Time-Varying Parameters in MODFLOW-2000

To allow stress data that are defined by a parameter to vary with time without defining separate parameters, the concepts of time-varying parameter and parameter instance are introduced into MODFLOW-2000 (Harbaugh and others, 2000) with version 1.7. A time-varying parameter is a parameter for which multiple instances can be defined. Each instance of a parameter is a different set of data to which the parameter value can be applied in order to construct data values for the cells associated with the parameter. The same parameter value applies to all instances of a parameter. Each parameter may include several instances, but only one instance of a parameter can be in use during a stress period. The instance being used can be changed each stress period. The Sensitivity and Parameter-Estimation Processes may be used with time-varying parameters as documented in Hill and others (2000).

Time-varying parameters have been incorporated into MODFLOW-2000 because they make it possible to specify time constraints on parameters when using parameter estimation. Consider for example a simulation in which winter ground-water recharge is known (or assumed) to be twice the summer recharge. Without time-varying parameters, two parameters would be required to simulate this – one for winter and one for summer. Parameter estimation could be used to estimate either or both parameters, but prior to version 1.7 there was no way to cause parameter estimation to find the optimal values while forcing the winter value to be twice the summer value. In contrast, the time-varying-parameter capability makes it possible to define one recharge parameter with two instances – one for winter and one for summer. The winter instance would consist of data that causes the recharge to be twice that of the summer instance. The use of parameter estimation to calculate the optimal value for the single time-varying parameter would always result in the winter recharge being twice the summer recharge.

Parameters are designated as time varying by specifying the optional keyword "*INSTANCES*" in the parameter definition, as described in later sections. Each instance is named by a 10-character name, which must be unique among instances defined for a particular parameter. However, names of instances may be reused for different parameters. In order to use a time-varying parameter in a stress period, the parameter and instance names must both be specified. Parameters not designated as time-varying are defined and activated without the need to specify instance names. The definition of an instance for a time-varying parameter is different depending on whether a parameter defines list or array data.

Instances for List Parameters

Recall that for every list parameter, the following data must be defined:
name,
type,
value,
number of cells to which the parameter applies (NLST), and
a record of data for each of the NLST cells.

Each time-varying list parameter is defined to have one or multiple instances, where each instance is NLST lines of data. Each line identifies one cell and its properties. Although each instance must include the same number of cells, different instances of a given parameter can include different cells.

The current version of MODFLOW-2000 includes support for time-varying list parameters in the River (RIV), Well (WEL), Drain (DRN), General-Head Boundary (GHB), Constant-Head Boundary (CHD), and Drain-Return (DRT) Packages (Harbaugh and others, 2000; Banta, 2000). Revised input instructions for packages that support time-varying parameters are in the Input Instructions section.

Instances for Array Parameters

Array parameters define data that are required for every cell in one or more model layers. For array parameters, the following data must be defined:
name,
type,
value,
number of clusters to which the parameter applies (NCLU), and
a record of data for each of the NCLU clusters.

Each time-varying array parameter is defined to have one or multiple instances, where each instance is a list of NCLU clusters. Although each instance must be defined using the same number of clusters, the clusters for each instance can vary.

The current version of MODFLOW-2000 includes support for time-varying array parameters in the Recharge (RCH), Evapotranspiration (EVT), and Evapotranspiration Segments (ETS) Packages (Harbaugh and others, 2000; Banta, 2000). Revised input instructions for packages that support time-varying parameters are in the Input Instructions section.

Input Instructions

River Package

Input to the River (RIV) Package is read from the file that has file type "RIV" 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 multiple times.

1. ***PARAMETER*** NPRIV MXL
This optional item must start with the keyword “PARAMETER”.

2. MXACTR IRIVCB [Option]
3. PARNAM PARTYP Parval NLST [***INSTANCES*** NUMINST]
If PARNAM is to be a time-varying parameter, the keyword “INSTANCES” and a value for NUMINST must be entered.

4a. INSTNAM
Item 4a is read only if PARNAM is time-varying. NUMINST repetitions of Item 4 (parts a and b) are read. After each repetition of Item 4a, NLST repetitions of Item 4b are read.

4b. Layer Row Column Stage Condfact Rbot [xyz]
NLST repetitions of Item 4b are required; they are read by module ULSTRD. (SFAC of the ULSTRD utility module applies to Condfact). The NLST repetitions of Item 4b follow each repetition of Item 4a when PARNAM is time-varying. Repeat Items 3 and 4 for each of NPRIV parameters.

FOR EACH STRESS PERIOD

5. ITMP NP
6. Layer Row Column Stage Cond Rbot [xyz]
ITMP repetitions of Item 6 are read by module ULSTRD if ITMP>0. (SFAC of the ULSTRD utility module applies to Cond.) Item 6 is not read if ITMP is negative or 0.

7. Pname [Iname]
Item 7 is repeated NP times. It is not read if NP is negative or 0. Iname is read if Pname is a time-varying parameter.

Explanation of Variables Read by the RIV Package

Text – is a character variable (199 characters) that starts in column 2. Any characters can be included in Text. The “#” character must be in column 1. Except for the name file, lines beginning with # are restricted to these first lines of the file. Text is printed when the file is read.

NPRIV – is the number of river parameters.

MXL – is the maximum number of river reaches that will be defined using parameters. MXL must equal or exceed the sum of NLST×N for all parameters, where N is the greater of 1 and NUMINST.

MXACTR – is the maximum number of river reaches in use during any stress period. MXACTR includes reaches that are defined using parameters as well as reaches that are defined without using parameters.

IRIVCB – is a flag and a unit number.

If IRIVCB > 0, it is the unit number to which cell-by-cell flow terms will be written when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control.
If IRIVCB = 0, cell-by-cell flow terms will not be written.
If IRIVCB < 0, river leakage for each reach will be written to the listing file when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control.

Option – is an optional list of character values.

"AUXILIARY abc" or "AUX abc" – defines an auxiliary variable, named "abc", which will be read for each river reach as part of Items 4 and 6. 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 Package, but they will be available for use by other processes. The auxiliary variable values will be read after the Rbot variable.
"CBCALLOCATE" or "CBC" – indicates that memory should be allocated to store cell-by-cell flow for each river reach in order to make these flows available for use in other packages.

PARNAM – is the name of a parameter. 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. For the RIV Package, the only allowed parameter type is RIV, which defines values of riverbed 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 river reaches that are included in a non-time-varying parameter or in each instance of a time-varying parameter.

INSTANCES – is an optional keyword that designates a parameter as time varying. The keyword is case-insensitive; that is, it may be entered in any combination of upper- and lower-case letters. If ***INSTANCES*** is present, it must be followed by a value for NUMINST. If ***INSTANCES*** is absent, PARNAM is non-time-varying and NUMINST should not be present.

NUMINST – is the number of instances that are included in the definition of a time-varying parameter, where each instance is a list of river reaches and associated properties. If the keyword ***INSTANCES*** is present, NUMINST must be present and must be at least 1. If the keyword ***INSTANCES*** is absent, NUMINST should not be present.

INSTNAM – is the name of an instance associated with the parameter PARNAM specified in the corresponding Item 3. The 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. Names entered for INSTNAM must be unique for any given parameter, but names may be reused for instances associated with different parameters.

Layer – is the layer number of the cell containing the river reach.

Row – is the row number of the cell containing the river reach.

Column – is the column number of the cell containing the river reach.

Stage – is the head in the river.

Condfact – is the factor used to calculate riverbed hydraulic conductance from the parameter value. The conductance is the product of Condfact and the parameter value.

Rbot – is the elevation of the bottom of the riverbed.

[xyz] – represents any auxiliary variables for a river reach that have been defined in Item 2. The auxiliary variables must be present in each repetition of Items 4 and 6 if they are defined in Item 2.

ITMP – is a flag and a counter.

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

If ITMP 0, ITMP will be the number of non-parameter reaches read for the current stress period.

NP – is the number of parameters in use in the current stress period.

Cond – is the riverbed hydraulic conductance.

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

Iname – is an instance name that is read only if Pname is a time-varying parameter. Multiple instances of the same time-varying parameter are not allowed in a stress period.

Recharge Package

Input to the Recharge (RCH) Package is read from the file that has type "RCH" 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.

FOR EACH SIMULATION

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

1. ***PARAMETER*** NPRCH
This optional item must start with the word “PARAMETER”.

2. NRCHOP IRCHCB

3. PARNAM PARTYP Parval NCLU [***INSTANCES*** NUMINST]
If PARNAM is to be a time-varying parameter, the keyword ***INSTANCES*** and a value for NUMINST must be entered.

4a. INSTNAM
Item 4a is read only if PARNAM is time-varying. NUMINST repetitions of Item 4 (parts a and b) are read. After each repetition of Item 4a, NCLU repetitions of Item 4b are read.

4b. Mltarr Zonarr IZ
Repeat Item 4b NCLU times. Each repetition of Item 4b is called a parameter cluster. The NCLU repetitions of Item 4b follow each repetition of Item 4a when PARNAM is time-varying. Repeat Items 3-4 for each parameter to be defined (that is, NPRCH times).

FOR EACH STRESS PERIOD

5. INRECH INIRCH

6. RECH(NCOL,NROW) - U2DREL if NPRCH=0 and if INRECH 0
7. Pname [Iname] [IRCHPF] - if NPRCH>0 and if INRECH>0
Either Item 6 or Item 7 may be read, but not both. If Item 7 is read, it is repeated INRECH times. Iname is read if Pname is a time-varying parameter. If IRCHPF is specified for a non-time-varying parameter, Iname must be omitted.

8. IRCH(NCOL,NROW) -- U2DINT If NRCHOP=2 and if INIRCH 0

Explanation of Variables Read by the RCH Package

Text – is a character variable (199 characters) that starts in column 2. Any characters can be included in Text. The “#” character must be in column 1. Except for the name file, lines beginning with # are restricted to these first lines of the file. Text is printed when the file is read.

NPRCH – is the number of recharge parameters.

NRCHOP – is the recharge option code. Recharge fluxes are defined in a layer variable, RECH, with one value for each vertical column. Accordingly, recharge is applied to one cell in

each vertical column, and the option code determines which cell in the column is selected for recharge.

1 – Recharge is only to the top grid layer.
2 – Vertical distribution of recharge is specified in layer variable IRCH.
3 – Recharge is applied to the highest active cell in each vertical column. A constant-head node intercepts recharge and prevents deeper infiltration.

IRCHCB – is a flag and a unit number.

If IRCHCB > 0, it is the unit number to which cell-by-cell flow terms will be written when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control.

If IRCHCB 0, cell-by-cell flow terms will not be written.

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 RCH Package, the only allowed parameter type is RCH, which defines values of the recharge flux.

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.

NCLU – is the number of clusters required to define a non-time-varying parameter or one instance of a time-varying parameter. Each repetition of Item 4b is a cluster (variables Mltarr, Zonarr, and IZ). There is usually only one cluster used to define a RCH non-time-varying parameter or instance of a time-varying parameter; however, it is acceptable to have more than one cluster.

INSTANCES – is an optional keyword that designates a parameter as time varying. The keyword is case-insensitive; that is, it may be entered in any combination of upper- and lower-case letters. If ***INSTANCES*** is present, it must be followed by a value for NUMINST. If ***INSTANCES*** is absent, PARNAM is non-time-varying and NUMINST should not be present.

NUMINST – is the number of instances that are included in the definition of a time-varying parameter, where each instance is a series of NCLU clusters. If the keyword ***INSTANCES*** is present, NUMINST must be present and must be at least 1. If the keyword ***INSTANCES*** is absent, NUMINST should not be present.

INSTNAM – is the name of an instance associated with parameter PARNAM specified in the corresponding Item 3. The 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. Names entered for INSTNAM must be unique for any given parameter, but names may be reused for instances associated with different parameters.

Mltarr – is the name of the multiplier array to be used to define cell values that are determined by a parameter. The name "NONE" means that there is no multiplier array, and the cell values will be set equal to Parval.

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

IZ – is up to 10 zone numbers (separated by spaces) that define the cells that are 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.

INRECH – is the RECH read flag. Its function depends on whether or not parameters are being used.

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

If INRECH 0, a layer variable of recharge fluxes, RECH, is read.

If INRECH < 0, recharge rates from the preceding stress period are used.

If parameters are being used (NPRCH>0):

If INRECH 0, INRECH is the number of parameters that will be used to define RECH in the current stress period. Item 7 defines the names of the parameters.

If INRECH < 0, recharge parameters from the preceding stress period are used.

INRECH = 0 is not allowed. That is, when parameters are used, at least one parameter must be specified each stress period.

INIRCH – is the IRCH read flag, which is read only if NRCHOP is two:

If INIRCH 0, a layer variable of layer numbers (IRCH) is read.

If INIRCH < 0, the variable (IRCH) used in the preceding stress period is reused.

RECH – is the recharge flux (LT^{-1}). Read only if INRECH is greater than or equal to zero and if NPRCH=0.

Pname – is the name of a parameter that will be used to define the RECH variable in the current stress period. Read INRECH values if NPRCH>0 and INRECH>0.

Iname – is an instance name that is read only if Pname is a time-varying parameter. Multiple instances of the same time-varying parameter are not allowed in a stress period.

IRCHPF – is an optional format code for printing the RECH variable after it has been defined by parameters. The format codes are the same as those used in the U2DREL array reading utility module.

IRCH – is the layer number variable that defines the layer in each vertical column where recharge is applied. Read only if NRCHOP is two and if INIRCH is greater than or equal to zero.

Well Package

Input to the Well (WEL) Package is read from the file that has file type "WEL" 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 multiple times.

1. ***PARAMETER*** NPWEL MXL
This optional item must start with the word “PARAMETER”.

2. MXACTW IWELCB [Option]

3. PARNAM PARTYP Parval NLST [***INSTANCES*** NUMINST]
If PARNAM is to be a time-varying parameter, the keyword “INSTANCES” and a value for NUMINST must be entered.

4a. INSTNAM
Item 4a is read only if PARNAM is time-varying. NUMINST repetitions of Item 4 (parts a and b) are read. After each repetition of Item 4a, NLST repetitions of Item 4b are read.

4b. Layer Row Column Qfact [xyz]
NLST repetitions of Item 4b are required; they are read by module ULSTRD. (SFAC of the ULSTRD utility module applies to Qfact). The NLST repetitions of Item 4b follow each repetition of Item 4a when PARNAM is time-varying. Repeat Items 3 and 4 for each of NPWEL parameters.

FOR EACH STRESS PERIOD

5. ITMP NP
6. Layer Row Column Q [xyz]
ITMP repetitions of Item 6 are read by module ULSTRD if ITMP>0. (SFAC of the ULSTRD utility module applies to Q.) Item 6 is not read if ITMP is negative or 0.

7. Pname [Iname]
Item 7 is repeated NP times. It is not read if NP is negative or 0. Iname is read if Pname is a time-varying parameter.

Explanation of Variables Read by the WEL Package

Text – is a character variable (199 characters) that starts in column 2. Any characters can be included in Text. The “#” character must be in column 1. Except for the name file, lines beginning with # are restricted to these first lines of the file. Text is printed when the file is read.

NPWEL – is the number of well parameters.

MXL – is the maximum number of wells that will be defined using parameters. MXL must equal or exceed the sum of NLST×N for all parameters, where N is the greater of 1 and NUMINST.

MXACTW – is the maximum number of wells in use during any stress period. MXACTW includes wells that are defined using parameters as well as wells that are defined without using parameters.

IWELCB – is a flag and a unit number.

If IWELCB > 0, it is the unit number to which cell-by-cell flow terms will be written when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control.
If IWELCB = 0, cell-by-cell flow terms will not be written.
If IWELCB < 0, well recharge for each well will be written to the listing file when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control.

Option – is an optional list of character values.

"AUXILIARY abc" or "AUX abc" – defines an auxiliary variable, named "abc", which will be read for each well as part of Items 4 and 6. 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 Qfact or Q variable.
"CBCALLOCATE" or "CBC" -- indicates that memory should be allocated to store cell-by-cell flow for each well in order to make these flows available for use in other packages.

PARNAM – is the name of a parameter. 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 WEL Package, the only allowed parameter type is Q, which defines values of the volumetric recharge rate.

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 wells that are included in a non-time-varying parameter or in each instance of a time-varying parameter.

INSTANCES – is an optional keyword that designates a parameter as time varying. The keyword is case-insensitive; that is, it may be entered in any combination of upper- and lower-case letters. If ***INSTANCES*** is present, it must be followed by a value for NUMINST. If ***INSTANCES*** is absent, PARNAM is non-time-varying and NUMINST should not be present.

NUMINST – is the number of instances that are included in the definition of a time-varying parameter, where each instance is a list of wells and associated properties. If the keyword ***INSTANCES*** is present, NUMINST must be present and must be at least 1. If the keyword ***INSTANCES*** is absent, NUMINST should not be present.

INSTNAM – is the name of an instance associated with the parameter PARNAM specified in the corresponding Item 3. The 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. Names entered for INSTNAM must be unique for any given parameter, but names may be reused for instances associated with different parameters.

Layer – is the layer number of the model cell that contains the well.

Row – is the row number of the model cell that contains the well.

Column – is the column number of the model cell that contains the well.

Qfact – is the factor used to calculate well recharge rate from the parameter value. The recharge rate is the product of Qfact and the parameter value.

[xyz] – represents any auxiliary variables for a boundary that have been defined in Item 2. The auxiliary variables must be present in each repetition of Items 4 and 6 if they are defined in Item 2.

ITMP – is a flag and a counter.

If ITMP < 0, non-parameter well data from the preceding stress period will be reused.
If ITMP 0, ITMP is the number of non-parameter wells to be read for the current stress period.

NP – is the number of parameters in use in the current stress period.

Q – is the volumetric recharge rate. A positive value indicates recharge and a negative value indicates discharge (pumping).

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

Iname – is an instance name that is read only if Pname is a time-varying parameter. Multiple instances of the same time-varying parameter are not allowed in a stress period.

Drain Package

Input to the Drain (DRN) Package is read from the file that has type "DRN" 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 multiple times.

1. ***PARAMETER*** NPDRN MXL
This optional item must start with the word “PARAMETER”.

2. MXACTD IDRNCB [Option]

3. PARNAM PARTYP Parval NLST [***INSTANCES*** NUMINST]
If PARNAM is to be a time-varying parameter, the keyword “INSTANCES” and a value for NUMINST must be entered.

4a. INSTNAM
Item 4a is read only if PARNAM is time-varying. NUMINST repetitions of Item 4 (parts a and b) are read. After each repetition of Item 4a, NLST repetitions of Item 4b are read.

4b. Layer Row Column Elevation Condfact [xyz]
NLST repetitions of Item 4b are required; they are read by module ULSTRD. (SFAC of the ULSTRD utility module applies to Condfact). The NLST repetitions of Item 4b follow each repetition of Item 4a when PARNAM is time-varying. Repeat Items 3 and 4 for each of NPDRN parameters.

FOR EACH STRESS PERIOD

5. ITMP NP
6. Layer Row Column Elevation Cond [xyz]
ITMP repetitions of Item 6 are read by module ULSTRD if ITMP>0. (SFAC of the ULSTRD utility module applies to Cond.) Item 6 is not read if ITMP is negative or 0.

7. Pname [Iname]
Item 7 is repeated NP times. It is not read if NP is negative or 0. Iname is read if Pname is a time-varying parameter.

Explanation of Variables Read by the DRN Package

Text – is a character variable (199 characters) that starts in column 2. Any characters can be included in Text. The “#” character must be in column 1. Except for the name file, lines beginning with # are restricted to these first lines of the file. Text is printed when the file is read.

NPDRN – is the number of drain parameters.

MXL – is the maximum number of drain cells that will be defined using parameters. MXL must equal or exceed the sum of NLST×N for all parameters, where N is the greater of 1 and NUMINST.

MXACTD – is the maximum number of drain cells in use during any stress period. MXACTD includes cells that are defined using parameters as well as cells that are defined without using parameters.

IDRNCB – is a flag and a unit number.

If IDRNCB > 0, it is the unit number to which cell-by-cell flow terms will be written when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control.
If IDRNCB = 0, cell-by-cell flow terms will not be written.
If IDRNCB < 0, drain leakage for each drain cell will be written to the listing file when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control.

Option – is an optional list of character values.

"AUXILIARY abc" or "AUX abc" – defines an auxiliary variable, named "abc", which will be read for each drain as part of Items 4 and 6. 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 Condfact or 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.

PARNAM – is the name of a parameter. 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. For the DRN Package, the only allowed parameter type is DRN, 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 cells that are included in a non-time-varying parameter or in each instance of a time-varying parameter.

INSTANCES – is an optional keyword that designates a parameter as time varying. The keyword is case-insensitive; that is, it may be entered in any combination of upper- and lower-case letters. If ***INSTANCES*** is present, it must be followed by a value for NUMINST. If ***INSTANCES*** is absent, PARNAM is non-time-varying and NUMINST should not be present.

NUMINST – is the number of instances that are included in the definition of a time-varying parameter, where each instance is a list of drain cells and associated properties. If the keyword ***INSTANCES*** is present, NUMINST must be present and must be at least 1. If the keyword ***INSTANCES*** is absent, NUMINST should not be present.

INSTNAM – is the name of an instance associated with the parameter PARNAM specified in the corresponding Item 3. The 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. Names entered for INSTNAM must be unique for any given parameter, but names may be reused for instances associated with different parameters.

ITMP – is a flag and a counter.

If ITMP < 0, non-parameter drain data from the last stress period will be reused.
If ITMP 0, ITMP will be the number of non-parameter drains read for the current stress period.

NP – is the number of parameters in use in the current stress period.

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 is the product of Condfact and the parameter value.

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

[xyz] – represents any auxiliary variables for a drain that have been defined in Item 2. The auxiliary variables must be present in each repetition of Items 4 and 6 if they are defined in Item 2.

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

Iname – is an instance name that is read only if Pname is a time-varying parameter. Multiple instances of the same time-varying parameter are not allowed in a stress period.

Evapotranspiration Package

Input to the Evapotranspiration (EVT) Package is read from the file that is type "EVT" 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.

FOR EACH SIMULATION

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

1. ***PARAMETER*** NPEVT
This optional item must start with the word "PARAMETER".

2. NEVTOP IEVTCB

3. PARNAM PARTYP Parval NCLU [***INSTANCES*** NUMINST]
If PARNAM is to be a time-varying parameter, the keyword ***INSTANCES*** and a value for NUMINST must be entered.

4a. INSTNAM
Item 4a is read only if PARNAM is time-varying. NUMINST repetitions of Item 4 (parts a and b) are read. After each repetition of Item 4a, NCLU repetitions of Item 4b are read.

4b. Mltarr Zonarr IZ
Repeat Item 4b NCLU times. Each repetition of Item 4b is called a parameter cluster. The NCLU repetitions of Item 4b follow each repetition of Item 4a when PARNAM is time-varying. Repeat Items 3-4 for each parameter to be defined (that is, NPEVT times).

FOR EACH STRESS PERIOD

5. INSURF INEVTR INEXDP INIEVT
6. SURF(NCOL,NROW) -- U2DREL If INSURF 0

7. EVTR(NCOL,NROW) - U2DREL If NPEVT=0 and if INEVTR 0
8. Pname [Iname] [IEVTPF] - if NPEVT>0 and if INEVTR>0
Either Item 7 or Item 8 may be read, but not both. If Item 8 is read, it is repeated INEVTR times. Iname is read if Pname is a time-varying parameter. If IEVTPF is specified for a non-time-varying parameter, Iname must be omitted.

9. EXDP(NCOL,NROW) -- U2DREL If INEXDP 0
10. IEVT(NCOL,NROW) -- U2DINT If NEVTOP=2 and if INIEVT 0

Explanation of Variables Read by the EVT Package

Text – is a character variable (199 characters) that starts in column 2. Any characters can be included in Text. The "#" character must be in column 1. Except for the name file, lines beginning with # are restricted to these first lines of the file. Text is printed when the file is read.

NPEVT – is the number of evapotranspiration parameters.

NEVTOP – is the evapotranspiration (ET) option code. ET variables (ET surface, maximum ET rate, and extinction depth) are specified in layer variables, SURF, EVTR, and EXDP, with one value for each vertical column. 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.

1 – ET is calculated only for cells in the top grid layer.
2 – The cell for each vertical column is specified by the user in variable IEVT.

IEVTCB – is a flag and a unit number.

If IEVTCB > 0, it is the unit number to which cell-by-cell flow terms will be written when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control.
If IEVTCB 0, cell-by-cell flow terms will not be written.

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 EVT Package, the only allowed parameter type is EVT, which defines values of the maximum ET flux.

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.

NCLU – is the number of clusters required to define a non-time-varying parameter or one instance of a time-varying parameter. Each repetition of Item 4b is a cluster (variables Mltarr, Zonarr, and IZ). There is usually only one cluster used to define an EVT non-time-varying parameter or instance of a time-varying parameter; however, it is acceptable to have more than one cluster.

INSTANCES – is an optional keyword that designates a parameter as time varying. The keyword is case-insensitive; that is, it may be entered in any combination of upper- and lower-case letters. If ***INSTANCES*** is present, it must be followed by a value for NUMINST. If ***INSTANCES*** is absent, PARNAM is non-time-varying and NUMINST should not be present.

NUMINST – is the number of instances that are included in the definition of a time-varying parameter, where each instance is a series of NCLU clusters. If the keyword ***INSTANCES*** is present, NUMINST must be present and must be at least 1. If the keyword ***INSTANCES*** is absent, NUMINST should not be present.

INSTNAM – is the name of an instance associated with parameter PARNAM specified in the corresponding Item 3. The 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. Names entered for INSTNAM must be unique for any given parameter, but names may be reused for instances associated with different parameters.

Mltarr – is the name of the multiplier array to be used to define the values that are determined by a parameter. The name “NONE” means that 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 that are associated with a parameter. The name “ALL” means that 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 that are 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.

INSURF – is the ET surface (SURF) read flag.

If INSURF 0, a layer variable containing the ET surface elevation (SURF) will be read.
If INSURF < 0, the ET surface from the preceding stress period will be reused.

INEVTR – is the EVTR read flag. Its function depends on whether or not parameters are being used.

If no parameters are being used (NPEVT=0):
If INEVTR 0, a layer variable containing the maximum ET rate (EVTR) will be read.
If INEVTR < 0, the maximum ET rate from the preceding stress period will be reused.
If parameters are being used (NPEVT>0):
If INEVTR > 0, INEVTR is the number of parameters that will be used to define EVTR in the current stress period. Item 8 defines the names of the parameters.
If INEVTR < 0, EVT parameters from the preceding stress period are used.
INEVTR = 0 is not allowed. That is, when parameters are used, at least one parameter must be specified each stress period

INEXDP – is the extinction depth (EXDP) read flag.

If INEXDP 0, a layer variable containing the extinction depth (EXDP) will be read.
If INEXDP < 0, the extinction depth from the preceding stress period will be reused.

INIEVT – is the layer indicator (IEVT) read flag. It is read only if the ET option (NEVTOP) is equal to two.

If INIEVT 0, a layer variable containing the layer indicators (IEVT) will be read.
If INIEVT < 0, layer indicators used during the preceding stress period will be reused.

SURF – is the elevation of the ET surface. This variable is read only if INSURF 0

EVTR – is the maximum ET flux (volumetric flow rate per unit area (LT^{-1})). This variable is read only if INEVTR 0 and if NPEVT=0.

Pname – is the name of a parameter that will be used to define the EVTR variable in the current stress period. Read INEVTR values if NPEVT>0 and INEVTR>0.

Iname – is an instance name that is read only if Pname is a time-varying parameter. Multiple instances of the same time-varying parameter are not allowed in a stress period.

IEVTPF – is an optional format code for printing the EVTR variable after it has been defined by parameters. The format codes are the same as those used in the U2DREL array reading utility module.

EXDP – is the ET extinction depth. This variable is read only if INEXDP 0.

IEVT – is the layer indicator variable. For each horizontal location, it indicates the layer from which ET is removed. It is read only if the ET option is equal to two and if INIEVT 0.

General-Head Boundary Package

Input to the General-Head Boundary (GHB) Package is read from the file that has file type "GHB" 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 multiple times.

1. ***PARAMETER*** NPGHB MXL
This optional item must start with the word “PARAMETER”.

2. MXACTB IGHBCB [Option]

3. PARNAM PARTYP Parval NLST [***INSTANCES*** NUMINST]
If PARNAM is to be a time-varying parameter, the keyword “INSTANCES” and a value for NUMINST must be entered.

4a. INSTNAM
Item 4a is read only if PARNAM is time-varying. NUMINST repetitions of Item 4 (parts a and b) are read. After each repetition of Item 4a, NLST repetitions of Item 4b are read.

4b. Layer Row Column Bhead Condfact [xyz]
NLST repetitions of Item 4b are required; they are read by module ULSTRD. (SFAC of the ULSTRD utility module applies to Condfact). The NLST repetitions of Item 4b follow each repetition of Item 4a when PARNAM is time-varying. Repeat Items 3 and 4 for each of NPGHB parameters.

FOR EACH STRESS PERIOD

5. ITMP NP
6. Layer Row Column Bhead Cond [xyz]
ITMP repetitions of Item 6 are read by module ULSTRD if ITMP>0. (SFAC of the ULSTRD utility module applies to Cond.) Item 6 is not read if ITMP is negative or 0.

7. Pname [Iname]
Item 7 is repeated NP times. It is not read if NP is negative or 0. Iname is read if Pname is a time-varying parameter.

Explanation of Variables Read by the GHB Package

Text – is a character variable (199 characters) that starts in column 2. Any characters can be included in Text. The “#” character must be in column 1. Except for the name file, lines beginning with # are restricted to these first lines of the file. Text is printed when the file is read.

NPGHB – is the number of general-head boundary parameters.

MXL – is the maximum number of general-head-boundary cells that will be defined using parameters. MXL must equal or exceed the sum of NLST×N for all parameters, where N is the greater of 1 and NUMINST.

MXACTB – is the maximum number of general-head boundary cells in use during any stress period. MXACTB includes cells that are defined using parameters as well as cells that are defined without using parameters.

IGHBCB – is a flag and a unit number.

If IGHBCB > 0, it is the unit number to which cell-by-cell flow terms will be written when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control.
If IGHBCB = 0, cell-by-cell flow terms will not be written.
If IGHBCB < 0, boundary leakage for each GHB cell will be written to the listing file when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control.

Option – is an optional list of character values.

"AUXILIARY abc" or "AUX abc" – defines an auxiliary variable, named "abc", which will be read for each general-head boundary as part of Items 4 and 6. 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 Condfact or Cond variable.
"CBCALLOCATE" or "CBC" -- indicates that memory should be allocated to store cell-by-cell flow for each general-head boundary in order to make these flows available for use in other packages.

PARNAM – is the name of a parameter. 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 GHB Package, the only allowed parameter type is GHB, which defines values of the general-head boundary 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 head-dependent boundary cells that are included in a non-time-varying parameter or in each instance of a time-varying parameter.

INSTANCES – is an optional keyword that designates a parameter as time varying. The keyword is case-insensitive; that is, it may be entered in any combination of upper- and lower-case letters. If ***INSTANCES*** is present, it must be followed by a value for NUMINST. If ***INSTANCES*** is absent, PARNAM is non-time-varying and NUMINST should not be present.

NUMINST – is the number of instances that are included in the definition of a time-varying parameter, where each instance is a list of general-head boundary cells and associated properties. If the keyword ***INSTANCES*** is present, NUMINST must be present and must be at least 1. If the keyword ***INSTANCES*** is absent, NUMINST should not be present.

INSTNAM – is the name of an instance associated with the parameter PARNAM specified in the corresponding Item 3. The 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. Names entered for INSTNAM must be unique for any given parameter, but names may be reused for instances associated with different parameters.

Layer – is the layer number of the cell affected by the head-dependent boundary.

Row – is the row number of the cell affected by the head-dependent boundary.

Column – is the column number of the cell affected by the head-dependent boundary.

Bhead – is the head on the boundary.

Condfact – is the factor used to calculate hydraulic conductance from the parameter value. The conductance is the product of Condfact and the parameter value.

[xyz] – represents any auxiliary variables for a boundary that have been defined in Item 2. The auxiliary variables must be present in each repetition of Items 4 and 6 if they are defined in Item 2.

ITMP – is a flag and a counter.

If ITMP < 0, non-parameter GHB data from the preceding stress period will be reused.
If ITMP 0, ITMP is the number of non-parameter general-head boundaries read for the current stress period.

NP – is the number of parameters in use in the current stress period.

Cond – is the hydraulic conductance of the interface between the aquifer cell and the boundary.

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

Iname – is an instance name that is read only if Pname is a time-varying parameter. Multiple instances of the same time-varying parameter are not allowed in a stress period.

Constant-Head Boundary Package

Input to the Constant-Head Boundary (CHD) Package is read from the file that has file type "CHD" 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 multiple times.

1. ***PARAMETER*** NPCHD MXL
This optional item must start with the word “PARAMETER”.

2. MXACTC [Option]

3. PARNAM PARTYP Parval NLST [***INSTANCES*** NUMINST]
If PARNAM is to be a time-varying parameter, the keyword “INSTANCES” and a value for NUMINST must be entered.

4a. INSTNAM
Item 4a is read only if PARNAM is time-varying. NUMINST repetitions of Item 4 (parts a and b) are read. After each repetition of Item 4a, NLST repetitions of Item 4b are read.

4b. Layer Row Column Shdfact Ehdfact [xyz]
NLST repetitions of Item 4b are required; they are read by module ULSTRD. (SFAC of the ULSTRD utility module applies to Shdfact and Ehdfact). The NLST repetitions of Item 4b follow each repetition of Item 4a when PARNAM is time-varying. Repeat Items 3 and 4 for each of NPCHD parameters.

FOR EACH STRESS PERIOD

5. ITMP NP
6. Layer Row Column Shead Ehead [xyz]
ITMP repetitions of Item 6 are read by module ULSTRD if ITMP>0. (SFAC of the ULSTRD utility module applies to Shead and Ehead.) Item 6 is not read if ITMP is negative or 0.

7. Pname [Iname]
Item 7 is repeated NP times. It is not read if NP is negative or 0. Iname is read if Pname is a time-varying parameter.

Explanation of Variables Read by the CHD Package

Text – is a character variable (199 characters) that starts in column 2. Any characters can be included in Text. The “#” character must be in column 1. Except for the name file, lines beginning with # are restricted to these first lines of the file. Text is printed when the file is read.

NPCHD – is the number of constant-head boundary parameters.

MXL – is the maximum number of constant-head-boundary cells that will be defined using parameters. MXL must equal or exceed the sum of NLST×N for all parameters, where N is the greater of 1 and NUMINST.

MXACTC – is the maximum number of constant-head boundary cells in use during any stress period. MXACTC includes cells that are defined using parameters as well as cells that are defined without using parameters.

Option – is an optional list of character values.

"AUXILIARY abc" or "AUX abc" – defines an auxiliary variable, named "abc", which will be read for each constant-head boundary as part of Items 4 and 6. 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 Ehdfact or Ehead variable.

PARNAM – is the name of a parameter. 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 CHD Package, the only allowed parameter type is CHD, which defines values of the start and end head at the boundary.

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 constant-head cells that are included in a non-time-varying parameter or in each instance of a time-varying parameter.

INSTANCES – is an optional keyword that designates a parameter as time varying. The keyword is case-insensitive; that is, it may be entered in any combination of upper- and lower-case letters. If ***INSTANCES*** is present, it must be followed by a value for NUMINST. If ***INSTANCES*** is absent, PARNAM is non-time-varying and NUMINST should not be present.

NUMINST – is the number of instances that are included in the definition of a time-varying parameter, where each instance is a list of constant-head cells and associated properties. If the keyword ***INSTANCES*** is present, NUMINST must be present and must be at least 1. If the keyword ***INSTANCES*** is absent, NUMINST should not be present.

INSTNAM – is the name of an instance associated with the parameter PARNAM specified in the corresponding Item 3. The 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. Names entered for INSTNAM must be unique for any given parameter, but names may be reused for instances associated with different parameters.

Layer – is the layer number of the constant-head boundary.

Row – is the row number of the constant-head boundary.

Column – is the column number of the constant-head boundary.

Shdfact – is the factor used to calculate the head at the boundary at the start of the stress period from the parameter value. The head is the product of Shdfact and the parameter value.

Ehdfact – is the factor used to calculate the head at the boundary at the end of the stress period from the parameter value. The head is the product of Ehdfact and the parameter value.

[xyz] – represents any auxiliary variables for a constant-head boundary that have been defined in Item 2. The auxiliary variables must be present in each repetition of Items 4 and 6 if they are defined in Item 2.

ITMP – is a flag and a counter.

If ITMP < 0, non-parameter CHD data from the preceding stress period will be reused.
If ITMP 0, ITMP is the number of non-parameter constant-head boundaries read for the current stress period.

NP – is the number of parameters in use in the current stress period.

Shead – is the head at the boundary at the start of the stress period.

Ehead – is the head at the boundary at the end of the stress period.

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

Iname – is an instance name that is read only if Pname is a time-varying parameter. Multiple instances of the same time-varying parameter are not allowed in a stress period.

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 [***INSTANCES*** NUMINST]
If PARNAM is to be a time-varying parameter, the keyword ***INSTANCES*** and a value for NUMINST must be entered.

3a. INSTNAM
Item 3a is read only if PARNAM is time-varying. NUMINST repetitions of Item 3 (parts a and b) are read. After each repetition of Item 3a, NCLU repetitions of Item 3b are read.

3b. Mltarr Zonarr IZ
Each repetition of Item 3b is called a parameter cluster. Repeat Item 3b NCLU times. The NCLU repetitions of Item 3b follow each repetition of Item 3a when PARNAM is time-varying. 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 [Iname] [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. Iname is read if Pname is a time-varying parameter. If IETSPF is specified for a non-time-varying parameter, Iname must be omitted.

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.

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 non-time-varying parameter or one instance of a time-varying parameter. Each repetition of Item 3b is a cluster (variables Mltarr, Zonarr, and IZ). Usually only one cluster is needed to define an ETS non-time-varying parameter or instance of a time-varying parameter; however, more than one cluster may be listed.

INSTANCES – is an optional keyword that designates a parameter as time varying. The keyword is case-insensitive; that is, it may be entered in any combination of upper- and lower-case letters. If ***INSTANCES*** is present, it must be followed by a value for NUMINST. If ***INSTANCES*** is absent, PARNAM is non-time-varying and NUMINST should not be present.

NUMINST – is the number of instances that are included in the definition of a time-varying parameter, where each instance is a series of NCLU clusters. If the keyword

INSTANCES is present, NUMINST must be present and must be at least 1. If the keyword ***INSTANCES*** is absent, NUMINST should not be present.

INSTNAM – is the name of an instance associated with parameter PARNAM specified in the corresponding Item 2. The 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. Names entered for INSTNAM must be unique for any given parameter, but names may be reused for instances associated with different parameters.

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.

Iname – is an instance name that is read only if Pname is a time-varying parameter. Multiple instances of the same time-varying parameter are not allowed in a 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.

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  [`***`INSTANCES`***`  NUMINST]`
If PARNAM is to be a time-varying parameter, the keyword "INSTANCES" and a value for NUMINST must be entered.

`3a.  INSTNAM`
Item 3a is read only if PARNAM is time-varying. NUMINST repetitions of Item 3 (parts a and b) are read. After each repetition of Item 3a, NLST repetitions of Item 3b are read.

`3b.  Layer Row Column Elevation Condfact [LayR RowR ColR Rfprop] [xyz]`
NLST repetitions of Item 3b are required; they are read by module ULSTRD (Harbaugh and others, 2000). (SFAC of the ULSTRD utility module applies to Condfact). The NLST repetitions of Item 3b follow each repetition of Item 3a when PARNAM is time-varying. 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 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  [Iname]`
Item 6 is repeated NP times. It is not read if NP ≤ 0. Iname is read if Pname is a time-varying parameter.

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. MXADRT includes cells that are defined using parameters as well as cells that are defined without 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. MXL must equal or exceed the sum of NLST×N for all parameters, where N is the greater of 1 and NUMINST.

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 Rfprop 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 a non-time-varying parameter or in each instance of a time-varying parameter.

INSTANCES – is an optional keyword that designates a parameter as time varying. The keyword is case-insensitive; that is, it may be entered in any combination of upper- and lower-case letters. If ***INSTANCES*** is present, it must be followed by a value for NUMINST. If ***INSTANCES*** is absent, PARNAM is non-time-varying and NUMINST should not be present.

NUMINST – is the number of instances that are included in the definition of a time-varying parameter, where each instance is a list of drain-return cells, associated recipient cells, and properties. If the keyword ***INSTANCES*** is present, NUMINST must be present and must be at least 1. If the keyword ***INSTANCES*** is absent, NUMINST should not be present.

INSTNAM – is the name of an instance associated with the parameter PARNAM specified in the corresponding Item 3. The 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. Names entered for INSTNAM must be unique for any given parameter, but names may be reused for instances associated with different parameters.

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 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.

Iname – is an instance name that is read only if Pname is a time-varying parameter. Multiple instances of the same time-varying parameter are not allowed in a stress period.

Examples

Two example input files show how time-varying parameters may be implemented. The first example uses the River Package to illustrate the use of time-varying list parameters. The second example uses the Recharge Package to illustrate the use of a time-varying array parameter. In both cases, instances are used to simulate seasonally varying stresses.

In Example 1, two time-varying river parameters are defined. The first parameter, named River_1, defines river reaches in three cells and uses four instances, named Winter, Spring, Summer, and Autumn. Each instance defines variables for three cells in model row 1; stage varies from instance to instance, but in this example the other variables are held constant. The second parameter, named River_2, defines river reaches in five cells and uses three instances. For parameter River_2, the instances are named Spring, Summer2, and Autumn2; the river represented by parameter River_2 is dry during winter. MXL, the sum of NLST×NUMINST for all parameters, is calculated as $3\times4+5\times3 = 27$. In each of the eight stress periods, one or both river parameters are activated with a specified instance. Note that instance names have no significance other than as defined for a specific parameter.

Example 1: River Package input file

```
PARAMETER  2  27                      Item 1: NPRIV MXL
8  0                                  Item 2: MXACTR IRIVCB
River_1  RIV  50.0  3  INSTANCES  4   Item 3: PARNAM PARTYP Parval NLST NUMINST
Winter                                Item 4a: INSTNAM
1  1  1  110.0  1.0   106.0           Item 4b: Layer Row Column Stage Condfact Rbot
1  1  2  109.0  1.0   105.0           Item 4b: Layer Row Column Stage Condfact Rbot
1  1  3  108.0  1.0   104.0           Item 4b: Layer Row Column Stage Condfact Rbot
Spring                                Item 4a: INSTNAM
1  1  1  115.0  1.0   106.0           Item 4b: Layer Row Column Stage Condfact Rbot
1  1  2  114.0  1.0   105.0           Item 4b: Layer Row Column Stage Condfact Rbot
1  1  3  113.0  1.0   104.0           Item 4b: Layer Row Column Stage Condfact Rbot
Summer                                Item 4a: INSTNAM
1  1  1  112.0  1.0   106.0           Item 4b: Layer Row Column Stage Condfact Rbot
1  1  2  111.0  1.0   105.0           Item 4b: Layer Row Column Stage Condfact Rbot
1  1  3  110.0  1.0   104.0           Item 4b: Layer Row Column Stage Condfact Rbot
Autumn                                Item 4a: INSTNAM
1  1  1  111.0  1.0   106.0           Item 4b: Layer Row Column Stage Condfact Rbot
1  1  2  110.0  1.0   105.0           Item 4b: Layer Row Column Stage Condfact Rbot
1  1  3  109.0  1.0   104.0           Item 4b: Layer Row Column Stage Condfact Rbot
River_2  RIV  70.0  5  INSTANCES  3   Item 3: PARNAM PARTYP Parval NLST NUMINST
Spring                                Item 4a: INSTNAM
1 40 11  225.0  1.0   218.0          Item 4b: Layer Row Column Stage Condfact Rbot
1 40 12  223.0  1.0   216.0          Item 4b: Layer Row Column Stage Condfact Rbot
1 40 13  221.0  1.0   214.0          Item 4b: Layer Row Column Stage Condfact Rbot
1 40 14  219.0  1.0   212.0          Item 4b: Layer Row Column Stage Condfact Rbot
1 40 15  217.0  1.0   210.0          Item 4b: Layer Row Column Stage Condfact Rbot
Summer2                               Item 4a: INSTNAM
1 40 11  222.0  1.0   218.0          Item 4b: Layer Row Column Stage Condfact Rbot
1 40 12  220.0  1.0   216.0          Item 4b: Layer Row Column Stage Condfact Rbot
1 40 13  218.0  1.0   214.0          Item 4b: Layer Row Column Stage Condfact Rbot
1 40 14  216.0  1.0   212.0          Item 4b: Layer Row Column Stage Condfact Rbot
1 40 15  214.0  1.0   210.0          Item 4b: Layer Row Column Stage Condfact Rbot
Autumn2                               Item 4a: INSTNAM
1 40 11  221.0  1.0   218.0          Item 4b: Layer Row Column Stage Condfact Rbot
1 40 12  219.0  1.0   216.0          Item 4b: Layer Row Column Stage Condfact Rbot
1 40 13  217.0  1.0   214.0          Item 4b: Layer Row Column Stage Condfact Rbot
1 40 14  215.0  1.0   212.0          Item 4b: Layer Row Column Stage Condfact Rbot
1 40 15  213.0  1.0   210.0          Item 4b: Layer Row Column Stage Condfact Rbot
0  2                                  Item 5: ITMP NP, stress period 1
River_1  Spring                       Item 7: Pname Iname
River_2  Spring                       Item 7: Pname Iname
0  2                                  Item 5: ITMP NP, stress period 2
River_1  Summer                       Item 7: Pname Iname
River_2  Summer2                      Item 7: Pname Iname
0  2                                  Item 5: ITMP NP, stress period 3
River_1  Autumn                       Item 7: Pname Iname
River_2  Autumn2                      Item 7: Pname Iname
0  1                                  Item 5: ITMP NP, stress period 4
River_1  Winter                       Item 7: Pname Iname
0  2                                  Item 5: ITMP NP, stress period 5
River_1  Spring                       Item 7: Pname Iname
River_2  Spring                       Item 7: Pname Iname
0  2                                  Item 5: ITMP NP, stress period 6
River_1  Summer                       Item 7: Pname Iname
River_2  Summer2                      Item 7: Pname Iname
0  2                                  Item 5: ITMP NP, stress period 7
River_1  Autumn                       Item 7: Pname Iname
River_2  Autumn2                      Item 7: Pname Iname
0  1                                  Item 5: ITMP NP, stress period 8
River_1  Winter                       Item 7: Pname Iname
```

In Example 2, one time-varying recharge parameter named Rechrg is defined with four instances. The instances are named Spring, Summer, RchAutumn, and RchWinter; the recharge rate is made variable by specifying a different multiplier array in the cluster defined for each instance. Since ALL is specified for Zonarr for each instance, the recharge rate variability in this

example is determined solely by the contents of the multiplier arrays. Alternatively or in addition, variability could be specified by using zone arrays and specifying different zones for different instances, or by referencing different zone arrays for different instances. Note that instance names have no significance other than as defined for a specific parameter.

Example 2: Recharge Package input file

```
PARAMETER  1                          Item 1: NPRCH
1  0                                  Item 2: NRCHOP IRCHCB
Rechrg  RCH  0.015  1  INSTANCES  4   Item 3: PARNAM PARTYP Parval NCLU NUMINST
Spring                                Item 4a: INSTNAM
MltArr_1  ALL                         Item 4b: Mltarr Zonarr
Summer                                Item 4a: INSTNAM
MltArr_2  ALL                         Item 4b: Mltarr Zonarr
RchAutumn                             Item 4a: INSTNAM
MltArr_3  ALL                         Item 4b: Mltarr Zonarr
RchWinter                             Item 4a: INSTNAM
MltArr_4  ALL                         Item 4b: Mltarr Zonarr
1                                     Item 5: INRECH, stress period 1
Rechrg  Spring  0                     Item 7: Pname Iname IRCHPF
1                                     Item 5: INRECH, stress period 2
Rechrg  Summer  0                     Item 7: Pname Iname IRCHPF
1                                     Item 5: INRECH, stress period 3
Rechrg  RchAutumn  0                  Item 7: Pname Iname IRCHPF
1                                     Item 5: INRECH, stress period 4
Rechrg  RchWinter  0                  Item 7: Pname Iname IRCHPF
1                                     Item 5: INRECH, stress period 5
Rechrg  Spring  0                     Item 7: Pname Iname IRCHPF
1                                     Item 5: INRECH, stress period 6
Rechrg  Summer  0                     Item 7: Pname Iname IRCHPF
1                                     Item 5: INRECH, stress period 7
Rechrg  RchAutumn  0                  Item 7: Pname Iname IRCHPF
1                                     Item 5: INRECH, stress period 8
Rechrg  RchWinter  0                  Item 7: Pname Iname IRCHPF
```

References

Banta, E.R., 2000, 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): U.S. Geological Survey Open-File Report 00-466, 127 p.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, Modflow-2000, the U.S. Geological Survey modular ground-water model — User guide to modularization concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Hill, M.C., Banta, E.R., Harbaugh, A.W., and Anderman, E.R., 2000, Modflow-2000, the U.S. Geological Survey modular ground-water model — User guide to the Observation, Sensitivity, and Parameter-Estimation Processes and three post-processing programs: U.S. Geological Survey Open-File Report 00-184, 209 p.