OPTION HAS BEEN SELECTED
   1 LAYERS        11 ROWS        11 COLUMNS
  1 STRESS PERIOD(S) IN SIMULATION

BAS6 -- BASIC PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 31
         5 ELEMENTS IN IR ARRAY ARE USED BY BAS

RCH6 -- RECHARGE PACKAGE, VERSION 6, 1/11/2000 INPUT READ FROM UNIT 36
# RCH file for etsdrt test case
    1 Named Parameters
OPTION 1 -- RECHARGE TO TOP LAYER
       121 ELEMENTS IN RX ARRAY ARE USED BY RCH
       121 ELEMENTS IN IR ARRAY ARE USED BY RCH

ETS1 -- EVAPOTRANSPIRATION SEGMENTS PACKAGE, VERSION 1, 5/2/2000
        INPUT READ FROM UNIT 37
# ETS input file for ets1 and etsdrt test cases
#
OPTION 1 -- EVAPOTRANSPIRATION FROM TOP LAYER
    1 Named Parameters
    2 SEGMENTS DEFINE EVAPOTRANSPIRATION RATE FUNCTION
       605 ELEMENTS IN RX ARRAY ARE USED BY ETS
       121 ELEMENTS IN IR ARRAY ARE USED BY ETS

DRT1 -- DRAIN RETURN PACKAGE, VERSION 1, 5/2/2000
INPUT READ FROM UNIT 34
# DRT file for drt1 and etsdrt test cases
MAXIMUM OF    1 ACTIVE DRAINS WITH RETURN FLOW AT ONE TIME
    1 Named Parameters         1 List entries
RETURN FLOW OPTION IS SELECTED
        18 ELEMENTS IN RX ARRAY ARE USED BY DRT

       744  ELEMENTS OF RX ARRAY USED OUT OF        744
       247  ELEMENTS OF IR ARRAY USED OUT OF        247

# BAS file for ets1, drt1, and etsdrt test cases
```

```
                    BOUNDARY ARRAY FOR LAYER   1
READING ON UNIT  31 WITH FORMAT: (FREE)

AQUIFER HEAD WILL BE SET TO -999.00     AT ALL NO-FLOW NODES (IBOUND=0).



                      INITIAL HEAD FOR LAYER   1
READING ON UNIT  31 WITH FORMAT: (FREE)
# OC file for ets1, drt1, and etsdrt test cases

OUTPUT CONTROL IS SPECIFIED ONLY AT TIME STEPS FOR WHICH OUTPUT IS DESIRED
HEAD PRINT FORMAT CODE IS   8    DRAWDOWN PRINT FORMAT CODE IS   0
HEADS WILL BE SAVED ON UNIT   0    DRAWDOWNS WILL BE SAVED ON UNIT   0

   HYD. COND. ALONG ROWS is defined by the following parameters:
HydCond

   HYD. COND. ALONG ROWS =  5.000005E-02 FOR LAYER   1

                           STRESS PERIOD NO.   1, LENGTH =   0.000000
                           ----------------------------------------------

                             NUMBER OF TIME STEPS =     1

                              MULTIPLIER FOR DELT =     1.000

                           INITIAL TIME STEP SIZE =   0.000000



RECH array defined by the following parameters:
 Parameter:  recharge
                RECHARGE =  1.000001E-03

       ET SURFACE (ETSS) =   100.000



ETSR array defined by the following parameters:
 Parameter:  ETS-Max
 EVAPOTRANS. RATE (ETSR) =  1.000001E-02

 EXTINCTION DEPTH (ETSX) =   36.0000

PXDP AND PETM ARRAYS FOR INTERSECTION    1 OF HEAD/ET RELATION:

EXTINCT. DEP. PROPORTION =  0.500000

      ET RATE PROPORTION =  0.100000

Parameter:  DRT-Cond
DRAIN NO.  LAYER   ROW   COL     DRAIN EL.  CONDUCTANCE
------------------------------------------------------------
     1      1      5      8       60.00           2.000

          ----DRAIN CELL----  --RECIPIENT CELL--   RETURN
DRAIN NO.  LAYER   ROW   COL   LAYER   ROW   COL    PROP.
     1      1      5      8      1      7      3  0.400000

    1 DRAIN-RETURN CELLS

SOLVING FOR HEAD

OUTPUT CONTROL FOR STRESS PERIOD  1   TIME STEP  1
   PRINT HEAD FOR ALL LAYERS

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

        1     2     3     4     5     6     7     8     9    10    11
 ......................................................................
  1   50.0  62.0  69.1  73.6  76.7  78.9  80.7  82.3  84.2  88.7 100.0
```

```
  2   50.0  62.0  69.1  73.6  76.7  78.8  80.6  82.2  84.2  88.7 100.0
  3   50.0  62.0  69.2  73.6  76.6  78.7  80.4  82.0  84.1  88.7 100.0
  4   50.0  62.1  69.2  73.7  76.6  78.6  80.0  81.3  83.9  88.6 100.0
  5   50.0  62.2  69.4  73.8  76.6  78.5  79.5  79.1  83.5  88.5 100.0
  6   50.0  62.4  69.8  74.0  76.7  78.7  80.1  81.3  83.9  88.6 100.0
  7   50.0  62.7  70.8  74.3  76.9  78.9  80.5  82.0  84.1  88.7 100.0
  8   50.0  62.4  69.8  74.1  76.9  79.0  80.7  82.2  84.2  88.7 100.0
  9   50.0  62.2  69.5  73.9  76.9  79.0  80.7  82.3  84.2  88.7 100.0
 10   50.0  62.2  69.3  73.8  76.9  79.0  80.8  82.3  84.3  88.7 100.0
 11   50.0  62.1  69.3  73.8  76.8  79.0  80.8  82.3  84.3  88.7 100.0

 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 =           0.0000         CONSTANT HEAD =         585.5532
           RECHARGE =           0.0000              RECHARGE =         990.0009
        ET SEGMENTS =           0.0000           ET SEGMENTS =           0.0000
       DRAINS (DRT) =           0.0000          DRAINS (DRT) =          15.3032

           TOTAL IN =           0.0000              TOTAL IN =        1590.8573

         OUT:                                     OUT:
         ----                                     ----
            STORAGE =           0.0000               STORAGE =           0.0000
      CONSTANT HEAD =           0.0000         CONSTANT HEAD =         372.6610
           RECHARGE =           0.0000              RECHARGE =           0.0000
        ET SEGMENTS =           0.0000           ET SEGMENTS =        1179.9382
       DRAINS (DRT) =           0.0000          DRAINS (DRT) =          38.2580

          TOTAL OUT =           0.0000             TOTAL OUT =        1590.8573

           IN - OUT =           0.0000              IN - OUT =           0.0000

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  0.0000      0.0000      0.0000      0.0000      0.0000
STRESS PERIOD TIME  0.0000      0.0000      0.0000      0.0000      0.0000
        TOTAL TIME  0.0000      0.0000      0.0000      0.0000      0.0000


DATA AT HEAD LOCATIONS

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

    1 h-1-8              82.268      82.268     0.00        10.0        0.00
    2 h-2-3              69.134      69.134     0.00        10.0        0.00
    3 h-3-5              76.624      76.624    0.763E-05    10.0        0.763E-04
    4 h-4-9              83.859      83.859     0.00        10.0        0.00
    5 h-5-6              78.478      78.478     0.00        10.0        0.00
    6 h-6-10             88.609      88.609     0.00        10.0        0.00
    7 h-7-2              62.689      62.689     0.00        10.0        0.00
    8 h-8-4              74.068      74.068     0.00        10.0        0.00
    9 h-9-10             88.723      88.723    0.763E-05    10.0        0.763E-04
   10 h-10-7             80.778      80.778   -0.763E-05    10.0       -0.763E-04
   11 h-11-5             76.848      76.848     0.00        10.0        0.00
   12 h-1-10             88.717      88.717     0.00        10.0        0.00
   13 h-2-7              80.587      80.587   -0.763E-05    10.0       -0.763E-04
```

```
   14 h-3-6              78.743      78.743    0.00        10.0        0.00
   15 h-4-4              73.664      73.664    0.00        10.0        0.00
   16 h-5-8              79.129      79.129    0.00        10.0        0.00
   17 h-6-3              69.763      69.763   0.763E-05    10.0       0.763E-04
   18 h-7-8              82.034      82.034    0.00        10.0        0.00
   19 h-8-9              84.204      84.204   0.763E-05    10.0       0.763E-04
   20 h-9-2              62.247      62.247    0.00        10.0        0.00
   21 h-10-3             69.318      69.318    0.00        10.0        0.00
   22 h-11-9             84.259      84.259    0.00        10.0        0.00

STATISTICS FOR HEAD RESIDUALS :
MAXIMUM WEIGHTED RESIDUAL  : 0.763E-04 OBS#      3
MINIMUM WEIGHTED RESIDUAL  :-0.763E-04 OBS#     10
AVERAGE WEIGHTED RESIDUAL  : 0.694E-05
# RESIDUALS >= 0. :     20
# RESIDUALS < 0.  :      2
NUMBER OF RUNS  :    2  IN   22 OBSERVATIONS

SUM OF SQUARED WEIGHTED RESIDUALS (HEADS ONLY)  0.34925E-07

DATA FOR FLOWS REPRESENTED USING THE DRAIN RETURN PACKAGE

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

   23 D-1            -38.3      -38.3      0.381E-05  0.261      0.997E-06

STATISTICS FOR DRT PACKAGE FLOW RESIDUALS :
MAXIMUM WEIGHTED RESIDUAL  : 0.997E-06 OBS#     23
MINIMUM WEIGHTED RESIDUAL  : 0.997E-06 OBS#     23
AVERAGE WEIGHTED RESIDUAL  : 0.997E-06
# RESIDUALS >= 0. :      1
# RESIDUALS < 0.  :      0
NUMBER OF RUNS  :    1  IN    1 OBSERVATIONS

SUM OF SQUARED WEIGHTED RESIDUALS (DRT FLOWS ONLY)  0.99420E-12

SUM OF SQUARED WEIGHTED RESIDUALS (ALL DEPENDENT VARIABLES)  0.34926E-07

STATISTICS FOR ALL RESIDUALS :
AVERAGE WEIGHTED RESIDUAL  : 0.668E-05
# RESIDUALS >= 0. :     21
# RESIDUALS < 0.  :      2
NUMBER OF RUNS  :    2  IN   23 OBSERVATIONS


INTERPRETTING THE CALCULATED RUNS STATISTIC VALUE OF     -3.24
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.
```