MODFLOW-USG Version 1.4: Description of Model Input and Output

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The MODFLOW-USG distribution is available online at:

> http://water.usgs.gov/ogw/mfusg/
> or
> http://dx.doi.org/10.5066/F7R20ZFJ

See the release.txt file included with the distribution for details on changes made for this release.

Contents

Description of MODFLOW-USG Input Files

Input formats and structures for the MODFLOW-USG packages follow those of MODFLOW-2005. The main difference when using an unstructured grid is that instead of using layer, row and column numbers to identify a cell, the cell numbers are identified directly. The option is also available within the flow packages, to allow for structured input, as used in MODFLOW-2005; therefore, any MODFLOW-2005 input file may be used with MODFLOW-USG after accommodation of solver input. For an unstructured grid, discretization input is required as per the CVFD scheme to identify flow connections, cell lengths and cell areas. The unstructured grid input are highlighted by use of a blue font to delineate the information that is needed in addition to the standard MODFLOW-2005 input.

List data and parameters may be used with MODFLOW-USG in accordance with MODFLOW-2005 conventions; however, when using the unstructured data option, the cell number is entered instead of layer, row and column numbers. This is also the case for all boundary condition data in which cell lists are provided. Specifically, any input of [layer, row, column] is replaced by input for [nodenumber]. Array data is also read using MODFLOW-2005 conventions. For example, the array readers U1DREL and U2DREL are commonly used by MODFLOW-USG to read the array data from the input files. Instructions for using the array reading utilities are included in this document.

MODFLOW-USG input uses the standard package formats provided with MODFLOW-2005, with addition of options, flags, or data to address the unstructured-grid capability. The input instructions provided here only include the packages and processes that have been included with this version of MODFLOW-USG.

Note that the center of a cell is termed the node in this document and hence terms like "number of cells", or "number of nodes" may be used interchangeably.

Basic (BAS) Package Input Instructions

The Basic Package reads several files: Name File, Discretization File, Basic Package file, Multiplier Array file, Zone Array file, Output Control Option file, the Time-Variant Specified-Head Option file, and the Parameter Value File. The Name File, Discretization File, and Basic Package File are required for all simulations. The other files are optional. The Name File, Basic Package file and Discretization File, are modified from MODFLOW-2005 for use with unstructured grid input.

Name File

The Name File contains the names of most of the input and output files used in a model simulation and controls whether or not parts of the model program are active. ("OPEN/CLOSE" files, described in the Input Instructions for Array Reading Utility Subroutines section, are not included in the Name File.) The Name File is read on unit 99. The Name File is constructed as follows.

FOR EACH SIMULATION

1. Ftype Nunit Fname [Fstatus]

The Name File contains one of the above lines (item 1) for each file. All variables are free format. The length of each line must be 299 characters or less. The lines can be in any order except for the line where Ftype (file type) is "LIST" as described below.

Comment lines are indicated by the # character in column one and can be located anywhere in the file. Any text characters can follow the # character. Comment lines have no effect on the simulation; their purpose is to allow users to provide documentation about a particular simulation. All comment lines are written in the listing file.

Explanation of Variables in the Name File:

Ftype—is the file type, which must be one of the following character values. Ftype may be entered in any combination of uppercase and lowercase. (For users of MODFLOW-2000, the GLOBAL file type is no longer supported in MODFLOW-2005 or MODFLOW-USG.) Also note that the HUF Package is not currently supported by MODFLOW-USG and that the UPW Package capability is included through a flag in the BCF6 or LPF packages. Further, the traditional MODFLOW solver packages are not supported because they only handle structured grids. Instead, the SMS Package presents several linearization and sparse matrix solver options for solution to the fully coupled groundwater and CLN flow equations.
LIST for the Listing File—This type must be present and must be the first file in the Name File.
DIS for the Discretization File for a structured grid
DISU for the Discretization File for an unstructured grid
BAS6 for the Basic Package
MULT for the multiplier array file
ZONE for the zone array file
OC for the Output Control Option
CHD for the Time-Variant Specified-Head Option
HFB for the Horizontal Flow Barrier Package
PVAL for the Parameter Value File
BCF6 for the Block-Centered Flow Package
LPF for the Layer Property Flow package
RCH for the Recharge Package

RIV for the River Package
WEL for the Well Package
DRN for the Drain Package
GHB for the General-Head Boundary Package
EVT for the Evapotranspiration Package
FHB for the transient Flow and Head Boundary Package
STR for the Streamflow Package
GAGE for the Gage Package
SFR2 for the Streamflow Routing Package
LAK for the Lake Package
SUB for the Subsidence Package
ETS for the Segmented Evapotranspiration Package
DRT for the Drain with Return Flow Package
SMS for the Sparse Matrix Solver Packages – Currently available SMS packages include:
> *XMD* for the χMD Solution Package of Ibaraki (2005)
> *PCGU* for the unstructured pre-conditioned conjugate gradient package of White and Hughes (2011)
CLN for the Connected Linear Network Process
GNC for the Ghost Node Correction Package

Note that the DIS and DISU files cannot be used together in the same simulation, similarly with the BCF6 and LPF files.

DATA(BINARY) for binary (unformatted) files, such as those used to save cell-by-cell budget data and binary (unformatted) head and drawdown data. Files of this type are rewound at the start of each parameter estimation iteration.

DATA for formatted (text) files, such as those used to save formatted head and drawdown and for input of data from files that are separate from the primary package input files. Files of this type are rewound at the start of each parameter-estimation iteration.

Nunit—is the Fortran unit number to be used when reading from or writing to the file. Any legal unit number on the computer being used can be specified except unit 99. Unit 99 is used for the Name File and for reading multi-valued variables using the OPEN/CLOSE option of the utility subroutines (see Input Instructions for Array Reading Utility Subroutines section). The unit number for each file must be unique.

Fname—is the name of the file, which is a character value. Pathnames may be specified as part of Fname.

Fstatus—is the optional file status, which applies only to file types Data and Data(Binary). Two values are allowed: OLD and REPLACE. "Old" indicates that the file should already exist. "Replace" indicates that if the file already exists, then it should be deleted before opening a new file. The default is to open the existing file if the file exists or create a new file if the file does not exist.

Basic (BAS6) Package File

The Basic (BAS6) Package file is specified with "BAS6" as the file type. Note that if the discretization file type is DISU then the simulation is for an *UNSTRUCTURED* grid.

FOR EACH SIMULATION
0. [#Text]
Item 0 is optional—"#" must be in column 1. Item 0 can be repeated multiple times.

1. Options (199 text characters)
If there are no options to specify, then a blank line must be included for Item 1.
Item 2 is read for layer 1 first; then for layer 2 and so forth. Note that there may be a different number of nodes specified for each layer (NDSLAY) for an unstructured grid.

If *UNSTRUCTURED* option is used then read item 2a.
2a. IBOUND(NDSLAY) — U1DINT
If not a cross section, a layer variable is read for each layer in the grid.
If a cross section, NLAY rows of NDSLAY values are read. (NLAY being the number of layers and NDSLAY being the number of cells within each layer)

Otherwise, if *UNSTRUCTURED* option is not used then read item 2b for structured input
2b. IBOUND(NCOL,NROW) or (NCOL,NLAY) -- U2DINT
If not a cross section, NROW rows of NCOL values are read.
If a cross section, NLAY rows of NCOL values are read.

3. HNOFLO (10-space field unless Item 1 contains 'FREE'.)

Item 4 is read for layer 1 first, then for layer 2, and so forth. Note that there may be different number of nodes per layer (NDSLAY) for an unstructured grid.
If *UNSTRUCTURED* option is used then read item 4a.
4a. STRT(NDSLAY) — U1DREL
If not a cross section, the starting-head is read for each layer in the grid where NDSLAY is the number of nodes in the layer.

Otherwise, if *UNSTRUCTURED* option is not used then read item 4b for structured input
4b. STRT(NCOL,NROW) or (NCOL,NLAY) -- U2DREL
If not a cross section, the starting head is read for each layer in the grid.
If a cross section, NLAY rows of NCOL values are read.

Explanation of Variables Read from the BAS Package File:

Text—is a character variable that starts in column 2. The first two comment lines will become variable HEADNG, which is used as a printout title throughout the program. (If there are no comment lines, then HEADNG will be blank.) HEADNG is limited to 80 columns, but subsequent Text lines can be up to 199 columns. Any characters can be included in Text. The "#" character must be in column 1. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

Options—is a character variable that is scanned for words (separated by one or more spaces) that specify program options. Six options are currently recognized. Unrecognized words are ignored, and a word may be specified in either uppercase or lowercase. A blank line is acceptable and indicates no options.

PRINTFV indicates that the finite-volume connectivity information for a regular grid is printed in the output file after being internally generated by the code. This option also prints the IA and JA arrays for structured or unstructured grids after being modified by the code to include CLN and GNC Packages.

XSECTION indicates that the model is a 1-row cross section for which STRT and IBOUND should each be read as single two-dimensional variables with dimensions of NCOL and NLAY for a structured grid. For an unstructured grid, NLAY rows of NDSLAY values are read. Likewise, head and drawdown should be printed and saved in disk files as single two-dimensional variables.

CHTOCH indicates that flow between adjacent constant-head cells should be calculated.

PRINTTIME indicates that a printout of the simulation time is required at the end of the simulation

FREE indicates that free format is used for input variables throughout the Basic Package and other packages as indicated in their input instructions. Be sure that all variables read using free format have a non-blank value and that a comma or at least one blank separates all adjacent values.

CONVERGE indicates that convergence is forced and the model will continue running even if the model fails to converge any time step. This option is an addition to MODFLOW-2005 capabilities and is useful to prevent termination of parameter estimation simulations if some of the forward runs do not converge.

IBOUND—is the boundary variable. One value is read for every model cell. Usually, these values are read one layer at a time; however, when the XSECTION option is specified, a single two-dimensional variable for the cross section is read. Note that although IBOUND may be read as one or more two-dimensional variables, IBOUND is stored internally only as a one-dimensional variable for all nodes in the domain.
If IBOUND(J,I,K) < 0, cell J,I,K has a constant head.
If IBOUND(J,I,K) = 0, cell J,I,K is no flow.
If IBOUND(J,I,K) > 0, cell J,I,K is variable head.

HNOFLO—is the value of head to be assigned to all no-flow cells (IBOUND = 0). Because head at no-flow cells is unused in model calculations, this does not affect model results but serves to identify no-flow cells when head is printed. This value is used also as drawdown at no-flow cells if the drawdown option is used. Even if the user does not anticipate having no-flow cells, a value for HNOFLO must be entered.

STRT—is initial (starting) head—that is, head at the beginning of the simulation. STRT must be specified for all simulations, including steady-state simulations. One value is read for every model cell. Usually, these values are read a layer at a time. When the XSECTION option is specified, however, a single two-dimensional variable for the cross section is read. If the *UNSTRUCTURED* option is selected then the number of nodes within a layer may not be the same for all layers and thus the STRT array may be of different sizes for the different layers. For simulations in which the first stress period is steady state, the values used for STRT generally do not affect the simulation [exceptions may occur if cells go dry and (or) rewet]. The execution time, however, will be less if STRT includes hydraulic heads that are close to the steady-state solution.

Multiplier Array (MULT) File

Input to define multiplier arrays is read from the file that is specified with "MULT" as the file type. Multiplier arrays can be used to calculate layer variables from parameter values.

FOR EACH SIMULATION

```
0. [#Text]
```
Item 0 is optional—"#" must be in column 1. Item 0 can be repeated multiple times.

```
1. NML
```

```
2. MLTNAM [FUNCTION]
```

If Item 2 does not contain the optional **FUNCTION** keyword, read Item 3 (3a or 3b):
If *UNSTRUCTURED* option is used then read item 3a.
```
3a. RMLT(NDSLAY) — U1DREL
```

Otherwise, if *UNSTRUCTURED* option is not used then read item 3b for structured input
3b. [RMLT(NCOL,NROW)] - U2DREL

Otherwise, if Item 2 contains the optional **FUNCTION** keyword, read Item 4:
4. [MLTNAM1 [op1 MLTNAM2] [op2 MLTNAM3] [op3 MLTNAM4] ...]

Repeat items 2 through 4 for each of the NML multiplier arrays.

Explanation of Variables Read from the Multiplier File:

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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

NML—is the number of multiplier arrays to be defined.

MLTNAM—is the name of a multiplier array. 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 are equivalent. The name "NONE" is a reserved word and should not be used for a multiplier array.

FUNCTION —is an optional keyword, which indicates that the multiplier array will be constructed from other multiplier arrays that have already been defined. Construction is by arithmetic combinations of the multipliers; see the explanation below for variable op1, op2, op3 ....

RMLT—is a two-dimensional (one layer) multiplier array.

MLTNAM1, MLTNAM2, MLTNAM3, ...—are the names of multiplier arrays that have already been defined.

op1, op2, op3, ...—are arithmetic operators used to define a multiplier array based on other multiplier arrays. Each operator can be either "+", "-", "*", or "/". Operations are applied from left to right to each array element. The operators must be separated from the multiplier array names by at least one space.

The following example input illustrates the use of the FUNCTION keyword to construct a multiplier array from other multiplier arrays. In this example, three multiplier arrays are defined, and accordingly the first line of the file contains "3". The first two arrays (named M1 and M2) are read using the U2DREL utility array reader (item 3), and the third array (named M3) is defined as the sum of M1 and M2. In this example, a model layer has 5 rows and 4 columns.

```
3
M1
INTERNAL 1.0 (4F6.0) 0
1.0  1.1  1.2  1.3
1.0  1.1  1.2  1.3
2.0  2.2  2.4  2.6
2.0  2.2  2.4  2.6
1.0  1.1  1.2  1.3
M2
INTERNAL 1.0 (4F6.0) 0
5.0  5.1  5.2  5.3
5.0  5.1  5.2  5.3
6.0  6.1  6.2  6.3
6.0  6.1  6.2  6.3
5.0  5.1  5.2  5.3
M3 FUNCTION
M1 + M2
```

The resulting values for multiplier M3 are:

```
6.0  6.2  6.4  6.6
6.0  6.2  6.4  6.6
8.0  8.3  8.6  8.9
8.0  8.3  8.6  8.9
6.0  6.2  6.4  6.6
```

Zone Array (ZONE) File

Input to define zone arrays is read from the file that is specified with "ZONE" as the file type. Zone arrays can be used to specify the cells in a layer variable that are associated with a parameter.

FOR EACH SIMULATION

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

1. NZN

2. ZONNAM

3. IZON(NCOL,NROW) - U2DINT
Items 2-3 are repeated for each of the NZN zone arrays.

Explanation of Variables Read from the Zone File:

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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

NZN—is the number of zone arrays to be defined.

ZONNAM—is the name of a zone array. 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 are equivalent. The name "ALL" is a reserved word and should not be used for a zone array.

IZON—is a two-dimensional (one layer) zone array.

Time-Variant Specified-Head (CHD) Option

Input to the Time-Variant Specified-Head (CHD) Option 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.

Once a cell is made constant head, the cell stays constant head throughout the remainder of the simulation. For example, if a cell is listed in the CHD file as constant head in stress period 1 and not listed in stress period 2, then the cell continues to be constant head in stress period 2 and throughout the remainder of the stress periods. The head is adjusted only in the stress periods in which a cell is listed. For the stress periods in which a constant-head cell is not listed, the head stays at the value that it had at the end of the previous stress period.

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]
```

If *UNSTRUCTURED* option is used then read item 4a.
```
4a. [Node Shdfact Ehdfact [xyz] ]
```

Otherwise, if *UNSTRUCTURED* option is not used then read item 4b for structured input
```
4b. [Layer Row Column Shdfact Ehdfact [xyz] ]
```

Repeat Items 3 and 4 NPCHD times. Items 3 and 4 are not read if NPCHD is negative or 0.
NLST repetitions of Item 4 are required; they are read by subroutine ULSTRD. (SFAC of the ULSTRD utility subroutine applies to Shdfact and Ehdfact).

FOR EACH STRESS PERIOD

```
5. ITMP NP
```

If *UNSTRUCTURED* option is used then read item 6a.
```
6a. Node Shdfact Ehdfact [xyz]
```

Otherwise, if *UNSTRUCTURED* option is not used then read item 6b for structured input
```
6b. Layer Row Column Shdfact Ehdfact [xyz]
```

ITMP repetitions of Item 6 are read by subroutine ULSTRD if ITMP > 0. (SFAC of the ULSTRD utility subroutine applies to Shead and Ehead.) Item 6 is not read if ITMP is negative or 0.

```
7. [Pname]
```
(Item 7 is repeated NP times. Item 7 is not read if NP is negative or 0.)

Explanation of Variables Read by the CHD Option:

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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

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.

MXACTC—is the maximum number of constant-head boundary cells in use during any stress period, including those that are defined 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 20 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 Ehead variable.
  "NOPRINT"—specifies that lists of constant-head cells will not be written to the Listing File.

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 Parameter Value File.

NLST—is the number of constant-head cells that are included in the parameter.

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.

Node—is the node 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.

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.

[xyz]—represents the values of the auxiliary variables for a constant-head boundary that have been defined in Item 2. The values of auxiliary variables must be present in each repetition of Items 4 and 6 if they are defined in Item 2. The values must be specified in the order used to define the variables 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.

Parameter Value (PVAL) File

The Parameter Value File is the file that is specified with "PVAL" as the file type. Parameter values in this file replace parameter values specified in the files where parameters are defined.

FOR EACH SIMULATION

```
0. [#Text]
```
Item 0 is optional—"#" must be in column 1. Item 0 can be repeated multiple times.

```
1. NP
```

```
2. PARNAM Parval
```
NP repetitions of Item 2 are read.

Explanation of Variables Read from the Parameter Value File:
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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

PARNAM—is the name of a parameter whose value is 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.

Parval—is the parameter value. This value overrides the parameter value specified in the file where the parameter is defined.

Structured Discretization File (DIS)

Discretization information for a structured finite-difference grid is read from the file that is specified by "DIS" as the file type.

FOR EACH SIMULATION

```
0. [#Text]
```
Item 0 is optional—"#" must be in column 1. Item 0 can be repeated multiple times.

```
1. NLAY NROW NCOL NPER ITMUNI LENUNI
```

```
2. LAYCBD(NLAY)
```

```
3. DELR(NCOL) – U1DREL
```
Figure 8-1 of the MODFLOW-2005 document illustrates the orientation of DELR and DELC.

```
4. DELC(NROW) – U1DREL
```

```
5. Top(NCOL,NROW) – U2DREL  is the top of the model domain.
```

```
6. BOTM(NCOL,NROW) – U2DREL  is the bottom of each model layer or confining bed.
```
Item 6 is repeated for each model layer and Quasi-3D confining bed in the grid. Thus, the number of BOTM variables must be NLAY plus the number of Quasi-3D confining beds. The BOTM variables are read in sequence going down from the top of the system. For example, in a 3-layer model with a Quasi-3D confining bed below layer 2, there would be 4 BOTM arrays. The arrays would be the bottom of layer 1, the bottom of layer 2, the bottom of the Quasi-3D confining bed below layer 2, and the bottom of layer 3.

FOR EACH STRESS PERIOD

```
16. PERLEN NSTP TSMULT Ss/Tr
```

Explanation of Variables Read from the Discretization File:

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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

NLAY—is the number of layers in the model grid of the groundwater domain.

NROW—is the number of rows in the model grid.

NCOL—is the number of columns in the model grid.

NPER—is the number of stress periods in the simulation.

ITMUNI—indicates the time unit of model data, which must be consistent for all data values that involve time. For example, if "years" is the chosen time unit, then stress-period length, time-step length, transmissivity, and so on, must all be expressed using "years" for their time units. Note that the program will still run even if

"undefined" time units are specified because the fundamental equations used in MODFLOW do not require that the time unit be identified; but the user should ensure that consistent units are used for all input data even when ITMUNI indicates an undefined time unit. When the time unit is defined, MODFLOW uses it to print a table of elapsed simulation time:

```
0 - undefined    3 - hours
1 -  seconds     4 - days
2 -  minutes     5 - years
```

LENUNI—indicates the length unit of model data, which must be consistent for all data values that involve length. For example, if "feet" is the chosen length unit, grid spacing, head, hydraulic conductivity, water volumes, and so forth, must all be expressed using "feet" for their length units. Note that the program will still run even if "undefined" length units are specified because the fundamental equations used in MODFLOW do not require that the length unit be identified; but but the user should ensure that consistent units are used for for all input data even when LENUNI indicates an undefined length unit:

```
0 - undefined
1 - feet
2 - meters
3 - centimeters
```

LAYCBD—is a flag, with one value for each model layer, that indicates whether or not a layer has a Quasi-3D confining bed below it. 0 indicates no confining bed, and not zero indicates a confining bed. LAYCBD for the bottom layer must be 0.

DELR—is the cell width along rows. Read one value for each of the NCOL columns. This is a multi-value one dimensional variable with one value for each column. (See figure 8-1 of the MODFLOW-2005 document.)

DELC—is the cell width along columns. Read one value for each of the NROW rows. This is a multi-value one dimensional variable with one value for each row. (See figure 8-1 of the MODFLOW-2005 document.)

TOP—is the top elevation of layer 1. For the common situation in which the top layer represents a water-table aquifer, setting Top equal to land-surface elevation may be reasonable.

BOTM—is the bottom elevation of a model layer or a Quasi-3d confining bed.

PERLEN—is the length of a stress period.

NSTP—is the number of time steps in a stress period.

TSMULT—is the multiplier for the length of successive time steps. The length of a time step is calculated by multiplying the length of the previous time step by TSMULT. The length of the first time step, Δt_1, is related to PERLEN, NSTP, and TSMULT by the relation

$$\Delta t_1 = PERLEN \frac{[TSMULT - 1]}{\left[TSMULT^{NSTP} - 1\right]}$$

Ss/Tr—is a character variable that indicates whether the stress period is transient or steady state. The only allowed options are "SS" and "TR", but these are case insensitive.

Unstructured Discretization File (DISU)

Discretization information for unstructured grids is read from the file that is specified by "DISU" as the file type.

FOR EACH SIMULATION

```
0. [#Text]
```
Item 0 is optional—"#" must be in column 1. Item 0 can be repeated multiple times.

```
1. NODES NLAY NJAG IVSD NPER ITMUNI LENUNI IDSYMRD

2. LAYCBD(NLAY)

3. NODELAY(NLAY) – U1DINT

4. Top(NDSLAY) – U1DREL
```
Repeat Item 4 for each layer in the model grid. Note that there may be different numbers of nodes per layer (NDSLAY) for an unstructured grid.

```
5. Bot(NDSLAY) –   U1DREL
```
Repeat Item 5 for each layer in the model grid. Note that there may be different numbers of nodes per layer (NDSLAY) for an unstructured grid.

```
6. Area(NDSLAY) –   U1DREL
```
Item 6 is read only once if IVSD = -1 to indicate that the grid is vertically stacked. Otherwise, repeat Item 6 for each layer in the model grid. Note that there may be different number of nodes per layer (NDSLAY) for an unstructured grid.

```
7. IAC(NODES) –   U1DINT

8. JA(NJAG)     – U1DINT
```

Read item 9 only if IVSD is specified as 1, indicating vertical sub-discretization
```
9. IVC(NJAG)     – U1DINT
```

Read items 10a and 10b only if IDSYMRD=1 for symmetric input of symmetric arrays
```
10a. CL1(NJAGS)     – U1DREL —

10b. CL2(NJAGS)     – U1DREL —
```

Read item 11 only if IDSYMRD=0
```
11. CL12(NJAG)     – U1DREL –

12. FAHL(NJAG/NJAGS)     – U1DREL –
```

FOR EACH STRESS PERIOD


```
13. PERLEN NSTP TSMULT Ss/Tr
```

Explanation of Variables Read from the Unstructured Discretization File:

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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

NODES—is the number of nodes in the model grid.

NLAY—is the number of layers in the model grid.

NJAG—is the total number of connections of an unstructured grid. NJAG is used to dimension the sparse matrix in a compressed row storage format. For symmetric arrays, only the upper triangle of the matrix may be entered. For that case, the symmetric portion (minus the diagonal terms) is dimensioned as NJAGS = (NJAG – Nodes)/2.

NJAGS—is the total number of non-zero entries for symmetric input of symmetric flow properties between cells. NJAGS = (NJAG – Nodes)/2.

IVSD—is the vertical sub-discretization index. For purposes of this flag, vertical sub-discretization is defined to occur when all layers are not a stacked representation of each other.

       If IVSD = 0   there is no sub-discretization of layers within the model domain. That is, grids are not nested in the vertical direction. However, one layer may have a different grid structure from the next due to different sub-gridding structures within each layer.

       If IVSD = 1   there could be sub-discretization of layers with vertically nested grids (as shown in Figure 5c in the MODFLOW-USG document) within the domain. For this case, the vertical connection index IVC is required to determine the vertical connections of every node. Otherwise, the vertical connections are internally computed and IVC is not read.

       If IVSD = -1   there is no vertical sub-discretization of layers, and further, the horizontal discretization of all layers is the same. For this case, the cell areas (AREA) are read only for one layer and are computed to be the same for all the stacked layers. A structured finite-difference grid is an example of this condition.

NPER—is the number of stress periods in the simulation.

ITMUNI—indicates the time unit of model data, which must be consistent for all data values that involve time. For example, if "years" is the chosen time unit, then stress-period length, time-step length, transmissivity, and so on, must all be expressed using "years" for their time units. Note that the program will still run even if "undefined" time units are specified because the fundamental equations used in MODFLOW do not require that the time unit be identified; but the user should ensure that consistent units are used for all input data even when ITMUNI indicates an undefined time unit. When the time unit is defined, MODFLOW uses it to print a table of elapsed simulation time:

```
0 – undefined    3 – hours
1 – seconds      4 – days
2 – minutes      5 – years
```

LENUNI—indicates the length unit of model data, which must be consistent for all data values that involve length. For example, if "feet" is the chosen length unit, grid spacing, head, hydraulic conductivity, water volumes, and so forth, must all be expressed using "feet" for their length units. Note that the program will still run even if "undefined" length units are specified because the fundamental equations used in MODFLOW do not require that the length unit be identified; but the user should ensure that consistent units are used for all input data even when LENUNI indicates an undefined length unit:

```
0 – undefined
1 – feet
```

```
          2 – meters
          3 – centimeters
```

IDSYMRD—is a flag indicating if the finite-volume connectivity information of an unstructured grid is input as a full matrix or as a symmetric matrix in the input file.

  If IDSYMRD = 0   finite-volume connectivity information is provided for the full matrix of the porous matrix grid-block connections of an unstructured grid. The code internally stores only the symmetric portion of this information. This input structure (IDSYMRD=0) is easy to organize but contains unwanted information which is parsed out when the information is stored.

  If IDSYMRD = 1   finite-volume connectivity information is provided only for the upper triangular portion of the porous matrix grid-block connections within the unstructured grid. This input structure (IDSYMRD=1) is compact but is slightly more complicated to organize. Only the non-zero upper triangular items of each row are read in sequence for all symmetric matrices.

Note that all symmetric arrays will be handled accordingly.

LAYCBD—is a flag, with one value for each model layer, that indicates whether or not a layer has a Quasi-3D confining bed below it. 0 indicates no confining bed, and not zero indicates a confining bed. LAYCBD for the bottom layer must be 0.

NODELAY—is the number of nodes in each layer.

Top—is the top elevation of the cells.

Bot—is the bottom elevation of the cells.

Area—is the horizontal area of the cells.

IAC—is a matrix indicating the number of connections plus 1 for each node. Note that the IAC array is only supplied for the GWF cells; the IAC array is internally expanded to include CLN or GNC nodes if they are present in a simulation.

JA—is a list of cell number (n) followed by its connecting cell numbers (m) for each of the m cells connected to cell n. This list is sequentially provided for the first to the last GWF cell. Note that the cell and its connections are only supplied for the GWF cells and their connections to the other GWF cells. This connectivity is internally expanded if CLN or GNC nodes are present in a simulation. Also note that the JA list input may be chopped up to have every node number and its connectivity list on a separate line for ease in readability of the file. To further ease readability of the file, the node number of the cell whose connectivity is subsequently listed, may be expressed as a negative number the sign of which is subsequently corrected by the code.

IVC—is an index array indicating the direction between a node n and all its m connections.

  IVC = 0 if the connection between n and m is horizontal. Also, this is a simple connection whereby the shared face is shared entirely by both cells n and m.

  IVC = 1 if the connecting node m is vertically oriented to node n.

Note that if the CLN Process is active, the connection between two CLN cells has IVC = 2 and the connection between a CLN cell and a GWF cell has IVC = 3.

  IVC = 2 if the connection between n and m is horizontal, and the connection is either staggered or nested. Thus, the shared face is not entirely shared by cells n and m. Note that if the CLN Process is active, the

connection between two CLN cells has IVC = 3 and the connection between a CLN cell and a GWF cell has IVC = 4.

CL1— is the perpendicular length between the center of a node (node 1) and the interface between the node and its adjoining node (node 2).

CL2— is the perpendicular length between node 2 and the interface between nodes 1 and 2, and is at the symmetric location of CL1.

CL12—is the array containing CL1 and CL2 lengths, where CL1 is the perpendicular length between the center of a node (node 1) and the interface between the node and its adjoining node (node 2). CL2, which is the perpendicular length between node 2 and the interface between nodes 1 and 2 is at the symmetric location of CL1. The array CL12 reads both CL1 and CL2 in the upper and lower triangular portions of the matrix respectively. Note that the CL1 and CL2 arrays are only supplied for the GWF cell connections and are internally expanded if CLN or GNC nodes exist in a simulation.

FAHL—contains the area of the interface A_{nm} between nodes n and m.

PERLEN—is the length of a stress period.

NSTP—is the number of time steps in a stress period.

TSMULT—is the multiplier for the length of successive time steps. The length of a time step is calculated by multiplying the length of the previous time step by TSMULT. The length of the first time step, Δt_1, is related to PERLEN, NSTP, and TSMULT by the relation

$$\Delta t_1 = PERLEN \frac{[TSMULT - 1]}{\left[TSMULT^{NSTP} - 1\right]}$$

Ss/Tr—is a character variable that indicates whether the stress period is transient or steady state. The only allowed options are "SS" and "TR", but these are case insensitive.

Output Control (OC) Option

Input to the Output Control Option of the Ground-Water and CLN Flow Processes is read from the file that is specified as type "OC" in the Name File. If no "OC" file is specified, default output control is used. Under the default, head and overall budget are written to the Listing File at the end of every stress period. If the CLN domain is active, the head and budget are also written to the Listing file when the groundwater head and budget output is requested. Binary output for the GWF and CLN flow Processes, if active, may be to the same head or drawdown file as specified here. Alternatively, the CLN flow Process produces its own output files as discussed in the CLN input file documentation. Be it in the same or separate files, the CLN output is produced whenever the GWF output is produced, as prescribed here. The default printout format for head and drawdown is 10G11.4. Output Control data may be specified as words or numeric codes. One of these methods must be used throughout any simulation.

Output Control Using Words

Recognized words are shown in bold italics; these words must be entered exactly as shown except that they may be entered in either uppercase or lowercase. Optional parts of lines are shown in brackets. One or more spaces must separate each word or variable, and the total line length must not exceed 199 characters.

FOR EACH SIMULATION

0. [#Text]
> Item 0 is optional—"#" must be in column 1. Item 0 can be repeated multiple times.

1. Any combination of the following lines:
> ***HEAD PRINT FORMAT*** IHEDFM
>> Specifies the format for writing head to the Listing File.
>
> ***HEAD SAVE FORMAT*** CHEDFM [***LABEL***]
>> Specifies the format for writing head to a file other than the Listing File. Omit this line to obtain a binary (unformatted) file. Binary files usually are smaller than text files, but they are not generally transportable among different computer operating systems or different Fortran compilers.
>
> ***HEAD SAVE UNIT*** IHEDUN
>> Specifies the file unit for writing head to a file other than the Listing File.
>
>
> ***DRAWDOWN PRINT FORMAT*** IDDNFM
>> Specifies the format for writing drawdown to the Listing File.
>
> ***DRAWDOWN SAVE FORMAT*** CDDNFM [***LABEL***]
>> Specifies the format for writing drawdown to a file other than the Listing File. Omit this line to obtain an unformatted (binary) file. Binary files usually are smaller than text files, but they are not generally transportable among different computer operating systems or different Fortran compilers.
>
> ***DRAWDOWN SAVE UNIT*** IDDNUN
>> Specifies the file unit for writing drawdown to a file other than the Listing File.

IBOUND SAVE FORMAT CBOUFM [***LABEL***]
>> Specifies the format for writing IBOUND to a file.

IBOUND SAVE UNIT IBOUUN
>> Specifies the file unit for writing IBOUND to a file.

COMPACT BUDGET [***AUX*** or ***AUXILIARY***]
>> ***COMPACT BUDGET*** indicates that the cell-by-cell budget file(s) will be written in a more compact form than is used in the 1988 version of MODFLOW (referred to as MODFLOW-88)(McDonald and Harbaugh, 1988); however, programs that read these data in the form written by MODFLOW-88 will be unable to read the new compact file. If this option is not used, MODFLOW-2005 will write the files using the MODFLOW-88 form. The optional word ***AUX*** (or ***AUXILIARY***) indicates that auxiliary data that are defined in packages (see input data for the RIV, WEL, DRN, and GHB Packages) should be saved in the budget file along with budget data.

> FOR EACH TIME STEP FOR WHICH OUTPUT IS DESIRED

2. ***PERIOD*** IPEROC ***STEP*** ITSOC [***DDREFERENCE***]

3. Any combination of the following lines:
>> ***PRINT HEAD*** [list layers if all layers not desired]
>>> Head is written to the Listing File.

>> ***PRINT DRAWDOWN*** [list layers if all layers not desired]
>>> Drawdown is written to the Listing File.

>> ***PRINT BUDGET***
>>> Overall volumetric budget is written to the Listing File.

>> ***SAVE HEAD*** [list layers if all layers not desired]
>>> Head is written to a file other than the Listing File.

>> ***SAVE DRAWDOWN*** [list layers if all layers not desired]
>>> Drawdown is written to a file other than the Listing File.

>> ***SAVE IBOUND*** [list layers if all layers not desired]
>>> IBOUND is written to a file other than the Listing File. This option is provided to allow changes in IBOUND to be recorded in simulations where IBOUND changes during a simulation.

>> ***SAVE BUDGET***
>>> Cell-by-cell budget data are written to the files that are designated in the packages that compute budget terms.

Item 2 and one or more Item-3 lines are specified for each time for which output is desired. These lines must be in the order of increasing simulation time.

Explanation of Variables Read by Output Control Using Words:

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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

IHEDFM—is a code for the format in which heads will be printed. (Positive values indicate wrap format; negative values indicate strip format.)

```
0  – 10G11.4          11 – 20F5.4
1  – 11G10.3          12 – 10G11.4
2  – 9G13.6           13 – 10F6.0
3  – 15F7.1           14 – 10F6.1
4  – 15F7.2           15 – 10F6.2
5  – 15F7.3           16 – 10F6.3
6  – 15F7.4           17 – 10F6.4
7  – 20F5.0           18 – 10F6.5
8  – 20F5.1           19 – 5G12.5
9  – 20F5.2           20 – 6G11.4
10 – 20F5.3           21 – 7G9.2
```

CHEDFM—is a character value that specifies the format for saving heads, and can only be specified if the word method of output control is used. The format must contain 20 characters or less and must be a valid Fortran format that is enclosed in parentheses. The format must be enclosed in apostrophes if it contains one or more blanks or commas. The optional word **LABEL** after the format is used to indicate that each layer of output should be preceded with a line that defines the output (simulation time, the layer being output, and so forth). If there is no line specifying CHEDFM, then heads are written to a binary (unformatted) file. Binary files are usually more compact than text files, but they are not generally transportable among different computer operating systems or different Fortran compilers.

IHEDUN—is the unit number on which heads will be saved.

IDDNFM—is a code for the format in which drawdowns will be printed. The codes are the same as for IHEDFM.

CDDNFM—is a character value that specifies the format for saving drawdown, and can only be specified if the word method of output control is used. The format must contain 20 characters or less and must be a valid Fortran format that is enclosed in parentheses. The format must be enclosed in apostrophes if it contains one or more blanks or commas. The optional word **LABEL** after the format is used to indicate that each layer of output should be preceded with a line that defines the output (simulation time, the layer being output, and so forth). If there is no line specifying CDDNFM, then drawdown is written to a binary (unformatted) file. Binary files are usually more compact than text files, but they are not generally transportable among different computer operating systems or different Fortran compilers.

IDDNUN—is the unit number on which drawdowns will be saved.

CBOUFM—is a character value that specifies the format for saving IBOUND, and can only be specified if the word method of output control is used. The format must contain 20 characters or less and must be a valid Fortran format that is enclosed in parentheses. The format must be enclosed in apostrophes if it contains one or more blanks or commas. The optional word **LABEL** is used to indicate that each layer of output should be preceded with a line that defines the output (simulation time, the layer being output, and so forth). If there is no line specifying CBOUFM, then IBOUND is written using format (20I4). IBOUND is never written as a binary (unformatted) file.

IBOUUN—is the unit number on which IBOUND will be saved.

IPEROC—is the stress period number at which output is desired.

ITSOC—is the time step number (within a stress period) at which output is desired.

DDREFERENCE—keyword indicating that the heads at the associated stress period and time step are to be used as the reference heads for calculating drawdown for all subsequent time steps up to the next occurrence of DDREFERENCE. Prior to the first occurrence (if any) of DDREFERENCE the initial heads (STRT) will be used as the reference heads for calculating drawdown.

Example Output Control Input Using Words:

```
HEAD PRINT FORMAT 15
HEAD SAVE FORMAT (20F10.3) LABEL
HEAD SAVE UNIT 30
COMPACT BUDGET
DRAWDOWN PRINT FORMAT 14

PERIOD 1 STEP 1
     PRINT HEAD 2 6
     PRINT DRAWDOWN
     PRINT BUDGET
     SAVE BUDGET
     SAVE HEAD

PERIOD 1 STEP 7
     SAVE HEAD 1 3 5
     PRINT DRAWDOWN
     SAVE BUDGET

PERIOD 2 STEP 5
     PRINT HEAD
     PRINT BUDGET
     SAVE BUDGET
     SAVE HEAD
```

Note that the first line cannot be blank, but after the first line blank lines are ignored when the word method is used to specify Output Control data. Indented lines are allowed because of the use of free format input.

Output Control Using Numeric Codes

All variables are free format if the word FREE is specified in Item 1 of the Basic Package input file; otherwise, the variables all 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. IHEDFM IDDNFM IHEDUN IDDNUN

         FOR EACH TIME STEP

```
2. INCODE IHDDFL IBUDFL ICBCFL
```

```
3. Hdpr Ddpr Hdsv Ddsv
```
(Item 3 is read 0, 1, or NLAY times, depending on the value of INCODE.)

Explanation of Variables Read by Output Control Using Numeric Codes:

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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

IHEDFM—is a code for the format in which heads will be printed. See the description above in the explanation of variables read by output control using words.

IDDNFM—is a code for the format in which drawdowns will be printed. The codes are the same as for IHEDFM.

IHEDUN—is the unit number on which heads will be saved.

IDDNUN—is the unit number on which drawdowns will be saved.

INCODE—is the code for reading Item 3.
  If INCODE < 0, Item 3 flags are used from the last time step. Item 3 is not read.
  If INCODE = 0, all layers are treated the same way. Item 3 will consist of one line.
  If INCODE > 0, Item 3 will consist of one line for each layer.

IHDDFL—is a head and drawdown output flag. This flag allows Item 3 flags to be specified in an early time step and then used or not used in subsequent time steps. Thus, using IHDDFL to avoid resetting Item 3 flags every time step may be possible.
  If IHDDFL = 0, no heads or drawdowns will be printed or saved regardless of which Item 3 flags are
  specified.
  If IHDDFL $\neq$ 0, heads and drawdowns will be printed or saved according to the Item 3 flags.

IBUDFL—is a budget print flag.
  If IBUDFL = 0, overall volumetric budget will not be printed.
  If IBUDFL $\neq$ 0, overall volumetric budget will be printed.

ICBCFL—is a flag for writing cell-by-cell flow data.
  If ICBCFL = 0, cell-by-cell flow terms are not written to any file.
  If ICBCFL $\neq$ 0, cell-by-cell flow terms are written to the LIST file or a budget file depending on flags
  set in the component of flow packages, that is, IWELCB, IRCHCB, and so forth.

Hdpr—is the output flag for head printout.
  If Hdpr = 0, head is not printed for the corresponding layer.
  If Hdpr $\neq$ 0, head is printed for the corresponding layer.

Ddpr—is the output flag for drawdown printout.
  If Ddpr = 0, drawdown is not printed for the corresponding layer.
  If Ddpr $\neq$ 0, drawdown is printed for the corresponding layer.

Hdsv—is the output flag for head save.

        If Hdsv = 0, head is not saved for the corresponding layer.

        If Hdsv $\neq$ 0, head is saved for the corresponding layer.

Ddsv—is the output flag for drawdown save.

        If Ddsv = 0, drawdown is not saved for the corresponding layer.

        If Ddsv $\neq$ 0, drawdown is saved for the corresponding layer.

Block-Centered Flow (BCF6) Package

Input for the Block-Centered Flow (BCF6) Package is read from the file that is type "BCF6" in the Name File. The BCF Package is an alternative to the LPF Package. Both packages should not be used simultaneously.

FOR EACH SIMULATION

If *UNSTRUCTURED* option is used then read item 1a
`1a. IBCFCB HDRY IWDFLG WETFCT IWETIT IHDWET IKVFLAG IKCFLAG`
These EIGHT variables are free format if the option "FREE" is specified in the Basic Package input file; otherwise, the variables all have 10-character fields.

Otherwise, if *UNSTRUCTURED* option is not used then read item 1b for structured input
`1b. IBCFCB HDRY IWDFLG WETFCT IWETIT IHDWET IKVFLAG`
These seven variables are free format if the option "FREE" is specified in the Basic Package input file; otherwise, the variables all have 10-character fields.

`2. Ltype(NLAY)`
Read one value for each layer. These values are free format if the word FREE is specified in Item 1 of the Basic Package input file; otherwise, the values are read using fixed format fields that are each 2 characters wide with 40 values per line. Use only as many lines as required for the number of model layers.

Read item 3 for structured grids. For unstructured grids, read item 3 only if IKCFLAG = 0 for nodal input of hydraulic conductivities.
`3. TRPY(NLAY) -- U1DREL`

If *UNSTRUCTURED* option is used then read item 4 if any layer is anisotropic (i.e., if any of TRPY is not equal to one.
`4. [ANGLEX(NJAG)] — U1DREL.`

If *UNSTRUCTURED* option is used then read items 5 through 11. A subset of the following one-dimensional variables is used to describe each node. The variables needed for each node depend on the layer-type code of the layer in which the node resides (LAYCON, which is defined as part of the Item-2 Ltype), whether the simulation has any transient stress periods (at least one stress period defined in the Discretization File specifies Ss/Tr as "TR"), and if the wetting capability is active (IWDFLG not 0). Unneeded variables must be omitted. In no situation will all variables be required.

The required variables for Items 5-10 for layer 1 are read first; then the variables for layer 2 and so forth. Also note that there may be different number of nodes per layer (NDSLAY) for an unstructured grid.

`5. [Sf1(NDSLAY)] — U1DREL` If there is at least one transient stress period.

If *IKCFLAG=0* for nodal input of conductivities, then read items 6 through 8

If LAYCON is 0 or 2 (see Ltype), then read transmissivity of the node into item 6a.
`6a. [Tran(NDSLAY)] — U1DREL.`

Otherwise, if LAYCON is 1 or 3 or 4 (see Ltype), read hydraulic conductivity of the node into item 6b.
`6b. [HY(NDSLAY)] — U1DREL.`

If IKVFLAG=0, NLAY > 1, and this is NOT the bottom layer then read item 7 for *Vcont*

7. `[Vcont(NDSLAY)]` — U1DREL. Note that *Vcont* read here is the interblock leakance between the node and a connected node below it. If there is no connecting node below, the *Vcont* value is ignored.

If IKVFLAG=1 and NLAY > 1, then read item 8 for *KV*
8. `[Kv(NDSLAY)]` — U1DREL.

Items 6 through 8 are read only for nodal input of conductivities (*IKCFLAG=0*).

9. `[Sf2(NDSLAY)]` — U1DREL If there is at least one transient stress period and LAYCON (see Ltype) of the layer is 2 or 3 or 4.

10. `[WETDRY(NDSLAY)]` — U1DREL If IWDFLG is not 0 and LAYCON of any layer is 1 or 3 (see Ltype). Items 5 through 10 are read for unstructured input for each layer of the grid.

If IKCFLAG is 1 or -1, indicating input of hydraulic conductivity (or transmissivity if confined) or inter-block conductance along connections, then read item 11 for all connections over all layers. Otherwise, Item 11 is not read.
11. `[Ksat(NJA)]` — U1DREL

Otherwise, if *UNSTRUCTURED* option is not used then read items 12 through 18 for structured input

A subset of the following two-dimensional variables is used to describe each layer. The variables needed for each layer depend on the layer-type code (LAYCON, which is defined as part of the Item-2 Ltype), whether the simulation has any transient stress periods (at least one stress period defined in the Discretization File specifies Ss/Tr as "TR"), and if the wetting capability is active (IWDFLG not 0). Unneeded variables must be omitted. In no situation will all variables be required. The required variables (Items 12-18) for layer 1 are read first; then the variables for layer 2 and so forth.

12. `[Sf1(NCOL,NROW)]` -- U2DREL If there is at least one transient stress period.

If LAYCON is 0 or 2 (see Ltype), then read item 13.
13. `[Tran(NCOL,NROW)]` -- U2DREL.

Otherwise, if LAYCON is 1 or 3 or 4 (see Ltype), read item 14.
14. `[HY(NCOL,NROW)]` -- U2DREL

If IKVFLAG is 0, then read item 15
15. `[Vcont(NCOL,NROW)]` -- U2DREL If not the bottom layer. Item 15 is omitted for the bottom-most layer or if there

Otherwise, if IKVFLAG is 1, then read item 16
16. `[Kv(NCOL,NROW)]` -- U2DREL

17. `[Sf2(NCOL,NROW)]` -- U2DREL If there is at least one transient stress period and LAYCON (see Ltype) is 2 or 3 or 4.

18. `[WETDRY(NCOL,NROW)]` -- U2DREL If IWDFLG is not 0 and LAYCON is 1 or 3 (see Ltype).
Items 12 through 18 are read for structured grid input only

Explanation of Variables Read by the BCF Package:

IBCFCB—is a flag and a unit number.

> If IBCFCB > 0, cell-by-cell flow terms will be written to this unit number when "SAVE BUDGET" or a nonzero value for ICBCFL is specified in Output Control. The terms that are saved are storage, constant-head flow, and flow between adjacent cells.

> If IBCFCB = 0, cell-by-cell flow terms will not be written.

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

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

IWDFLG—is a flag that determines if the wetting capability is active.

> If IWDFLG = 0, the wetting capability is inactive.

> If IWDFLG is not 0, the wetting capability is active

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

IWETIT—is the iteration interval for attempting to wet cells. Wetting is attempted every IWETIT iteration. This applies to outer iterations and not inner iterations. If IWETIT is 0, the value is changed to 1.

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

> If IHDWET = 0, equation 5-32A is used: $h = BOT + WETFCT (h_m - BOT)$ where is the head at the neighboring cell that causes cell n to convert to wet.

> If IHDWET is not 0, equation 5-32B is used: $h = BOT + WETFCT (THRESH)$

IKVFLAG—is a flag indicating if vertical hydraulic conductivity is input instead of leakance between two layers.
> If IKVFLAG = 0, the leakance between two layers is input as is standard for the BCF package.

> If IKVFLAG is not 0, the vertical hydraulic conductivity of each layer is input and leakance is computed internally by the code as is done by the LPF package.

Note that the IKVFLAG should be zero for a model containing quasi 3D layers with input of leakance. Otherwise, the LPF package may be used.

IKCFLAG—is a flag indicating if hydraulic conductivity or transmissivity information is input for each of the nodes or whether this information is directly input for the nodal connections. The easiest input format is to provide the hydraulic conductivity or transmissivity values to the cells using a zero value for IKCFLAG.

If IKCFLAG = 0,   the hydraulic conductivity or transmissivity values are input on a cell-by-cell basis with inter-block hydraulic conductivity or transmissivity value being computed as per the LAYAVG averaging scheme.

If IKCFLAG = 1,   the hydraulic conductivity or transmissivity values are read for the connection between cells *n* and *m*.

If IKCFLAG = -1,   the conductance values are read for the connection between cells *n* and *m*.

Ltype—contains a combined code for each layer that specifies both the layer type (LAYCON) and the method of computing interblock conductance. Use as many lines as needed to enter a value for each layer. Values are two-digit numbers:

The left digit defines the method of calculating interblock transmissivity, LAYAVG. The methods are described by Goode and Appel (1992).

0 or blank—harmonic mean (the method used in MODFLOW-88).
1—arithmetic mean
2—logarithmic mean
3—arithmetic mean of saturated thickness and logarithmic-mean hydraulic conductivity.

The right digit defines the layer type (LAYCON), which is the same as in MODFLOW-88:

0—confined—Transmissivity and storage coefficient of the layer are constant for the entire simulation.
1—unconfined—Transmissivity of the layer varies and is calculated from the saturated thickness and hydraulic conductivity. The storage coefficient is constant. This type code is valid only for layer 1.
2—confined/unconfined—Transmissivity of the layer is constant. The storage coefficient may alternate between confined and unconfined values. Vertical flow from above is limited if the layer desaturates.
3—confined/unconfined—Transmissivity of the layer varies and is calculated from the saturated thickness and hydraulic conductivity. The storage coefficient may alternate between confined and unconfined values. Vertical flow from above is limited if the aquifer desaturates.
4—confined/unconfined—Unconfined transmissivity and convertible storage coefficient as in LAYCON of 3 above, however, the transmissivity is computed using upstream water table depth.

TRPY—is a one-dimensional variable containing a horizontal anisotropic factor for each layer and is the ratio of transmissivity or hydraulic conductivity (whichever is being used) along a column to transmissivity or hydraulic conductivity along a row. Set to 1.0 for isotropic conditions. This is a single variable with one value per layer. Do not read a variable for each layer—that is, include only one array control line for the entire variable.

ANGLEX—is the angle (in radians) between the horizontal x-axis and the outward normal to the face between a node and its connecting nodes (see figure 8 in documentation). The angle varies between zero and 6.283185 (two pi being 360 degrees). Also, the angle is needed only for evaluating anisotropy of a horizontal connection and the value that is entered for a vertical connection is ignored.

Sf1—is the primary storage coefficient. Read only if one or more transient stress periods are specified in the Discretization File. For LAYCON equal to 1, Sf1 will always be specific yield, whereas for LAYCON equal to 2 or 3, Sf1 will always be confined storage coefficient. For LAYCON equal to 0, Sf1 would normally be confined storage coefficient; however, a LAYCON value of 0 also can be used to simulate water-table conditions where drawdowns everywhere are expected to remain a small fraction of the saturated thickness, and where there is no layer above, or flow from above is negligible. In this case, specific yield values would be entered for Sf1.

Tran—is the transmissivity along rows. Tran is multiplied by TRPY to obtain transmissivity along columns. For an unstructured grid, Tran is the transmissivity in the horizontal direction and TRPY is not input. Read only for layers where LAYCON is 0 or 2.

HY—is the hydraulic conductivity along rows. HY is multiplied by TRPY to obtain hydraulic conductivity along columns. For an unstructured grid, HY is the hydraulic conductivity in the horizontal direction and TRPY is not input. Read only for layers where LAYCON is 1 or 3 or 4.

Vcont—is the vertical hydraulic conductivity divided by the thickness from a layer to the layer below (also called leakance). The value for a cell is the hydraulic conductivity divided by thickness for the material between the node in that cell and the node in the cell below. Because there is not a layer beneath the bottom layer, Vcont cannot be specified for the bottom layer. If unstructured grids are used, Vcont is read for every node, however, the value is ignored when a node does not have corresponding node in an underlying layer.

Kv—is the vertical hydraulic conductivity of the cell and the leakance is computed for each vertical connection.

Sf2—is the secondary storage coefficient. Read only for layers where LAYCON is 2, 3, or 4 and only if there are one or more transient stress periods specified in the Discretization File. The secondary storage coefficient is always specific yield.

WETDRY—is a combination of the wetting threshold (THRESH) and a flag to indicate which neighboring cells can cause a cell to become wet. If WETDRY < 0, only the cells below a dry cell can cause the cell to become wet. If WETDRY > 0, then any of the adjacent connected cells can cause a cell to become wet. If WETDRY is 0, the cell cannot be wetted. The absolute value of WETDRY is the wetting threshold. When the sum of BOT and the absolute value of WETDRY at a dry cell is equaled or exceeded by the head at an adjacent cell, the cell is wetted. Read only if LAYCON is 1 or 3 and IWDFLG is not 0.

Ksat—is the inter-block saturated hydraulic conductivity or transmissivity (if IKCFLAG = 1) or the inter-block conductance (if IKCFLAG = - 1) of the connection between nodes n and m. This is the most general form of input of hydraulic flow properties and includes the impact of anisotropy in any direction, hydraulic flow barriers or confining layers between nodes. For IKCFLAG = 1, if LAYCON is 0 or 2 for a layer, then Ksat is the transmissivity for a horizontal direction connection and the saturated vertical hydraulic conductivity for a vertical direction connection. For IKCFLAG = 1, if LAYCON is 4 for a layer, then Ksat is the saturated hydraulic conductivity for a horizontal direction connection and the saturated vertical hydraulic conductivity for a vertical direction connection. LAYCON cannot be 1 or 3 with IKCFLAG=1 because individual cell hydraulic conductivities are required for transmissivity computations with LAYTYP=1, which are not available when IKCFLAG=1 If IKCFLAG=-1, the inter-block conductance of the connected cells is input.

Layer-Property Flow (LPF) Package

Input for the Layer-Property Flow (LPF) Package is read from the file that is type "LPF" in the Name File. Free format is used for reading all values. The LPF Package is an alternative to the BCF Package. The two packages should not be used simultaneously.

FOR EACH SIMULATION

```
0. [#Text]
```
Item 0 is optional—"#" must be in column 1. Item 0 can be repeated multiple times.

If *UNSTRUCTURED* option is used, then read item 1a
```
1a. ILPFCB HDRY NPLPF IKCFLAG [Options]
```
These variables are free format.

Otherwise, if *UNSTRUCTURED* option is not used, then read item 1b for structured input
```
1b. ILPFCB HDRY NPLPF [Options]
```
These variables are free format.

```
2. LAYTYP(NLAY)
```

```
3. LAYAVG(NLAY)
```

```
4. CHANI(NLAY)
```

```
5. LAYVKA(NLAY)
```

```
6. LAYWET(NLAY)
```

```
7. [WETFCT IWETIT IHDWET]
```
(Include item 7 only if LAYWET indicates at least one wettable layer.)

```
8. [PARNAM PARTYP Parval NCLU]
```

```
9. [Layer Mltarr Zonarr IZ]
```
Each repetition of Item 9 is called a parameter cluster. Repeat Item 9 NCLU times.
Repeat Items 8-9 for each parameter to be defined (that is, NPLPF times).

A subset of the following two-dimensional variables is used to describe each layer. All the variables that apply to layer 1 are read first, followed by layer 2, followed by layer 3, and so forth. A variable not required due to simulation options (for example, Ss and Sy for a completely steady-state simulation) must be omitted from the input file. Also note that there may be different numbers of nodes per layer (NDSLAY) for an unstructured grid.

These variables are either read by the array-reading utility subroutine, U2DREL for a structured grid or U1DREL for an unstructured grid, or they are defined through parameters. If a variable is defined through parameters, then the variable itself is not read; however, a single line containing a print code is read in place of the control line. The print code determines the format for printing the values of the variable as defined by parameters. The print codes are the same as those used in a control line. If any parameters of a given type are used, parameters must be used to define the corresponding variable for all layers in the model.

If *UNSTRUCTURED* option is used, then read item 10 if IKCFLAG=0 for nodal input of the conductivity parameters and there is anisotropy in the system (that is, any of CHANI is not equal to one).

10. `[ANGLEX(NJAG)]` – U1DREL.

If *UNSTRUCTURED* option is used then read items 11 through 18. Items 11 through 17 are read layer by layer and item 18 (if needed) is read for the entire grid after items 11 through 17 are read (where needed) for all layers in the grid.

If IKCFLAG=0 for nodal input of conductivities, then read items 11, 12 and 13 otherwise skip these data items.
11. `HK(NDSLAY)` If any HK parameters are included, read only a print code.

12. `[HANI(NDSLAY)]` Include item 12 only if CHANI is less than or equal to 0. If any HANI parameters are included, read only a print code.

13. `VKA(NDSLAY)` If any VK or VANI parameters are included, read only a print code.

Items 11, 12 and 13 are read only for nodal input of hydraulic conductivities (*IKCFLAG=0*).

14. `[Ss(NDSLAY)]` Include item 14 only if at least one stress period is transient. If there are any SS parameters, read only a print code.

15. `[Sy(NDSLAY)]` Include item 15 only if at least one stress period is transient and LAYTYP is not 0. If any SY parameters are included, read only a print code.

16. `[VKCB(NDSLAY)]` Include item 16 only if IKCFLAG=0 and LAYCBD (in the Discretization File) is not 0. If any VKCB parameters are included, read only a print code.

17. `[WETDRY(NDSLAY)]` Include item 17 only if LAYWET is not 0 and LAYTYP is not 0 or 4.

If IKCFLAG is 1 or -1, indicating input of hydraulic conductivity (or transmissivity if confined) or inter-block conductance along connections then read item 18 for all connections over all layers. Otherwise, Item 18 is not read.
18. `[Ksat(NJA)]` – U1DREL

Otherwise, if *UNSTRUCTURED* option is not used, then read items 19 through 25 for structured input. Items 19 through 25 are read layer by layer.

19. `HK(NCOL,NROW)` If any HK parameters are included, read only a print code.

20. `[HANI(NCOL,NROW)]` Include item 20 only if CHANI is less than or equal to 0. If any HANI parameters are included, read only a print code.

21. `VKA(NCOL,NROW)` If any VK or VANI parameters are included, read only a print code.

22. `[Ss(NCOL,NROW)]` Include item 22 only if at least one stress period is transient. If there are any SS parameters, read only a print code.

23. `[Sy(NCOL,NROW)]` Include item 23 only if at least one stress period is transient and LAYTYP is not 0. If any SY parameters are included, read only a print code.

24. `[VKCB(NCOL,NROW)]` Include item 24 only if LAYCBD (in the Discretization File) is not 0. If any VKCB parameters are included, read only a print code.

25. `[WETDRY(NCOL,NROW)]` Include item 25 only if LAYWET is not 0 and LAYTYP is not 0.

Explanation of Variables Read by the LPF 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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

ILPFCB—is a flag and a unit number.

> If ILPFCB > 0, cell-by-cell flow terms will be written to this unit number when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control. The terms that are saved are storage, constant-head flow, and flow between adjacent cells.

> If ILPFCB = 0, cell-by-cell flow terms will not be written.

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

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

NPLPF—is the number of LPF parameters.

IKCFLAG—is a flag indicating if hydraulic conductivity or transmissivity information is input for each of the cells or whether this information is directly input for the nodal connections.

> If IKCFLAG =0,   the hydraulic conductivity or transmissivity values are input on a cell-by-cell basis with inter-block hydraulic conductivity or transmissivity value being computed as per the LAYAVG averaging scheme.

> If IKCFLAG = 1,   the hydraulic conductivity or transmissivity values are read for the connection between cells *n* and *m*.

> If IKCFLAG = -1,   the conductance values are read for the connection between cells *n* and *m*.

OPTIONS—are optional keywords that activate options:

> STORAGECOEFFICIENT indicates that variable Ss and SS parameters are read as storage coefficient rather than specific storage.

> CONSTANTCV indicates that vertical conductance for an unconfined cell is computed from the cell thickness rather than the saturated thickness.

> THICKSTRT indicates that layers having a negative LAYTYP are confined, and their cell thickness for conductance calculations will be computed as STRT-BOT rather than TOP-BOT.

NOCVCORRECTION indicates that vertical conductance is not corrected when the vertical flow correction is applied.

NOVFC indicates that the vertical flow correction under dewatered conditions (described on p. 5-8 of USGS Techniques and Methods Report 6-A16) is turned off. Also, the vertical conductance correction described on p. 5-18 of that report is turned off.

NOPARCHECK indicates that, when parameters define an array, there is no check to see if a value is defined for all cells. The value is 0 at cells for which parameters do not define a value. If this option is not specified, the simulation aborts if a value is not defined for all cells.

LAYTYP—contains a flag for each layer that specifies the layer type.
    0 – confined
    >0 – convertible
    =4 – convertible, with transmissivity computed using upstream water-table depth
    <0 – convertible unless the THICKSTRT option is in effect. When THICKSTRT is in effect, a negative value of LAYTYP indicates that the layer is confined, and its saturated thickness will be computed as STRT-BOT.

LAYAVG—contains a flag for each layer that defines the method of calculating interblock transmissivity.
    0—harmonic mean
    1— logarithmic mean
    2— arithmetic mean of saturated thickness and logarithmic-mean hydraulic conductivity

CHANI—contains a value for each layer that is a flag or the horizontal anisotropy. If CHANI is less than or equal to 0, then variable HANI defines horizontal anisotropy. If CHANI is greater than 0, then CHANI is the horizontal anisotropy for the entire layer, and HANI is not read. If any HANI parameters are used, CHANI for all layers must be less than or equal to 0.

LAYVKA—contains a flag for each layer that indicates whether variable VKA is vertical hydraulic conductivity or the ratio of horizontal to vertical hydraulic conductivity.
    0—indicates VKA is vertical hydraulic conductivity
    not 0—indicates VKA is the ratio of horizontal to vertical hydraulic conductivity, where the horizontal hydraulic conductivity is specified as HK in item 10.

LAYWET—contains a flag for each layer that indicates whether wetting is active.
    0—indicates wetting is inactive
    not 0—indicates wetting is active

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

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

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

If IHDWET = 0, equation 5-32A in Harbaugh (2005) is used: $h = BOT + WETFCT (h_n - BOT)$.

If IHDWET is not 0, equation 5-32B in Harbaugh (2005) is used: h = BOT + WETFCT(THRESH) .

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 LPF Package, the allowed parameter types are:

HK—defines variable HK, horizontal hydraulic conductivity

HANI—defines variable HANI, horizontal anisotropy

VK—defines variable VKA for layers for which VKA represents vertical hydraulic conductivity (LAYVKA=0)

VANI—defines variable VKA for layers for which VKA represents vertical anisotropy (LAYVKA ≠ 0)

SS—defines variable Ss, the specific storage

SY—defines variable Sy, the specific yield

VKCB—defines variable VKCB, the vertical hydraulic conductivity of a Quasi-3D confining layer.

Parval—is the parameter value. This parameter value may be overridden by a value in the Parameter Value File.

NCLU—is the number of clusters required to define the parameter. Each repetition of Item 9 is a cluster (variables Layer, Mltarr, Zonarr, and IZ). Each layer that is associated with a parameter usually has only one cluster. For example, parameters which apply to cells in a single layer generally will be defined by just one cluster. However, having more than one cluster for the same layer is acceptable.

Layer—is the layer number to which a cluster definition applies.

Mltarr—is the name of the multiplier array to be used to define variable values that are associated with a parameter. The name "NONE" means that there is no multiplier array, and the variable 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 specified layer are part of 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.

ANGLEX—is the angle (in radians) between the horizontal x-axis and the outward normal to the face between a node and its connecting nodes (see figure 8 in MODFLOW-USG report). The angle varies between zero and 6.283185 (two pi being 360 degrees). Also, the angle is needed only for evaluating anisotropy of a horizontal connection and the value that is entered for a vertical connection is ignored.

HK—is the hydraulic conductivity along rows. HK is multiplied by horizontal anisotropy (see CHANI and HANI) to obtain hydraulic conductivity along columns.

HANI—is the ratio of hydraulic conductivity along columns to hydraulic conductivity along rows, where HK of item 10 specifies the hydraulic conductivity along rows. Thus, the hydraulic conductivity along columns is the product of the values in HK and HANI. Read only if CHANI $\leq$ 0.

VKA—is either vertical hydraulic conductivity or the ratio of horizontal to vertical hydraulic conductivity depending on the value of LAYVKA. If LAYVKA is 0, VKA is vertical hydraulic conductivity. If LAYVKA is not 0, VKA is the ratio of horizontal to vertical hydraulic conductivity. In this case, HK is divided by VKA to obtain vertical hydraulic conductivity, and values of VKA typically are greater than or equal to 1.0.

Ss—is specific storage unless the STORAGECOEFFICIENT option is used. When STORAGECOEFFICIENT is used, Ss is confined storage coefficient. Read only for a transient simulation (at least one transient stress period).

Sy—is specific yield. Read only for a transient simulation (at least one transient stress period) and if the layer is convertible (LAYTYP is not 0).

VKCB—is the vertical hydraulic conductivity of a quasi-three-dimensional confining bed below a layer. Read only if there is a confining bed. Because the bottom layer cannot have a confining bed, VKCB cannot be specified for the bottom layer.

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

Ksat—is the inter-block saturated hydraulic conductivity or transmissivity (if IKCFLAG = 1) or the inter-block saturated conductance (if IKCFLAG = - 1) of the connection between nodes *n* and *m*. This is the most general form of input of hydraulic flow properties and includes the impact of anisotropy in any direction, hydraulic flow barriers or confining layers between nodes. For IKCFLAG = 1, if LAYTYP is 0 for a layer, then Ksat is the transmissivity for a horizontal direction connection and the saturated vertical hydraulic conductivity for a vertical direction connection. For IKCFLAG = 1, if LAYTYP is 4 for a layer, then Ksat is the saturated hydraulic conductivity for a horizontal direction connection and the saturated vertical hydraulic conductivity for a vertical direction connection. LAYTYP cannot be 1 with IKCFLAG=1 because individual cell hydraulic conductivities are required for transmissivity computations with LAYTYP=1, which are not available when IKCFLAG=1. If IKCFLAG=-1, the inter-block conductance of the connected cells is input. Note that the variable CHANI is ignored if Ksat is read to provide the inter-block flow variable.

Horizontal Flow Barrier (HFB6) Package

Input for the Horizontal Flow Barrier (HFB6) Package is read from the file that has file type "HFB6" in the Name File. All variables are read in free format. Note that the HFB package only applies for the Groundwater Flow Process.

FOR EACH SIMULATION

```
0. [#Text]
```
Item 0 is optional—"#" must be in column 1. Item 0 can be repeated multiple times.

```
1. NPHFB MXFB NHFBNP [NOPRINT]
```
The optional keyword "NOPRINT" specified that lists of flow barriers will not be written to the Listing File.

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

If *UNSTRUCTURED* option is used then read item 3a
```
3a. [Node1 Node2 Factor ]
```
These variables are free format.

Otherwise, if *UNSTRUCTURED* option is not used then read item 3b for structured input
```
3b. [Layer IROW1 ICOL1 IROW2 ICOL2 Factor ]
```
Repeat Items 2 and 3 NPHFB times. Items 2 and 3 are not read if NPHFB is negative or zero.
NLST repetitions of Item 3 are required; they are read by subroutine ULSTRD. (SFAC of the ULSTRD utility subroutine applies to Factor).

If *UNSTRUCTURED* option is used then read item 4a
```
4a. Node1 Node2 Hydchr
```
These variables are free format.

Otherwise, if *UNSTRUCTURED* option is not used then read item 4b for structured input

```
4b. Layer IROW1 ICOL1 IROW2 ICOL2 Hydchr
```
NHFBNP repetitions of Item 4 are read. Item 4 is not read if NHFBNP is negative or zero.

```
5. NACTHFB
```

```
6. Pname
```
NACTHFB repetitions of Item 6 are read. Item 6 is not read if NACTHFB is negative or zero.

Explanation of Variables Read by the HFB 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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

NPHFB—is the number of horizontal flow barrier parameters to be defined in Items 2 and 3. Note: An HFB parameter must be defined in Items 2 and 3, and made active using Item 6, to have an effect in the simulation.

MXFB—is the maximum number of HFB barriers that will be defined using parameters.

NHFBNP—is the number of HFB barriers not defined by parameters.

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 HFB Package, the only allowed parameter type is HFB, which defines values of the hydraulic characteristic of the barrier.

Parval—is the parameter value. This parameter value may be overridden by a value in the Parameter Value File.

NLST—is the number of horizontal flow barrier cells included in the parameter.

Layer—is the number of the model layer in which the horizontal flow barrier is located.

IROW1—is the row number of the cell on one side of the horizontal flow barrier.

ICOL1—is the column number of the cell on one side of the horizontal flow barrier.

IROW2—is the row number of the cell on the other side of the horizontal flow barrier.

ICOL2—is the column number of the cell on the other side of the horizontal flow barrier.

Node1—is the node number of the cell on one side of the horizontal flow barrier. Note that the HFB is applied only between two nodes of the GWF Process domain.

Node2—is the node number of the cell on the other side of the horizontal flow barrier. Note that the HFB is applied only between two nodes of the GWF Process domain.

Factor—is the factor used to calculate hydraulic characteristic from the parameter value. The hydraulic characteristic is the product of Factor and the parameter value.

Hydchr—is the hydraulic characteristic of the horizontal flow barrier. The hydraulic characteristic is the barrier hydraulic conductivity divided by the width of the horizontal flow barrier.

NACTHFB—is the number of active HFB parameters.

Pname—is the name of a parameter to be used in the simulation. NACTHFB parameter names will be read.

Recharge (RCH) 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 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* NPRCH]
This optional item must start with the word "PARAMETER".

2a. NRCHOP IRCHCB

Item 2b is read only if *UNSTRUCTURED* option is used and NRCHOP =2
2b. MXNDRCH

3. [PARNAM PARTYP Parval NCLU [INSTANCES NUMINST]]
Repeat Item 3 combined with the indicated repetitions of Item 4 NPRCH times. Items 3 and 4 are not read if NPRCH is negative or 0. If PARNAM is to be a time-varying parameter, the keyword "INSTANCES" and a value for NUMINST must be entered.

4a. [INSTNAM]

4b. [Mltarr Zonarr IZ]
After each Item 3 for which the keyword "INSTANCES" is not entered, read Item 4b and not Item 4a.
After each Item 3 for which the keyword "INSTANCES" is entered, read Item 4a and Item 4b for each instance. NCLU repetitions of Item 4b are required. 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.

FOR EACH STRESS PERIOD

Read item 5a only if NRCHOP = 2
5a. INRECH INIRCH

Read item 5b only if NRCHOP is not 2.
5b. INRECH

If *UNSTRUCTURED* option is used, then read items 6a and 6b.
6a. [RECH(INIRCH)] -- U1DREL if NPRCH=0 and if INRECH $\geq$ 0
Note that INIRCH is equal to the number of nodes in the top layer if NRCHOP =1 or 3.

6b. [Pname [Iname] [IRCHPF]] -- if NPRCH > 0 and if INRECH > 0
Either Item 6a or Item 6b may be read, but not both. Item 6b, if read, is repeated INRECH times. Iname is read if Pname is a time-varying parameter.

Otherwise, if *UNSTRUCTURED* option is not used, then read items 7a anf 7b for structured input.
7a. [RECH(NCOL,NROW)] -- U2DREL if NPRCH=0 and if INRECH $\geq$ 0

`7b. [Pname [Iname] [IRCHPF]] -- if NPRCH > 0 and if INRECH > 0`
Either Item 7a or Item 7b may be read, but not both. Item 7b, if read, is repeated INRECH times. Iname is read if Pname is a time-varying parameter.

If *UNSTRUCTURED* option is used, then read item 8a
`8a. [IRCH(INIRCH)] -- U1DINT If NRCHOP=2 and if INIRCH` $>=0$

Otherwise, if *UNSTRUCTURED* option is not used, then read item 8b for structured input
`8b. [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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

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. Note that if the top-most layer is inactive for unstructured grids, this option assigns all recharge flux to the first active node in the layers below. Hence, if there is a vertical nesting involved, with multiple active nodes underlying an inactive node, then the recharge is not spread over all of these underlying active underlying nodes. The quantity of water, however, is conserved for the prescribed recharge rate.

IRCHCB—is a flag and a unit number.
    If IRCHCB > 0, cell-by-cell flow terms will be written to this unit number when "SAVE BUDGET" or a nonzero value for ICBCFL is specified in Output Control.
    If IRCHCB ≤ 0, cell-by-cell flow terms will not be written.

MXNDRCH—is the maximum number of nodes to which recharge is applied in a simulation. This parameter is read only when the UNSTRUCTURED option is used with NRCHOP=2 (whereby the nodes to which recharge is applied are a user input).

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 Parameter Value File.

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). Usually only one cluster is used to define a RCH non-time-varying parameter or an instance of a time-varying parameter; however, more than one cluster is acceptable.

INSTANCES—is an optional keyword that designates a parameter as time varying. The keyword is not case sensitive; that is, any combination of the same characters with different case can be used. 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 for a time-varying parameter, where each instance is a list of river reaches and associated properties. If the keyword *INSTANCES* is present, it must be followed by a value for NUMINST. If *INSTANCES* is absent, NUMINST should not be present.

INSTNAM—is the name of an instance associated with the parameter named in the corresponding Item 3. The instance name can be 1 to 10 characters and is not case sensitive. That is, any combination of the same characters with different case will be equivalent. Instance names must be unique for a parameter, but instance names may be reused for 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 $\geq$ 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. Items 6b (for unstructured grids) or 7b (for structured grids) define 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 $\geq$ 0, a layer variable of layer numbers (IRCH) is read for a structured grid. For an unstructured grid, INIRCH is further equal to the number of nodes for which recharge values are read in the simulation, with the nodes being identified in array IRCH.
> 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 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 subroutine.

IRCH—is the layer number that defines the layer in each vertical column where recharge is applied when a structured MODFLOW grid is used. For an unstructured grid, IRCH is the node number to which the recharge is applied, where the list includes INIRCH number of nodes. Read only if NRCHOP is two and if INIRCH is greater than or equal to zero.

Evapotranspiration (EVT) 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 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 NPEVT]
```
This optional item must start with the word "PARAMETER".

```
2a. NEVTOP IEVTCB
```

Item 2b is read only for an unstructured grid and NEVTOP = 2
```
2b. MXNDEVT
```

```
3. [PARNAM PARTYP Parval NCLU [INSTANCES NUMINST] ]
```
Repeat Item 3 combined with the indicated repetitions of Item 4 NPEVT times. Items 3 and 4 are not read if NPEVT is negative or 0.
If PARNAM is to be a time-varying parameter, the keyword "INSTANCES" and a value for NUMINST must be entered.

```
4a. [INSTNAM]
```

```
4b. [Mltarr Zonarr IZ]
```
After each Item 3 for which the keyword "INSTANCES" is not entered, read Item 4b and not Item 4a.
After each Item 3 for which the keyword "INSTANCES" is entered, read Item 4a and Item 4b for each instance. NCLU repetitions of Item 4b are required. Each repetition of Item 4 is called a parameter cluster. The NCLU repetitions of Item 4b follow each repetition of Item 4a when PARNAM is time varying.

FOR EACH STRESS PERIOD

Read item 5a only if NEVTOP = 2
```
5a. INSURF INEVTR INEXDP INIEVT
```

Read item 5b only if NRCHOP is not 2.
```
5b. INSURF INEVTR INEXDP
```

If *UNSTRUCTURED* option is used, then read items 6 THROUGH 11.
```
6. [SURF(INIEVT)] -- U2DREL If INSURF ≥ 0
```

```
7. [EVTR(INIEVT)] -- 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. Item 8, if read, is repeated INEVTR times. Iname is read if Pname is a time-varying parameter.

9. `[EXDP(INIEVT)]` -- U2DREL If INEXDP ≥ 0

10. `[IEVT(INIEVT)]` -- U2DINT If NEVTOP = 2 and if INIEVT ≥ 0

Note in items 6 through 10 that INIEVT is equal to the number of nodes in the top layer if NEVTOP = 1 or 3. Items 6 through 10 are read for unstructured input only.

Otherwise, if *UNSTRUCTURED* option is not used, then read items 11 through 15 for structured input

11. `[SURF(NCOL,NROW)]` -- U2DREL If INSURF ≥ 0

12. `[EVTR(NCOL,NROW)]` -- U2DREL If NPEVT = 0 and if INEVTR ≥ 0

13. `[Pname [Iname] [IEVTPF]]` -- if NPEVT > 0 and if INEVTR > 0
Either Item 13 or Item 14 may be read, but not both. Item 13, if read, is repeated INEVTR times. Iname is read if Pname is a time-varying parameter.

14. `[EXDP(NCOL,NROW)]` -- U2DREL If INEXDP ≥ 0

15. `[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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

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.
     3—ET is applied to the highest active cell in each vertical column. Note that if the top-most layer is inactive for unstructured grids, this option assigns all ET flux to the first active node in the layers below. Hence if there is a vertical nesting involved, with multiple active nodes underlying an inactive node then the ET is not spread over all of these active underlying nodes. The quantity of water however, is conserved for the prescribed ET rate if the cell can provide the ET rate without becoming dry.

IEVTCB—is a flag and a unit number.
     If IEVTCB > 0, cell-by-cell flow terms will be written to this unit number when "SAVE BUDGET" or a nonzero value for ICBCFL is specified in Output Control.
     If IEVTCB $\leq$ 0, cell-by-cell flow terms will not be written.

MXNDEVT—is the maximum number of nodes on which ET is applied in a simulation. This parameter is read only for an unstructured grid with NEVTOP=2 (whereby the nodes on which ET is applied are a user input).

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, variable EVTR.

Parval—is the parameter value. This parameter value may be overridden by a value in the Parameter Value File.

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). Usually only one cluster is used to define an EVT non-time-varying parameter or an instance of a time-varying parameter; however, more than one cluster is acceptable.

INSTANCES—is an optional keyword that designates a parameter as time varying. The keyword is not case sensitive; that is, any combination of the same characters with different case can be used. 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 for a time-varying parameter, where each instance is a list of river reaches and associated properties. If the keyword *INSTANCES* is present, it must be followed by a value for NUMINST. If *INSTANCES* is absent, NUMINST should not be present.

INSTNAM—is the name of an instance associated with the parameter named in the corresponding Item 3. The instance name can be 1 to 10 characters and is not case sensitive. That is, any combination of the same characters with different case will be equivalent. Instance names must be unique for a parameter, but instance names may be reused for 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 13? 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 $\geq$ 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 that is read only if the ET option (NEVTOP) is equal to two.
If INIEVT $\geq$ 0, An array containing the layer indicators (IEVT) will be read for a structured grid. For an unstructured grid, INIEVT is further equal to the number of nodes for which ET values are read in the simulation, with the nodes being identified in the array IEVT.

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 $\geq$ 0

EVTR—is the maximum ET flux [volumetric flow rate per unit area (LT^{-1})]. This variable is read only if INEVTR $\geq$ 0 and if NPEVT=0. Contrary to the usual convention in MODFLOW, EVTR values should be specified as positive values even though they represent an outflow from the groundwater system.

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 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 subroutine.

EXDP—is the ET extinction depth. This variable is read only if INEXDP $\geq$ 0.

IEVT—is the layer indicator variable. For each horizontal location, IEVT indicates the layer from which ET is removed when a structured MODFLOW grid is used. For an unstructured grid, IEVT is the node number to which the ET is applied, where the list includes INIEVT number of nodes. Read only if NEVTOP is two and if INIEVT is greater than or equal to zero.

Flow and Head Boundary (FHB) Package

The original FHB package of Leak and Lilly(1997) has been modified to work with unstructured grids. Input for the FHB package is in free format, which requires each of the numbered data groups to start on a new input record. More than one record can be used for any data group and numbers within data groups must be separated by at least one space or a comma. Integer data types cannot include a decimal point. Blank spaces are not treated as zeros.

FOR EACH SIMULATION

1. Data:	NBDTIM	NFLW	NHED	IFHBSS	IFHBCB	NFHBX1	NFHBX2
Type:	Integer	Integer	Integer	Integer	Integer	Integer	Integer

Omit data item 2 if NFHBX1=0. Input item 2 consists of one record for each of NFHBX1 auxiliary variables.

2. Data:	VarName	Weight
Type:	Character	Real

Omit data item 3 if NFHBX2=0. Input item 3 consists of one record for each of NFHBX2 auxiliary variables.

3. Data:	VarName	Weight
Type:	Character	Real

Data items 4a and 4b are required for all simulations. Include NBDTIM times in data item 4b.

4a. Data:	IFHBUN	CNSTM	IFHBPT
Type:	Integer	Real	Integer

4b. Data:	BDTIM(NBDTIM)
Type:	Real

Omit data items 5a and 5b or 5c if NFLW=0. Input item 5b or 5c consists of one set of numbers for each of NFLW cells. Each set of numbers includes layer, row, and column indices (for item 5b), node index (for item 5c), an integer auxiliary variable, and NBDTIM values of specified flow.

5a. Data:	IFHBUN	CNSTM	IFHBPT
Type:	Integer	Real	Integer

Omit data item 5b for unstructured grid input

5b. Data:	Layer	Row	Column	IAUX	FLWRAT(NBDTIM)
Type:	Integer	Integer	Integer	Integer	Real

Omit data item 5c for structured grid input

5c. Data:	Node	IAUX	FLWRAT(NBDTIM)
Type:	Integer	Integer	Real

Omit data items 6a and 6b if NFHBX1=0 or if NFLW=0. Include one set of data items 6a and 6b for each of NFHBX1 auxiliary variables. Input item 6b consists of one set of numbers for each of NFLW cells. Each set includes NBDTIM values of the variable.

6a. Data:	IFHBUN	CNSTM	IFHBPT
Type:	Integer	Real	Integer

6b. Data:	AuxVar(NBDTIM)
Type:	Real

Omit data items 7a and 7b or 7c if NHED=0. Input item 7b or 7c consists of one set of numbers for each of NFLW cells. Each set of numbers includes layer, row, and column indices (for item 7b), node index (for item 7c), an integer auxiliary variable, and NBDTIM values of specified head.

7a. Data:	IFHBUN	CNSTM	IFHBPT
Type:	Integer	Real	Integer

Omit data item 7b for unstructured grid input

7b. Data:	Layer	Row	Column	IAUX	SBHED(NBDTIM)
Type:	Integer	Integer	Integer	Integer	Real

Omit data item 7c for structured grid input

7c. Data:	Node	IAUX	SBHED(NBDTIM)
Type:	Integer	Integer	Real

Omit data items 8a and 8b if NFHBX2=0 or if NHED=0. Include one set of data items 8a and 8b for each of NFHBX2 auxiliary variables. Input item 8b consists of one set of numbers for each of NHED cells. Each set includes NBDTIM values of the variable.

8a. Data:	IFHBUN	CNSTM	IFHBPT
Type:	Integer	Real	Integer

8b. Data:	AuxVar(NBDTIM)
Type:	Real

Explanation of Fields Used in Input Instructions

NBDTIM—is the number of times at which flow and head will be specified for all selected cells.

> If NBDTIM = 1, specified flow and head values will remain constant for the entire simulation.
> If NBDTIM > 1, specified flow and head values will be computed for each time step using linear interpolation.

NFLW—is the number of cells at which flows will be specified.

NHED—is the number of cells at which head will be specified.

IFHBSS—is the FHB steady-state option flag. If the simulation is transient, the flag is read but not used. For steady-state simulations, the flag controls how specified-flow, specified-head, and auxiliary-variable values will be computed for each steady-state solution.

If IFHBSS = 0, values of flow, head, and auxiliary variables will be taken at the starting time of the simulation. This results in use of the first value in arrays FLWRAT, SBHED, and AuxVar for each respective boundary cell.

If IFHBCB 0, values of flow, head, and auxiliary variables will be interpolated in the same way that values are computed for transient simulations.

IFHBCB—is a flag and unit number.

If IFHBCB > 0, it is the unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL is set (see McDonald and Harbaugh, 1988, chap. 4, p. 14–15).

If IFHBCB 0, cell-by-cell flow terms will not be recorded.

NFHBX1—is the number of auxiliary variables whose values will be computed for each time step for each specified-flow cell.

NFHBX2—is the number of auxiliary variables whose values will be computed for each time step for each specified-head cell.

VarName—is the name of an auxiliary variable. Name can include up to 16 characters with no embedded blank characters.

Weight—is the time-weighting factor for an auxiliary variable specifying the fraction of each time step at which the value of the variable will be interpolated. Value must be in the range from 0.0 to 1.0.

IFHBUN—is the unit number on which data lists will be read. The same or different unit numbers can be used to read lists in data items 4b, 5b, 5c, 6b, 7b, 7c, and 8b.

CNSTM—is a constant multiplier for data list BDTIM (data item 4b), FLWRAT (part of data item 5b or 5c), SBHED (part of data item 7b or 7c), and auxiliary variables in data items 6b and 8b.

IFHBPT—is a flag for printing values of data lists in items 4b, 5b, 5c, 6b, 7b, 7c, and 8b.

If IFHBPT > 0 data list read at the beginning of the simulation will be printed.

If IFHBCB < 0 data list read at the beginning of the simulation will not be printed.

BDTIM—is simulation time at which values of specified flow and (or) values of specified head will be read. NBDTIM values are required.

Layer—is the layer index of specified-flow cell (data item 5b) or specified-head cell (data item 7b).

Row—is the row index of specified-flow cell (data item 5b) or specified-head cell (data item 7b).

Column—is the column index of specified-flow cell (data item 5b) or specified-head cell (data item 7b).

Node—is the node number of specified-flow cell (data item 5c) or specified-head cell (data item 7c).

IAUX—is an integer auxiliary variable associated with each specified-flow and specified-head boundary cell. A value is read but not used in simulations of ground-water flow with MODFLOW-96. IAUX can be used by programs such as MODPATH (Pollock, 1994) to store information such as the cell face associated with the specified-flow or specified-head boundary.

FLWRAT—is volumetric rate of flow at specified-flow cells. A list of NBDTIM values must be specified for each of NFLW specified-flow cells.

AuxVar—is value of real auxiliary variable at specified-flow and specified-head cells. A list of NBDTIM values must be specified for each of NFLW specified-flow cells and for each of NHED specified-head cells.

SBHED—is an array containing NBDTIM values of the head for each specified-head cell.

Well (WEL) Package

Input to the Well (WEL) Package is read from the file that has 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. Extra considerations are provided in the WEL package than those of MODFLOW-2005. First, an option is provided via keyword AUTOFLOWREDUCE, whereby a simulated well will adjust pumping according to supply under bottom-hole conditions. Also, if CLN cells exist in a simulation with a structured grid, the input requirements for these wells are different and the user needs to input CLN cell number instead of layer, row and column. Therefore an option is provided to separately read the CLN cell numbers and their pumping rates. This option may also be used with unstructured grids, however, the global node numbers and their pumping rates may also be directly read. The global matrix contains the GWF cells first, followed by the CLN domain cells and the global node numbers are ordered accordingly. Also, for the case of CLN cells within a structured finite-difference grid, parameter wells are only applied to the GWF cells and not to the CLN cells.

FOR EACH SIMULATION

```
0. [#Text]
```
Item 0 is optional—"#" must be in column 1. Item 0 can be repeated multiple times.

```
1a. [PARAMETER NPWEL MXL]
```
This optional item must start with the word "PARAMETER".

```
2. MXACTW IWELCB [Option]
```

```
3. [PARNAM PARTYP Parval NLST [INSTANCES NUMINST] ]
```
Repeat Item 3 combined with the indicated repetitions of Item 4 NPWEL times. Items 3 and 4 are not read if NPWEL is negative or 0.
If PARNAM is to be a time-varying parameter, the keyword "INSTANCES" and a value for NUMINST must be entered.

```
4a. [INSTNAM]
```

```
4b. Layer Row Column Qfact [xyz]
```
Enter Item 4b if a structured grid is used

```
4c. Node  Qfact [xyz]
```
Enter Item 4c if an unstructured grid is used

After each Item 3 for which the keyword "INSTANCES" is not entered, read Item 4b, or 4c and not Item 4a. After each Item 3 for which the keyword "INSTANCES" is entered, read Item 4a and Item 4b, or 4c for each instance.
NLST repetitions of Item 4b or 4c are required; they are read by subroutine ULSTRD. (SFAC of the ULSTRD utility subroutine applies to Qfact). The NLST repetitions of Item 4b or 4c follow each repetition of Item 4a when PARNAM is time varying.

FOR EACH STRESS PERIOD

```
5. ITMP NP ITMPCLN
```

```
6a. Layer Row Column Q [xyz]
```

(ITMP repetitions of Item 6a are read by subroutine ULSTRD if ITMP > 0. (SFAC of the ULSTRD utility subroutine applies to Q.) Item 6a is not read if ITMP is negative or zero.

```
6b. Node Q [xyz]
```

(ITMP repetitions of Item 6b are read by subroutine ULSTRD if ITMP > 0. (SFAC of the ULSTRD utility subroutine applies to Q.) Item 6b is not read if ITMP is negative or zero.

```
6c. ICLNNODE Q [xyz]
```

(ITMPCLN repetitions of Item 6c are read by subroutine ULSTRD if ITMPCLN > 0. (SFAC of the ULSTRD utility subroutine applies to Q.) Item 6c is not read if ITMPCLN is negative or zero.

```
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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

NPWEL—is the number of well parameters.

MXL—is the maximum number of wells that will be defined using parameters.

MXACTW—is the maximum number of wells in use during any stress period, including those that are defined using parameters.

IWELCB—is a flag and a unit number.

> If IWELCB > 0, cell-by-cell flow terms will be written to this unit number when "SAVE BUDGET" or a nonzero 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 nonzero 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 20 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 Q variable.

"NOPRINT"—specifies that lists of wells will not be written to the Listing File.

"AUTOFLOWREDUCE" —specifies that the well pumping rate is reduced as per the flux to the well node under bottom-hole conditions. If well pumping is in a subsurface node, the bottom elevation of the cell is used to evaluate the bottom-hole elevation. If well pumping is in a CLN cell, the bottom elevation of the CLN cell is used to evaluate the bottom-hole elevation. Thus, in essence, the pumping reverts to constant head conditions with reduced flux if water levels try to fall below the bottom-hole elevation. The full pumping flux is resumed if the water levels bounce back as a result of changing stress conditions in the system. If this option is not specified, then the well pumping rate is maintained as per the MODFLOW-2005 well boundary condition.

"IUNITAFR" —specifies that wells with pumping rates that have been automatically reduced will be written to an output file. The unit number for this output file must immediately follow the "IUNITAFR" keyword option.   If this option is used then a file of type "DATA" should be included in the Name file with a unit number that matches the unit number specified here. This option can also be used to specify the unit number for the listing file, in which case, the reduced flow information will be written to the listing file.

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 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 Parameter Value File.

NLST—is the number of wells in a non-time-varying parameter. For a time-varying parameter, NLST is the number of wells in each instance.

INSTANCES—is an optional keyword that designates a parameter as time varying. The keyword is not case sensitive; that is, any combination of the same characters with different case can be used. 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 for a time-varying parameter, where each instance is a list of river reaches and associated properties. If the keyword INSTANCES is present, it must be followed by a value for NUMINST. If INSTANCES is absent, NUMINST should not be present.
INSTNAM—is the name of an instance associated with the parameter named in the corresponding Item 3. The instance name can be 1 to 10 characters and is not case sensitive. That is, any combination of the same characters with different case will be equivalent. Instance names must be unique for a parameter, but instance names may be reused for 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.

ICLNNODE—is the Connected Linear Network-node number that contains the well.

Node—is the global node number of the model cell (GWF cell or CLN cell) that contains the well. The global node number of a GWF cell for a structured grid may be computed as (KLAY-1)*NROW*NCOL + (IROW-1)*NCOL + JCOL where KLAY is the layer number, IROW is the row number and JCOL is the column number of the GWF Process cell. For a CLN cell, the global node number is the CLN cell node number plus the total number of GWF Process cells.

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 the values of the auxiliary variables for a well that have been defined in Item 2. The values of auxiliary variables must be present in each repetition of Items 4 and 6 if they are defined in Item 2. The values must be specified in the order used to define the variables in Item 2.

ITMP—is a flag and a counter for subsurface nodes.

> If ITMP < 0, non-parameter well data from the last stress period for subsurface nodes will be reused.

> ITMP ≥ 0, ITMP will be the number of non-parameter wells read for the current stress period for subsurface nodes.

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

ITMPCLN—is a flag and a counter. Note that ITMPCLN is read only if the CLN domain exists in a simulation. This is required for a structured grid in which layer, row and column assignments are read for each node, to accommodate input of pumping conditions within conduit- geometry CLN cells. For unstructured grids, well input for CLN cells may be provided here, or may be directly provided via the ITMP well nodes using their global node numbers.

> If ITMPCLN < 0, non-parameter well data from the last stress period for CLN cells will be reused.

> If ITMPCLN ≥ 0, ITMPCLN will be the number of non-parameter wells read for the current stress period for CLN cells.

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 parameter are not allowed in a stress period.

Drain (DRN) 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]]
```
Repeat Item 3 combined with the indicated repetitions of Item 4 NPDRB times. Items 3 and 4 are not read if NPDRN is negative or 0.
If PARNAM is to be a time-varying parameter, the keyword "INSTANCES" and a value for NUMINST must be entered.

```
4a. [INSTNAM]
```

```
4b. [Layer Row Column Elevation Condfact [xyz] ]
```
Omit Item 4b if an unstructured grid is used

```
4c. Node Condfact [xyz]
```
Omit Item 4c if a structured grid is used

After each Item 3 for which the keyword "INSTANCES" is not entered, read Item 4b or 4c and not Item 4a. After each Item 3 for which the keyword "INSTANCES" is entered, read Item 4a and Item 4b or 4c for each instance.
NLST repetitions of Item 4b or 4c are required; they are read by subroutine ULSTRD. (SFAC of the ULSTRD utility subroutine applies to Condfact). The NLST repetitions of Item 4b or 4c follow each repetition of Item 4a when PARNAM is time varying.

FOR EACH STRESS PERIOD

```
5. ITMP NP
```

```
6a. Layer Row Column Elevation Cond [xyz]
```
Omit Item 6a if an unstructured grid is used

```
6b. Node Elevation Cond [xyz]
```
Omit Item 6b if a structured grid is used

ITMP repetitions of Item 6a or 6b are read by subroutine ULSTRD if ITMP > 0. (SFAC of the ULSTRD utility subroutine applies to Cond.) Item 6a or 6b is not read if ITMP is negative or 0.

```
7. [Pname [Iname] ]
```
(Item 7 is repeated NP times. Item 7 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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

NPDRN—is the number of drain parameters.

MXL—is the maximum number of drain cells that will be defined using parameters.

MXACTD—is the maximum number of drain cells in use during any stress period, including those that are defined using parameters.

IDRNCB—is a flag and a unit number.

> If IDRNCB > 0, cell-by-cell flow terms will be written to this unit number when "SAVE BUDGET" or a nonzero 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 20 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.
> "NOPRINT"—specifies that lists of drains will not be written to the Listing File.

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 Parameter Value File.

NLST—is the number of drain in a non-time-varying parameter. For a time-varying parameter, NLST is the number of drain cells in each instance.

INSTANCES—is an optional keyword that designates a parameter as time varying. The keyword is not case sensitive; that is, any combination of the same characters with different case can be used. 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 for a time-varying parameter, where each instance is a list of river reaches and associated properties. If the keyword *INSTANCES* is present, it must be followed by a value for NUMINST. If *INSTANCES* is absent, NUMINST should not be present.

INSTNAM—is the name of an instance associated with the parameter named in the corresponding Item 3. The instance name can be 1 to 10 characters and is not case sensitive. That is, any combination of the same characters with different case will be equivalent. Instance names must be unique for a parameter, but instance names may be reused for 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.

Node—is the node number of the model cell that contains 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.

[xyz]—represents the values of the auxiliary variables for a drain that have been defined in Item 2. The values of auxiliary variables must be present in each repetition of Items 4 and 6 if they are defined in Item 2. The values must be specified in the order used to define the variables in Item 2.

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.

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

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 parameter are not allowed in a stress period.

River (RIV) 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 word "PARAMETER".

2. MXACTR IRIVCB [Option]

3. [PARNAM PARTYP Parval NLST [*INSTANCES* NUMINST]]
Repeat Item 3 combined with the indicated repetitions of Item 4 NPRIV times. Items 3 and 4 are not read if NPRIV is negative or 0.
If PARNAM is to be a time-varying parameter, the keyword "INSTANCES" and a value for NUMINST must be entered.

4a. [INSTNAM]

4b. [Layer Row Column Stage Condfact Rbot [xyz]]
Omit Item 4b if an unstructured grid is used

4c. Node Stage Condfact Rbot [xyz]
Omit Item 4c if a structured grid is used

After each Item 3 for which the keyword "INSTANCES" is not entered, read Item 4b or 4c and not Item 4a. After each Item 3 for which the keyword "INSTANCES" is entered, read Item 4a and Item 4b or 4c for each instance.
NLST repetitions of Item 4b or 4c are required; they are read by subroutine ULSTRD. (SFAC of the ULSTRD utility subroutine applies to Condfact). The NLST repetitions of Item 4b or 4c follow each repetition of Item 4a when PARNAM is time varying.

FOR EACH STRESS PERIOD

5. ITMP NP

6a. Layer Row Column Stage Cond Rbot [xyz]
Omit Item 6a if an unstructured grid is used

6b. Node Stage Cond Rbot [xyz]
Omit Item 6b if a structured grid is used

ITMP repetitions of Items 6a or 6b are read by subroutine ULSTRD if ITMP > 0. (SFAC of the ULSTRD utility subroutine applies to Cond.) Items 6a or 6b are not read if ITMP is negative or 0.

7. [Pname [Iname]]

(Item 7 is repeated NP times. Item 7 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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

NPRIV—is the number of river parameters.

MXL—is the maximum number of river reaches that will be defined using parameters.

MXACTR—is the maximum number of river reaches in use during any stress period, including those that are defined using parameters.

IRIVCB—is a flag and a unit number.
> If IRIVCB > 0, cell-by-cell flow terms will be written to this unit number when "SAVE BUDGET" or a nonzero 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 nonzero 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 20 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.
> "NOPRINT"—specifies that lists of river reaches will not be written to the Listing File.

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 Parameter Value File.
NLST—is the number of river reaches in a non-time-varying parameter. For a time-varying parameter, NLST is the number of reaches in each instance.

INSTANCES—is an optional keyword that designates a parameter as time varying. The keyword is not case sensitive; that is, any combination of the same characters with different case will be equivalent. 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 for a time-varying parameter, where each instance is a list of river reaches and associated properties. If the keyword *INSTANCES* is present, it must be followed by a value for NUMINST. If *INSTANCES* is absent, NUMINST should not be present.

INSTNAM—is the name of an instance associated with the parameter named in the corresponding Item 3. The instance name can be 1 to 10 characters and is not case sensitive. That is, any combination of the same characters with different case will be equivalent. Instance names must be unique for a parameter, but instance names may be reused for 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.

Node—is the node number of the model cell that contains 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 the values of the auxiliary variables for a river reach that have been defined in Item 2. The values of auxiliary variables must be present in each repetition of Items 4 and 6 if they are defined in Item 2. The values must be specified in the order used to define the variables 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 parameter are not allowed in a stress period.

General-Head Boundary (GHB) 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]]
Repeat Item 3 combined with the indicated repetitions of Item 4 NPGHB times. Items 3 and 4 are not read if NPGHB is negative or 0.
If PARNAM is to be a time-varying parameter, the keyword "INSTANCES" and a value for NUMINST must be entered.

4a. [INSTNAM]

4b. [Layer Row Column Bhead Condfact [xyz]]
Omit Item 4b if an unstructured grid is used

4c. Node Bhead Condfact [xyz]
Omit Item 4c if a structured grid is used

After each Item 3 for which the keyword "INSTANCES" is not entered, read Item 4b or 4c and not Item 4a. After each Item 3 for which the keyword "INSTANCES" is entered, read Item 4a and Item 4b or 4c for each instance.
NLST repetitions of Item 4b or 4c are required; they are read by subroutine ULSTRD. (SFAC of the ULSTRD utility subroutine applies to Condfact). The NLST repetitions of Item 4b or 4c follow each repetition of Item 4a when PARNAM is time varying.

FOR EACH STRESS PERIOD

5. ITMP NP

6a. Layer Row Column Bhead Cond [xyz]
Omit Item 6a if an unstructured grid is used

6b. Node Bhead Cond [xyz]
Omit Item 6b if a structured grid is used

ITMP repetitions of Item 6a or 6b are read by subroutine ULSTRD if ITMP > 0. (SFAC of the ULSTRD utility subroutine applies to Cond.) Item 6a or 6b are not read if ITMP is negative or 0.

7. [Pname [Iname]]

(Item 7 is repeated NP times. Item 7 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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

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.

MXACTB—is the maximum number of general-head boundary cells in use during any stress period, including those that are defined using parameters.

IGHBCB—is a flag and a unit number.

> If IGHBCB > 0, cell-by-cell flow terms will be written to the unit number when "SAVE BUDGET" or a nonzero 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 20 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.
> "NOPRINT"—specifies that lists of general-head boundary cells will not be written to the Listing File.

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 Parameter Value File.

NLST—is the number of head-dependent boundaries in a non-time-varying parameter. For a time-varying parameter, NLST is the number of head-dependent boundaries in each instance.

INSTANCES—is an optional keyword that designates a parameter as time varying. The keyword is not case sensitive; that is, any combination of the same characters with different case can be used. 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 for a time-varying parameter, where each instance is a list of river reaches and associated properties. If the keyword *INSTANCES* is present, it must be followed by a value for NUMINST. If *INSTANCES* is absent, NUMINST should not be present.

INSTNAM—is the name of an instance associated with the parameter named in the corresponding Item 3. The instance name can be 1 to 10 characters and is not case sensitive. That is, any combination of the same characters with different case will be equivalent. Instance names must be unique for a parameter, but instance names may be reused for 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.

Node—is the node number of the model cell affected by the head-dependent boundary.

Bhead—is the boundary head.

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 the values of the auxiliary variables for a boundary that have been defined in Item 2. The values of auxiliary variables must be present in each repetition of Items 4 and 6 if they are defined in Item 2. The values must be specified in the order used to define the variables 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 parameter are not allowed in a stress period.

Stream (STR7) Package

Input to the modified version of the Streamflow-Routing (STR) Package is read from the file that has file type "STR" in the MODFLOW name file. Optional variables are shown in brackets. All variables are read with fixed format (except as noted) unless the "FREE" option is specified in the Basic Package.

FOR EACH SIMULATION

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

```
1.  [PARAMETER NPSTR MXL]
```
   This optional record is read with free format; it must start with the word "PARAMETER".

```
2.  MXACTS NSS NTRIB NDIV ICALC CONST ISTCB1 ISTCB2
       I10   I10   I10   I10   I10  F10.0  I10    I10
```

```
3.  [PARNAM PARTYP Parval NLST [INSTANCES NUMINST]]
```
   Item 3 is read with free format. 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 Col Seg Reach Flow   Stage   Condfact  Sbot    Stop]
       I5    I5  I5  I5   I5   F15.0  F10.0   F10.0    F10.0  F10.0
```
   NLST repetitions of Item 4b are required. 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 NPSTR parameters.
Omit Item 4b if an unstructured grid is used

```
4c. [Node   Seg   Reach Flow   Stage   Condfact  Sbot    Stop]
       I10    I10  I10   F10.0  F10.0   F10.0    F10.0  F10.0
```
   NLST repetitions of Item 4c are required. The NLST repetitions of Item 4c follow each repetition of Item 4a when PARNAM is time varying. Repeat Items 3 and 4 for each of NPSTR parameters.
Omit Item 4c if a structured grid is used

FOR EACH STRESS PERIOD

```
5.  ITMP IRDFLG IPTFLG
     I10   I10    I10
```

```
6a. Layer Row Col Seg Reach Flow    Stage  Cond    Sbot    Stop
     I5    I5  I5  I5   I5    F15.0  F10.0  F10.0  F10.0  F10.0
```
Omit Item 6a if an unstructured grid is used

```
6b. Node  Seg Reach   Flow    Stage  Cond    Sbot    Stop
     I10   I10  I10   F10.0  F10.0  F10.0  F10.0  F10.0
```
Omit Item 6b if a structured grid is used

Item 6a or 6b is repeated ITMP times if NPSTR=0. If ITMP<0, Item 6a or 6b records are used from the previous stress period.

7. `[Pname [Iname]]`
Item 7 is repeated ITMP times if NPSTR>0. Free format is used. Iname is read if Pname is a time-varying parameter.
[Note that either Item 6 or Item 7 may be read, but not both.]

8. `Width Slope Rough`
   `F10.0 F10.0 F10.0`
Item 8 is read only if ICALC > 0, in which case Item 8 is repeated for every stream reach. The records must be is the same order as the stream reaches.

9. `Itrib(NTRIB)`
   `10I5`
Item 9 is read only if NTRIB > 0, in which case Item 9 is repeated NSS times in sequential order of the segments. Each record contains NTRIB values.

10. `Iupseg`
   `I10`
Item 10 is read only if NDIV>0, in which case Item 10 is repeated NSS times in sequential order of the segments.

Explanation of Variables Read by the STR Package:

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

NPSTR—is the number of stream parameters that will be defined.

MXL—is the maximum number of stream reaches that will be defined using parameters. MXL must equal or exceed the sum of NLST x NUMINST for all parameters.

MXACTS—is the maximum number of stream reaches that will be in use during any stress period. MXACTS includes reaches that are defined using parameters as well as reaches that are defined without using parameters.

NSS—is the number of stream segments

NTRIB—is the number of stream tributaries that can connect to one segment. The program is currently dimensioned so that NTRIB cannot exceed 10.

NDIV—is a flag, which when positive, specifies that diversions from segments are to be simulated.

ICALC—is a flag, which when positive, specifies that stream stages in reaches are to be calculated.

CONST—is a constant value used in calculating stream stage in reaches. It is specified whenever ICALC is greater than 0. This constant is 1.486 for flow units of cubic feet per second and 1.0 for units of cubic meters per second. The constant must be multiplied by 86,400 when using time units of days in the simulation.

ISTCB1—is a flag and a unit number for the option to write seepage between the stream reaches and model cells into the list file or an unformatted (binary) file.

If ISTCB1>0, it is the unit number to which seepage between each stream reach and the corresponding model cell will be saved whenever the variable ICBCFL in the Output Control Option is set.

If ISTCB1=0, seepage between each stream reach and the corresponding model cell will not be written into any file.

If ISTCB1<0, streamflow for each reach and seepage between each stream reach and the corresponding models cell will be written into the LIST file whenever the variable ICBCFL in the Output Control Option is set.

ISTCB2—is a flag and a unit number for the option to store streamflow out of each reach in an unformatted (binary) file.

If ISTCB2 > 0, it is the unit number to which streamflow in each stream reach will be saved whenever the variable ICBCFL in the Output Control Option is set.

If ISTCB2 ≤ 0, streamflow in each stream reach will not be stored in a disk file.

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 STR Package, the only allowed parameter type is STR, which defines values of streambed conductance.

Parval—is the parameter value. This parameter value may be overridden by a value in the Parameter Value File.

NLST—is the number of stream reaches that are included in each instance defined for the 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 stream reaches and associated properties. If the keyword *INSTANCES* is present, NUMINST must be present. 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 containing the stream reach.

Row—is the row number of the model cell containing the stream reach.

Col—is the column number of the model cell containing the stream reach.

Node—is the node number of the model cell containing the stream reach.

Seg—is a number assigned to a group of reaches. Segments must be numbered in downstream order and are read into the program in sequential order.

Reach—is a sequential number in a segment that begins with 1 for the farthest upstream reach and continues in downstream order to the last reach in the segment. Reaches must be read in sequentially because the order in which reaches are read determines the order of connection.

Flow—is the streamflow entering a segment. This value is used only for the first reach of each segment. The value should be specified as either 0 or blank when the reach number (Reach) is not 1. When the inflow to the first reach of a segment is the sum of the outflow from upstream tributary segments, Flow should be specified as -1. When the segment is a diversion, the Flow for the first reach is the amount to divert; however, there will be no diversion if the segment from which the diversion is obtained contains less than the value of Flow.

Stage—is the stream stage. The value of Stage is not used if ICALC>0.

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

Sbot—is the elevation of the bottom of the streambed.

Stop—is the elevation of the top of the streambed. The value of Stop is used if the option to calculate stream stage is active (ICALC>0) or when the streambed has zero flow.

ITMP—is a flag and a counter. Its meaning depends on whether or not stream parameters are being used.
    If STR parameters are being used (NPSTR>0), ITMP is the number of stream parameters being used in the current stress period.
    IF STR parameters are not being used (NPSTR=0), ITMP is the number of stream reaches for which data will be read in the current stress period. If ITMP < 0, STR data from the preceding stress period will be reused.

IRDFLG—is a flag, which when positive, suppresses printing of the stream input data for a stress period. The input data are printed if IRDFLG is 0 and ICBCFL in the Output Control Option is set.

IPTFLG—is a flag, which when positive, suppresses printing of stream results for a stress period. Results are printed if IPTFLG is 0, ICBCFL in the Output Control Option is set, and ISTCB1 < 0.

Cond—is the streambed hydraulic conductance.

Pname—is the name of a parameter that is being used in the current stress period. ITMP parameter names will be read. They must be specified in an order that meets the downstream ordering requirements for Seg and Reach.

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.

Width—is the width of the stream channel. It is read only when stream stage is calculated (ICALC>0).

Slope—is the slope of the stream channel. It is read only when stream stage is calculated (ICALC>0).

Rough—is Manning's roughness coefficient. It is read only when stream stage is calculated (ICALC>0).

Itrib—contains the segment number for each tributary that flows into a segment. NTRIB values are read for each segment. Unused values of Itrib should be set to 0. Itrib records are read only when NTRIB>0.

Iupseg—is the number of the upstream segment from which water is diverted. If the segment is not a diversion, Iupseg should be specified as 0. Iupseg records are read only when NDIV>0.

Streamflow-Routing (SFR2) Package with Unsaturated Flow beneath Streams.

MODFLOW Name File

The Streamflow-Routing Package is activated automatically by including a record in the MODFLOW name file using the file type (Ftype) "SFR" to indicate that relevant calculations are to be made in the model and to specify the related input data file. The user can optionally specify that stream gages and monitoring stations are to be represented at one or more locations along a stream channel by including a record in the MODFLOW name file using the file type (Ftype) "GAGE" that specifies the relevant input data file giving locations of gages. The modifications in SFR2 do not require any changes to the data input for SFR1. SFR2 is compatible with MODFLOW-2000 (Harbaugh and others, 2000), but not with earlier versions of MODFLOW.

Input Data Instructions

The modification of SFR2 to simulate unsaturated flow relies on the specific yield values as specified in the Layer Property Flow (LPF) Package or the Block-Centered Flow (BCF) Package. Thus, the option for unsaturated flow beneath streams is only available when either LPF or BCF is used in the simulation. When the option to use vertical hydraulic conductivity in the LPF Package is specified, the layer(s) that contain cells where unsaturated flow will be simulated must be specified as convertible. That is, the variable LAYTYP specified in LPF must not be equal to zero, otherwise the model will print an error and stop execution.

Additional variables that must be specified to define hydraulic properties of the unsaturated zone are all included within the SFR2 input file. All values are entered in as free format. Data input for SFR1 works without modification if unsaturated flow is not simulated. Parameters can be used to define streambed hydraulic conductivity only when data input follows the SFR1 input structure (Prudic and others, 2004). The calculation of sensitivities for, or estimation of, parameters using the Sensitivity Process are not supported by SFR1 nor SFR2. Additionally, the Ground-Water Transport Process is only available using the original SFR1 input structure and is currently not available when simulating unsaturated flow beneath streams.

For each simulation, the first record in the SFR2 input file must read:

FOR EACH SIMULATION

0. [#Text] Text A character variable (up to 199 characters) that is printed when the file is read. The "#" character must be in column 1, and, accordingly, the variable starts in column 2. Any characters can be included in Text.

   Note 1: Item 0 can be repeated multiple times.

   1a. Data: {REACHINPUT   TRANSROUTE}

   REACHINPUT   An optional character variable that is a flag to change the default format for entering reach and segment data input and to simulate unsaturated flow beneath streams. When REACHINPUT is specified, optional variable ISFROPT must be specified in item 1c; optional variables NSTRAIL, ISUZN, and NSFRSETS also must be specified if ISFROPT>0.

   TRANSROUTE   An optional character variable that is a flag to indicate that transient streamflow routing is active. When TRANSROUTE is specified, optional variables IRTFLG, NUMTIM, WEIGHT, and FLWTOL also must be specified in Item 1c.

1b. Data: {TABFILES NUMTAB MAXVAL}

TABFILES   An optional character variable that is a flag to indicate that inflows to one or more stream segments will be specified with tabular inflow files.

NUMTAB   An integer value equal to the number of tabular inflow files that will be read if TABFILES is specified. A separate input file is required for each segment that receives specified inflow. Thus, the maximum value of NUMTAB that can be specified is equal to the total number of segments specified in Item 1c with variables NSS. The name (Fname) and unit number (Nunit) of each tabular file must be specified in the MODFLOW-USG Name File using tile type (Ftype) DATA.

MAXVAL   An integer value equal to the largest number of rows of specified inflows for any of the tabular inflow files if TABFILES is specified. MAXVAL is used for memory allocation. For example, if there are two tabular inflow files and the files contain 100 and 200 inflow values, respectively, then MAXVAL would be specified as 200.

1c. Data: NSTRM NSS NSFRPAR NPARSEG CONST DLEAK ISTCB1 ISTCB2 {ISFROPT} {NSTRAIL} {ISUZN} {NSFRSETS} {IRTFLG} {NUMTIM} {WEIGHT} {FLWTOL}

NSTRM   An integer value equal to the number of stream reaches (finite-difference cells) that are active during the simulation. The value of NSTRM also represents the number of lines of data to be included in Item 2, described below.

NSS   An integer value equal to the number of stream segments (consisting of one or more reaches) that are used to define the complete stream network. The value of NSS represents the number of segments that must be defined through a combination of parameters and repetitions of Item 6 every stress period.

NSFRPAR   An integer value equal to the number of stream parameters (associated with one or more segments) to be defined. This variable must be zero when NSTRM is negative.

NPARSEG   An integer value equal to (or exceeding) the number of stream-segment definitions associated with all parameters. This number can be more than the total number of segments (NSS) in the stream network because the same segment can be defined in multiple parameters, and because parameters can be time-varying. NPARSEG must equal or exceed the sum of NLST × N for all parameters, where N is the greater of 1 and NUMINST; that is, NPARSEG must equal or exceed the total number of repetitions of item 4b. This variable must be zero when NSTRM is negative.

CONST   A real value (or conversion factor) used in calculating stream depth for stream reach. If stream depth is not calculated using Manning's equation for any stream segment (that is, ICALC does not equal 1 or 2), then a value of zero can be entered. If Manning's equation is used, a constant of 1.486 is used for flow units of cubic feet per second, and a constant of 1.0 is used for units of cubic meters per second. The constant must be multiplied by 86,400 when using time units of days in the simulation. An explanation of time units used in MODFLOW is given by Harbaugh and others (2000, p. 10.)

DLEAK   A real value equal to the tolerance level of stream depth used in computing leakage between each stream reach and active model cell. Value is in units of length. Usually a value of 0.0001 is sufficient when units of feet or meters are used in model.

ISTCB1   An integer value used as a flag for writing stream-aquifer leakage values. If ISTCB1 > 0, it is the unit number to which unformatted leakage between each stream reach and corresponding model cell will be saved to a file whenever the cell-by-cell budget has been specified in Output Control

(see Harbaugh and others, 2000, pages 52-55). If ISTCB1 = 0, leakage values will not be printed or saved. If ISTCB1 < 0, all information on inflows and outflows from each reach; on stream depth, width, and streambed conductance; and on head difference and gradient across the streambed will be printed in the main listing file whenever a cell-by-cell budget has been specified in Output Control.

ISTCB2   An integer value used as a flag for writing to a separate formatted file all information on inflows and outflows from each reach; on stream depth, width, and streambed conductance; and on head difference and gradient across the streambed. If ISTCB2 > 0, then ISTCB2 also represents the unit number to which all information for each stream reach will be saved to a separate file when a cell-by-cell budget has been specified in Output Control. If ISTCB2 < 0, it is the unit number to which unformatted streamflow out of each reach will be saved to a file whenever the cell-by-cell budget has been specified in Output Control.

If keyword REACHINPUT has been specified:
ISFROPT   An integer value that defines the input structure
    1   No vertical unsaturated flow beneath streams. Streambed elevation, stream slope, streambed thickness, and streambed hydraulic conductivity are read for each reach only once at the beginning of the simulation.
    2   Streambed and unsaturated-zone properties are read for each reach only once at the beginning of the simulation except saturated vertical hydraulic conductivity for the unsaturated zone is the same as the vertical hydraulic conductivity of the corresponding layer in LPF and is not read in separately.
    3   Same as 2 except saturated vertical hydraulic conductivity for the unsaturated zone is read for each reach.
    4   Streambed and unsaturated-zone properties are read for the beginning and end of each stream segment. Streambed properties can vary each stress period. Saturated vertical hydraulic conductivity for the unsaturated zone is the same as the vertical hydraulic conductivity of the corresponding layer in LPF and is not read in separately.
    5   Same as 4 except saturated vertical hydraulic conductivity for the unsaturated zone is read for each segment at the beginning of the first stress period only.

Note 2: If BCF is used and unsaturated flow is active then ISFROPT must equal 3 or 5.

When ISFROPT is greater than 1, read the following variables:
NSTRAIL   An integer value that is the number of trailing wave increments used to represent a trailing wave. Trailing waves are used to represent a decrease in the surface infiltration rate. The value can be increased to improve mass balance in the unsaturated zone. Values between 10 and 20 work well, although, for large problems we recommend fewer trailing waves (10) due to memory and computational requirements. Please see Smith (1983) for further details.

ISUZN   An integer value that is the maximum number of vertical cells used to the define the unsaturated zone beneath a stream reach. If ICALC is 1 for all segments then ISUZN should be set to 1.
NSFRSETS   An integer value that is the maximum number of different sets of trailing waves used to allocate arrays. Arrays are allocated by multiplying NSTRAIL by NSFRSETS. A value of 30 is sufficient for problems where the stream depth varies often.

If keyword TRANSROUTE has been specified:

IRTFLG   An integer value that indicates the method of transient streamflow routing. IRTFLG must be specified if TRANSROUTE has been specified. Currently, the only routing method available is the kinematic-wave equation approach (see USGS Techniques and Methods 6-D1, p. 68-69). Enter IRTFLG=1, if streamflow will be routed using the kinematic-wave equation; otherwise, IRTFLG should be specified as 0 (steady flow).

If IRTFLG = 1:

NUMTIM   An integer value equal to the number of sub time steps used to route streamflow. The time step that will be used to route streamflow will be equal to the MODFLOW-2005 time step divided by NUMTIM.

WEIGHT   A real number equal to the time weighting factor used to calculate the change in channel storage. WEIGHT has a value between 0.5 and 1. Refer to equation 83 in USGS Techniques and Methods 6-D1 for further details.

FLWTOL   A real number equal to the streamflow tolerance for convergence of the kinematic wave equation used for transient streamflow routing. A value of 0.00003 cubic meters per second has been used successfully in test simulations (and would need to be converted to whatever units are being used in the particular simulation).

Note 3: The first two variables (NSTRM and NSS) are used for dimensioning arrays, and must be equal to the actual number of stream reaches defined in Item 2 and the number of segments that define the complete stream network, respectively.

Note 4: SFR2 differs from the Stream (STR1) Package (Prudic, 1989) because the new package solves for stream depth at the midpoint of each reach instead of at the beginning of the reach. To solve for depth at the midpoint of each reach, like SFR1, SFR2 uses Newton's iterative method and consequently, a tolerance (DLEAK) is used for stopping the iterative process.

ONE RECORD FOR EACH STREAM REACH:

2a. Data: KRCH IRCH JRCH ISEG IREACH RCHLEN {STRTOP} {SLOPE} {STRTHICK} {STRHC1} {THTS} {THTI} {EPS} {UHC}
Omit Item 2a if an unstructured grid is used

2b. Data: NRCH ISEG IREACH RCHLEN {STRTOP} {SLOPE} {STRTHICK} {STRHC1} {THTS} {THTI} {EPS} {UHC}
Omit Item 2b if a structured grid is used

KRCH   An integer value equal to the layer number of the cell containing the stream reach.

IRCH   An integer value equal to the row number of the cell containing the stream reach.

JRCH   An integer value equal to the column number of the cell containing the stream reach.

NRCH   An integer value equal to the node number of the cell containing the stream reach.

ISEG   An integer value equal to the number of stream segment in which this reach is located. Stream segments contain one or more reaches and are assumed to have uniform or linearly varying characteristics.

IREACH   An integer value equal to the sequential number in a stream segment of this reach (where a reach corresponds to a single cell in the model). Numbering of reaches in a segment begins with 1 for the farthest upstream reach and continues in downstream order to the last reach of the segment.

RCHLEN   A real number equal to the length of channel of the stream reach within this model cell. The length of a stream reach can exceed the model cell dimensions because of the meandering nature of many streams. The length is used to calculate the streambed conductance for this reach. Also, the sum of the lengths of all stream reaches within a segment is used to calculate the average slope of the channel for the segment and subsequently other values, such as the elevation of the streambed and stream stage.

STRTOP   A real number equal to the top elevation of the streambed. This variable is read when ISFROPT is 1, 2, or 3.

SLOPE   A real number equal to the stream slope across the reach. This variable is read when ISFROPT is 1, 2, or 3. Slope must be greater than zero.

STRTHICK   A real number equal to the thickness of the streambed. This variable is read when ISFROPT is 1, 2, or 3.

STRHC1   A real number equal to the hydraulic conductivity of the streambed. This variable is read when ISFROPT is 1, 2, or 3.

THTS   A real number equal to the saturated volumetric water content in the unsaturated zone. This variable is read when ISFROPT is 2 or 3.

THTI   A real number equal to the initial volumetric water content. THTI must be less than or equal to THTS and greater than or equal to THTS minus the specific yield defined in either LPF or BCF. This variable is read when ISFROPT is 2 or 3.

EPS   A real number equal to the Brooks-Corey exponent used in the relation between water content and hydraulic conductivity within the unsaturated zone (Brooks and Corey, 1966). This variable is read when ISFROPT is 2 or 3.

UHC   A real number equal to the vertical saturated hydraulic conductivity of the unsaturated zone. This variable is necessary when using BCF, whereas it is optional when using LPF. This variable is read when ISFROPT is 3.

Note 5: Records are read in sequential order from upstream to downstream, first by segments, and then sequentially by reaches. Segments should be numbered in downstream order but this is not necessary. However, if the segments are not numbered in downstream order, the inflows and outflows from each segment will still be computed but the computed inflows into a segment from upstream tributary streams having a higher segment number will be from the previous iteration. Reaches must be listed and read in sequentially because the order determines the connections of inflows and outflows within a stream segment.

Note 6: The stream network is assumed to remain fixed geometrically over the duration of a simulation. The active part of the stream network, however, can be made to vary over time by making selected stream segments inactive for selected stress periods. This would be implemented by setting the streambed hydraulic conductivity, segment inflow, overland runoff, and direct precipitation to

zero for the inactive segments in Items 4 or 6 for the specific stress periods when they are known to be inactive or dry.

Note 7: If the model cell corresponding to a stream reach is inactive, the program will search for the uppermost active cell in the vertical column to apply the leakage. If there are no active cells or if the cell is a constant head, no interaction is allowed and flow in the reach is passed to the next reach.

Note 8: When STRTOP, SLOPE, STRTHICK, and STRHC1 are specified for each reach, the variables are not read using Items 6b or 6c.

Note 9: The residual water content for each cell is not specified by the user because it is calculated based on the specified saturated water content minus the specific yield of the active model cell corresponding to the stream reach. The calculation is performed internally to assure continuity between unsaturated and saturated zone storage.

Note 10: Although unsaturated flow variables will not be used for reaches that are designated as ICALC = 0, 3, and 4 within the segment information, values must be included for all reaches when ISFROPT = 2 or 3. Dummy values may be used for reaches that are designated as ICALC = 0, 3, and 4.

When NSFRPAR = 0, skip Items 3**and** 4**and enter all stream segment data using Items** 5**and 6; and**

When NSFRPAR > 0, Items 3**and** 4**are repeated NSFRPAR times:**

3. Data: PARNAM PARTYP Parval NLST [***INSTANCES*** NUMINST]

PARNAM   A set of characters used to name 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 cases will be equivalent.

PARTYP   Type of parameter to be defined. For the SFR2 Package, the only allowed parameter type is SFR, which defines values of the streambed hydraulic conductivity.

Parval   A real number that is a parameter value that may be overridden by a value in the Sensitivity Process input file when ISENALL in that file is less than zero.

NLST   An integer value that is the number of stream segments associated with this parameter (this value also indicates how many times Item 4 is repeated in the next block of input data).

INSTANCES   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   An integer value that is the number of instances that are included in the definition of a time-varying parameter, where each instance is a sequence of Item 4 (Parts 4b through 4g) defining 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.

When PARNAM is not time-varying, Part 4a **is not read, and Parts** 4b **through** 4g **are read sequentially for each of NLST stream segments; and**

When PARNAM is time-varying, NUMINST instances are read. For each instance, Part 4a is read, and then Parts 4b through 4g are read sequentially for each of NLST stream segments (see notes 11 and 12):

4a. Data: {INSTNAM}

INSTNAM   The name of an instance associated with the parameter PARNAM specified in the corresponding Item 3 (INSTNAM is read only if PARNAM is time-varying). 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.

4b. Data: NSEG ICALC OUTSEG IUPSEG {IPRIOR} {NSTRPTS} FLOW RUNOFF ETSW PPTSW {ROUGHCH} {ROUGHBK} {CDPTH} {FDPTH} {AWDTH} {BWDTH}

NSEG   An integer value of the stream segment for which information is given to identify inflow, outflow, and computation of stream depth.

ICALC   An integer value used to indicate method used to calculate stream depth in this segment.
• If ICALC ≤ 0, stream depth in each reach is specified at the beginning of a stress period and remains unchanged unless flow at the midpoint of a reach is zero, then depth is set to zero in that reach. No unsaturated flow is allowed.
• If ICALC > 0, stream depth is calculated and updated each iteration of the MODFLOW solver within a time step.
• If ICALC = 1, stream depth is calculated using Manning's equation and assuming a wide rectangular channel. Unsaturated flow is simulated when ISFROPT > 1.
• If ICALC = 2, stream depth is calculated using Manning's equation and assuming an eight-point channel cross section for each segment (which allows for the computation of a wetted perimeter and for changing hydraulic conductance of the streambed in relation to changes in flow). Unsaturated flow is simulated when ISFROPT > 1.
• If ICALC = 3, stream depth and width are calculated using a power function relating each to streamflow (Q) using equations 8 and 9 where —DEPTH(y) = CDPTH × QFDPTH and WIDTH(w) = AWDTH × QBWDTH. No unsaturated flow is allowed.
• If ICALC = 4, stream depth and width are calculated using a table relating streamflow to depth and width (the table is defined in Part 4f). No unsaturated flow is allowed.

OUTSEG   An integer value of the downstream stream segment that receives tributary inflow from the last downstream reach of this segment. If this segment (identified by NSEG) does not feed (or discharge into) another downstream (tributary) segment, then enter a value of "0" for this variable. If the segment ends within the modeled grid and OUTSEG = 0, outflow from the segment is not routed anywhere and is no longer part of the stream network. One may wish to use this if all flow in the stream gets diverted into a lined canal or into a pipe. If the flow out of this segment discharges into a lake, set OUTSEG equal to the negative value of the lake identification number (where the minus sign is used as a flag to tell the model that flow enters a lake rather than a tributary stream segment).

IUPSEG   An integer value of the upstream segment from which water is diverted (or withdrawn) to supply inflow to this stream segment if this segment originates as a diversion from an upstream segment. If the source of a stream segment is discharge from a lake, set IUPSEG equal to the negative value of the lake identification number (where the minus sign is used as a flag to tell the model

that streamflow into this segment is derived from lake outflow rather than a stream segment). If this stream segment (identified by NSEG) does not receive inflow as a diversion from an upstream segment, then set IUPSEG = 0.

IPRIOR   An integer value that only is specified if IUPSEG > 0 (do not specify a value in this field if IUPSEG = 0 or IUPSEG < 0). IPRIOR defines the prioritization system for diversion, such as when insufficient water is available to meet all diversion stipulations, and is used in conjunction with the value of FLOW (specified below).
• When IPRIOR = 0, then if the specified diversion flow (FLOW) is greater than the flow available in the stream segment from which the diversion is made, the diversion is reduced to the amount available, which will leave no flow available for tributary flow into a downstream tributary of segment IUPSEG.
• When IPRIOR = -1, then if the specified diversion flow (FLOW) is greater than the flow available in the stream segment from which the diversion is made, no water is diverted from the stream. This approach assumes that once flow in the stream is sufficiently low, diversions from the stream cease, and is the "priority" algorithm that originally was programmed into the STR1 Package (Prudic, 1989).
• When IPRIOR = -2, then the amount of the diversion is computed asa fraction of the available flow in segment IUPSEG; in this case, $0.0 \leq FLOW \leq 1.0$.
• When IPRIOR = -3, then a diversion is made only if the streamflow leaving segment IUPSEG exceeds the value of FLOW. If this occurs, then the quantity of water diverted is the excess flow and the quantity that flows from the last reach of segment IUPSEG into its downstream tributary (OUTSEG) is equal to FLOW. This represents a flood-control type of diversion, as described by Danskin and Hanson (2002).

NSTRPTS   An integer value specified only when ICALC = 4. It is used to dimension a table relating streamflow with stream depth and width as specified in Items 4e and 6e. NSTRPTS must be at least 2 but not more than 50. If the table exceeds 3×50 (for streamflow, stream depth, and width) values, then MAXPTS in the allocation subroutine GWF1SFR1ALP will need to be increased from 3×50 to $3 \times$ (the desired maximum value).

FLOW   A real number that is the streamflow (in units of volume per time) entering or leaving the upstream end of a stream segment (that is, into the first reach).
• If the stream is a headwater stream, FLOW defines the total inflow to the first reach of the segment. The value can be any number ≥ 0.
• If the stream is a tributary stream, FLOW defines additional specified inflow to or withdrawal from the first reach of the segment (that is, in addition to the discharge from the upstream segment of which this is a tributary). This additional flow does not interact with the ground-water system. For example, a positive number might be used to represent direct outflow into a stream from a sewage treatment plant, whereas a negative number might be used to represent pumpage directly from a stream into an intake pipe for a municipal water treatment plant. (Also see additional explanatory notes below.)
• If the stream is a diversionary stream, and the diversion is from another stream segment, FLOW defines the streamflow diverted from the last reach of stream segment IUPSEG into the first reach of this segment. The diversion is computed or adjusted according to the value of IPRIOR.
• If the stream is a diversionary stream, and the diversion is from a lake, FLOW defines a fixed rate of discharge diverted from the lake into the first reach of this stream segment (unless the lake goes dry) and flow from the lake is not dependent on the value of ICALC. However, if FLOW = 0, then the lake outflow into the first reach of this segment will be calculated on the basis of lake stage relative to the top of the streambed for the first reach using one of the methods defined by ICALC.

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RUNOFF   A real number that is the volumetric rate of the diffuse overland runoff that enters the stream segment (in units of volume per time). The specified rate is apportioned to each reach of the segment in direct relation to the fraction of the total length of the stream channel in the segment that is present in each reach.

ETSW   A real number that is the volumetric rate per unit area of water removed by evapotranspiration directly from the stream channel (in units of length per time). ETSW is defined as a positive value.

PPTSW   A real number that is the volumetric rate per unit area of water added by precipitation directly on the stream channel (in units of length per time).

ROUGHCH   A real number that is Manning's roughness coefficient for the channel in all reaches in this segment. This variable is only specified if ICALC = 1 or 2.

ROUGHBK   A real number that is Manning's roughness coefficient for the overbank areas in all reaches in this segment. This variable is only specified if ICALC = 2.

CDPTH   A real number that is the coefficient used in the equation: (DEPTH = CDPTH × QFDPTH) that relates stream depth in all reaches in this segment to streamflow. This variable is only specified if ICALC = 3.

FDPTH   A real number that is the coefficient used in the equation:(DEPTH = CDPTH × QFDPTH) that relates stream depth in all reaches in this segment to streamflow. This variable is only specified if ICALC = 3.

AWDTH   A real number that is the coefficient used in the equation:(WIDTH = AWDTH × QBWDTH) that relates stream width in all reaches in this segment to streamflow. This variable is only specified if ICALC = 3.

BWDTH   A real number that is the coefficient used in the equation:(WIDTH = AWDTH × QBWDTH) that relates stream width in all reaches in this segment to streamflow. This variable is only specified if ICALC = 3.

4c. Data: Hc1fact THICKM1 ELEVUP {WIDTH1} {DEPTH1}

Hc1fact   A real number that is a factor used to calculate hydraulic conductivity of the streambed at the upstream end of this segment from the parameter value (in units of length per time).

THICKM1   A real number that is the thickness of streambed material at the upstream end of this segment (in units of length).

ELEVUP   A real number that is the elevation of the top of the streambed at the upstream end of this segment (in units of length).

WIDTH1   A real number that is the average width of the stream channel at the upstream end of this segment (in units of length). This variable is only specified if ICALC $\leq$ 1.

DEPTH1   A real number that is the average depth of water in the channel at the upstream end of this segment (units of length). This variable is only specified if ICALC = 0, in which case the stream

stage in a reach is assumed to equal the elevation of the top of the streambed plus the depth of water.

4d. Data: Hc2fact THICKM2 ELEVDN {WIDTH2} {DEPTH2}

Hc2fact   A real number that is the factor used to calculate hydraulic conductivity of the streambed at the downstream end of this segment from the parameter value (units of length per time).

THICKM2   A real number that is the thickness of streambed material at the downstream end of this segment (units of length).

ELEVDN   A real number that is the elevation of the top of the streambed at the downstream end of this segment (units of length).

WIDTH2   A real number that is the average width of the stream channel at the down-stream end of this segment (units of length). This variable is only specified if ICALC ≤ 1.

DEPTH2   A real number that is the average depth of water in the channel at the down-stream end of this segment (units of length). This variable is only specified if ICALC = 0, in which case the stream stage in a reach is assumed to equal the elevation of the top of the streambed plus the depth of water.

If ICALC = 2:

4e.   Data: XCPT1 XCPT2 ... XCPT8
           Data: ZCPT1 ZCPT2 ... ZCPT8

XCPTi A real number that is the distance relative to the left bank of the stream channel (when looking downstream) for the eight points (XCPT1 through XCPT8) used to describe the geometry of this segment of the stream channel. By definition, location XCPT1 represents the left edge of the channel cross section, and its value should be set equal to 0.0; values XCPT2 through XCPT8 should equal to or be greater than the previous distance.

ZCPTi A real number that is the height relative to the top of the lowest elevation of the streambed (thalweg). One value (ZCPT1 through ZCPT8) is needed for each of the eight horizontal distances defined by XCPTi. The location of the thalweg (set equal to 0.0) can be any location from XCPT2 through XCPT7.

If ICALC = 4:

4f.   Data: FLOWTAB(1) FLOWTAB(2) … FLOWTAB(NSTRPTS)
           Data: DPTHTAB(1) DPTHTAB(2) … DPTHTAB(NSTRPTS)
           Data: WDTHTAB(1) WDTHTAB(2) … WDTHTAB(NSTRPTS)

FLOWTAB   A real number that is the streamflow (units of volume per time) related to a given depth and width. One value is needed for each streamflow that has a corresponding value of depth and width up to the total number of values used to define the table—FLOWTAB(1) through FLOWTAB(NSTRPTS). NSTRPTS is defined in Part 4b.

DPTHTAB   A real number that is the average depth (units of length) corresponding to a given flow. The number and order of values, DPTHTAB(1)through DPTHTAB(NSTRPTS)must coincide with the streamflow values (FLOWTAB)listed on the line immediately preceding.

WDTHTAB   A real number that is the stream width (units of length) corresponding to a given flow. The number and order of values, WDTHTAB(1)through WDTHTAB(NSTRPTS), must coincide with the streamflow values (FLOWTAB) listed on first line in Part 4f.

Note 11: Item 4, Parts 4b through 4g must be completed sequentially for each of the NLST stream segments; that is, Parts 4b through 4g for one stream segment must be entered before Parts 4b through 4g of the next stream segment. However, the data for stream segments need not be entered sequentially by stream segment number. For example, data for stream segment 2 can be entered before data for stream segment 1.

Note 12: When the defined parameter (PARNAM) is not time-varying, Item 4, Part 4a is omitted, and each stream segment controlled by parameter PARNAM is defined by one sequence of Parts 4b through 4g. When the defined parameter (PARNAM) is time-varying, Item 4, Parts 4a through 4g must be completed for each of NUMINST instances. For each instance, Part 4a is defined followed by Parts 4b through 4g for each of the NLST stream segments associated with that instance. For example, NUMINST = 2, NLST = 3, ICALC = 1, the sequence of records for Item 4 would be: 4a, 4b, 4c, 4d, 4b, 4c, 4d, 4b, 4c, 4d, 4a, 4b, 4c, 4d, 4b, 4c, 4d, 4b, 4c, and 4d.

Note 13: Record 4b will contain 8 to 13 variables; depending on the values of ICALC and IUPSEG. (ICALC determines how stream depth is to be calculated; when ICALC is 1 or 2, depth is calculated using Manning's equation, which, in turn, requires a channel roughness coefficient (ICALC = 1) or a channel and bank roughness coefficient (ICALC = 2). Similarly, Parts 4c and 4d will include 3 to 5 values.

Note 14: A stream segment that receives inflow from upstream segments is allowed to have as many as ten upstream segments feeding it, as defined by the respective values of OUTSEG in Part 4b.

Note 15: Stream properties and stresses defined in Parts 4b are assumed constant and uniform within a single stream segment. Additionally, hydraulic conductivity, streambed thickness, elevation of top of streambed, stream width, and stream depth may vary smoothly and linearly within a single stream segment. For these variables, data values at the upstream end of the segment are described in Part 4c and data values at the downstream end of the segment are described in Part 4d. Values of these variables for individual reaches of a segment are estimated using linear interpolation. To make any variable the same throughout the segment, simply specify equal values in Parts 4c and 4d. The two elevations in Parts 4c and 4d are used in conjunction with the total length of the stream segment (calculated from RCHLEN given for each reach in Item 2) to compute the slope of the stream and the elevations for any intermediate reaches. The streambed thickness is subtracted from the top of streambed elevations to calculate the elevations of the bottom of the streambed (used in calculations of leakage).

Note 16: If Part 4e is included (for ICALC = 2), it is assumed that the cross-sectional geometry defined by these data is the same over the entire length of the segment. Similarly, if Part 4f is included (for ICALC = 4), it is assumed the tabulated relation between streamflow and stream depth and width is the same over the entire length of the segment.

Note 17: If the Lake (LAK3) Package (Merritt and Konikow, 2000) is also implemented, then flow out of the lake into a stream segment is dependent on the option used to compute stream depth (ICALC = 1, 2, 3, or 4). Constant discharge from a lake can be simulated no matter what value of ICALC is assigned to the stream segment emanating from the lake by assigning a positive value to FLOW in Part 4b.

Note 18: If a diversionary flow is large enough to warrant representation in the model, but is discharged into a pipeline, lined canal, or other structure or system that does not interact with the aquifer and the flow might exceed the available streamflow, then there is an alternative means to represent it. Instead of specifying a negative value of FLOW, we suggest representing the withdrawal by a single-reach diversionary stream segment, which would be located in the same model cell as the reach from the upstream segment (IUPSEG) from which the diversion is made; specifying the segment's streambed hydraulic conductivity equal to 0 will preclude interaction with the aquifer and setting OUTSEG = 0 will remove the flow from the system. The diversion will then be subject to the constraints associated with the value of IPRIOR.

FOR EACH STRESS PERIOD:

5. Data: ITMP IRDFLG IPTFLG {NP}

ITMP   An integer value for reusing or reading stream segment data that can change each stress period. ITMP = 0 when all stream segment data is defined by Item 4 (NSFRPAR > 0; number of stream parameters is greater than 0). If ITMP < 0, then stream segment data not defined in Item 4 will be reused from the last stress period (Item 6 is not read for the current stress period). If ITMP > 0, then stream segment data not defined in Item 4 (for a number of segments equal to the value of ITMP) will be defined in Item 6 below. ITMP must be defined ≥ 0 for the first stress period of a simulation.

IRDFLG   An integer value for printing input data specified for this stress period. If IRDFLG = 0, input data for this stress period will be printed. If IRDFLG > 0, then input data for this stress period will not be printed.

IPTFLG   An integer value for printing streamflow-routing results during this stress period. If IPTFLG = 0, or whenever the variable ICBCFL is specified, the results for specified time steps during this stress period will be printed. If IPTFLG > 0, then the results during this stress period will not be printed.

NP   An integer value of the number of parameters used in the current stress period. The parameters being used are subsequently listed in Item 7 below. NP and Item 7 below are not read when NSFRPAR = 0.

Note 20: In each stress period, the sum of ITMP plus the sum of all NLST values in Item 3 associated with the NP parameters listed in Item 7 must equal or be less than (some stream segments may not be active during a stress period) the total number of stream segments in the stream network (NSS of Item 1). Stream segments defined by Items 3, 4, and 7 cannot be repeated using ITMP and Item 6.

Items 6a and 6b: Items 6a and 6b may include no input when all are defined by stream reaches in Item 2 or they may include as many as nine variables, depending on the values of REACHINPUT, ISFROPT, and ICALC specified in Items 1 and 4a.

If ITMP > 0:

6a. Data: NSEG ICALC OUTSEG IUPSEG {IPRIOR} {NSTRPTS} FLOW RUNOFF ETSW PPTSW {ROUGHCH} {ROUGHBK} {CDPTH} {FDPTH} {AWDTH} {BWDTH}

See Item 4, Part 4b for variable definitions in item 6a.

6b. Data: {HCOND1} {THICKM1} {ELEVUP} {WIDTH1} {DEPTH1} {THTS1} {THTI1} {EPS1} {UHC1}

HCOND1   Hydraulic conductivity of the streambed at the upstream end of this segment (units of length per time). This variable is read for each stress period when NSTRM is positive or when REACHINPUT has been specified and ISFROPT is 0, 4, or 5.

THICKM1   Thickness of streambed material at the upstream end of this segment (in units of length). This variable is read each stress period for all segments when NSTRM is positive or when REACHINPUT has been specified and ISFROPT is 0. When ISFROPT is 4 or 5, the variable is read each stress period for a segment when ICALC is 0, 3, or 4, and is read only the first stress period when ICALC is 1 or 2.

ELEVUP   Elevation of the top of the streambed at the upstream end of this segment (in units of length). This variable is read each stress period for all segments when NSTRM is positive or when REACHINPUT has been specified and ISFROPT is 0. When ISFROPT is 4 or 5, the variable is read each stress period for a segment when ICALC is 0, 3, or 4, and is read only the first stress period when ICALC is 1 or 2.

WIDTH1   Average width of the stream channel at the upstream end of this segment (in units of length). This variable is read each stress period for all segments identified with an ICALC of 0 and is not dependent on ISFROPT. When ICALC is 1, the variable is read each stress period when NSTRM is positive or when REACHINPUT has been specified and ISFROPT is 0 or 1, and is read only for the first stress period when ISFROPT is 2, 3, 4, or 5.

DEPTH1   Average depth of water in the channel at the upstream end of this segment (units of length). This variable is only specified if ICALC is 0 and is not dependent on the value of NSTRM or ISFROPT. The stream stage in a reach is assumed to equal the elevation of the top of the streambed plus the depth of water.

THTS1   Saturated volumetric water content in the unsaturated zone beneath the upstream end of this segment. This variable is read for the first stress period when ICALC is 1 or 2 and ISFROPT is 4 or 5.

THTI1   Initial volumetric water content beneath the upstream end of this segment. THTI1 must be less than or equal to THTS and greater than or equal to THTS minus the specific yield defined in either LPF, BCF, or HUF. This variable is read for the first stress period when ICALC is 1 or 2 and ISFROPT is 4 or 5.

EPS1   Brooks-Corey exponent used in the relation between water content and hydraulic conductivity within the unsaturated zone beneath the upstream end of this segment. This variable is read for the first stress period when ICALC is 1 or 2 and ISFROPT is 4 or 5.

UHC1   Vertical saturated hydraulic conductivity of the unsaturated zone beneath the upstream end of this segment. This variable is necessary when using BCF or HUF, whereas it is optional when using LPF. This variable is read only for the first stress period when ICALC is 1 or 2 and ISFROPT is 5.

6c. Data: {HCOND2} {THICKM2} {ELEVDN} {WIDTH2} {DEPTH2}{THTS2} {THTI2} {EPS2} {UHC2}

HCOND2   Hydraulic conductivity of the streambed at the downstream end of this segment (units of length per time). This variable is read for each stress period when NSTRM is positive or when REACHINPUT has been specified and ISFROPT is 0, 4, or 5.

THICKM2   Thickness of streambed material at the downstream end of this segment (in units of length). This variable is read each stress period for all segments when NSTRM is positive or when

REACHINPUT has been specified and ISFROPT is 0. When ISFROPT is 4 or 5, the variable is read each stress period for a segment when ICALC is 0, 3, or 4, and is read only the first stress period when ICALC is 1 or 2.

ELEVDN   Elevation of the top of the streambed at the downstream end of this segment (in units of length). This variable is read each stress period for all segments when NSTRM is positive or when REACHINPUT has been specified and ISFROPT is 0. When ISFROPT is 4 or 5, the variable is read each stress period for a segment when ICALC is 0, 3, or 4, and is read only the first stress period when ICALC is 1 or 2.

WIDTH2   Average width of the stream channel at the downstream end of this segment (in units of length). This variable is read each stress period for all segments identified with an ICALC of 0 and is not dependent on ISFROPT. When ICALC is 1, the variable is read each stress period when NSTRM is positive or when REACHINPUT has been specified and ISFROPT is 0 or 1, and is read only for the first stress period when ISFROPT is 2, 3, 4, or 5.

DEPTH2   Average depth of water in the channel at the downstream end of this segment (units of length). This variable is only specified if ICALC is 0 and is not dependent on the value of NSTRM or ISFROPT. The stream stage in a reach is assumed to equal the elevation of the top of the streambed plus the depth of water.

THTS2   Saturated volumetric water content in the unsaturated zone beneath the downstream end of this segment. This variable is read for the first stress period when ICALC is 1 or 2 and ISFROPT is 4 or 5.

THTI2   Initial volumetric water content beneath the downstream end of this segment. THTI2 must be less than or equal to THTS and greater than or equal to THTS minus the specific yield defined in either LPF, BCF, or HUF. This variable is read for the first stress period when ICALC is 1 or 2 and ISFROPT is 4 or 5.

EPS2   Brooks-Corey exponent used in the relation between water content and hydraulic conductivity within the unsaturated zone beneath the downstream end of this segment. This variable is read for the first stress period when ICALC is 1 or 2 and ISFROPT is 4 or 5.

UHC2   Vertical saturated hydraulic conductivity of the unsaturated zone beneath the downstream end of this segment. This variable is necessary when using BCF or HUF, whereas it is optional when using LPF. This variable is read only for the first stress period when ICALC is 1 or 2 and ISFROPT is 5.

Note 21: Stream properties and stresses are assumed to be constant and uniform within a single stream segment. Additionally, hydraulic conductivity, streambed thickness, elevation of the top of streambed, stream width, and stream depth may vary smoothly and linearly within a single stream segment. For these variables, data values at the upstream end of the segment are described in Item 4b and data values at the downstream end of the segment are described in Item 4c. Values of these variables for individual reaches of a segment are estimated using linear interpolation. To make any variable the same throughout the segment, simply specify equal values in Items 4b and 4c. The two elevations in Items 4b and 4c are used in conjunction with the total length of the stream segment (calculated from RCHLEN given for each reach in Item 2) to compute the slope of the stream and the elevations for any intermediate reaches. The streambed thickness is subtracted from the top of the streambed elevations to calculate the elevations of the bottom of the streambed (used in calculations of leakeage).

If ICALC = 2:

6d.   Data: XCPT1 XCPT2 ... XCPT8
           Data: ZCPT1 ZCPT2 ... ZCPT8

See Item 4, Part 4e for variable definitions. These variables are read only for the first stress period when ISFROPT is 2, 3, 4, or 5.

If ICALC = 4:

6e.   `Data: FLOWTAB(1) FLOWTAB(2) ... FLOWTAB(NSTRPTS)`
       `Data: DPTHTAB(1) DPTHTAB(2) ... DPTHTAB(NSTRPTS)`
       `Data: WDTHTAB(1) WDTHTAB(2) ... WDTHTAB(NSTRPTS)`

If keyword TABFILES has been specified, repeat Item 4f NUMTAB times for the first stress period only:

4f. Data: SEGNUM NUMVAL IUNIT

SEGNUM   An integer value equal to the segment number to which the specified inflows will be applied.

NUMVAL   An integer value equal to the number of rows in the tabular inflow file. Each inflow file may contain a different number of rows, but the number of rows in any file cannot exceed MAXVAL specified in Item 1b.

IUNIT   An integer value equal to the unit number of the tabular inflow file. IUNIT must match the unit number for the file specified in the Name File.

Note 22: The external files that contain the specified inflows are referred to as tabular flow files. Each tabular file consists of two columns of input that are read using free format: TIME and INFLOW. Time is the point in the simulation when the inflow is specified for the segment; INFLOW is the specified flow, in units of length cubed per time. The units for TIME and INFLOW should be consistent with those specified for variables ITMUNI and LENUNI in the MODFLOW Discretization File. Times listed in the tabular flow file do not need to correspond to the beginning of MODFLOW time steps. If the beginning of the MODFLOW time steps fall between times listed in the tabular flow file, then the specified inflow is calculated using a time-weighted average of specified flows within the MODFLOW time step. Times can be listed in the tabular flow file either more frequently or less frequently than the MODFLOW time steps.

Note 23: Item 6 must be completed ITMP times. The data need not be defined in sequential order by stream segment number. All active segments in the stream network must be defined for each stress period through a combination of ITMP and Item 6 and NP and Item 7.

Note 24: If ITMP ≤ 0, then Item 6 is excluded for this stress period. If ITMP < 0, then values for Item 6 from the previous stress period are reused. If ITMP = 0, then no Item 6 records are read, and all segments must be defined using parameters.

Note 26: All the explanatory notes applicable to Item 4 (except those related to parameters) are also relevant to Item 6.

If NP > 0, then:

7. `Data: Pname [Iname]`

Pname	The name of a parameter that is being used in the current stress period. Repeat Item 7 NP times (see Item 5).
Iname	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.

Example SFR2 input file demonstrating the use of the REACHINPUT and TABFILES functionalities
The following is part of an example SFR2 input file that demonstrates the REACHINPUT and TABFILES functionalities. The example was developed from the 'testsfr2' example that is provided with the MODFLOW-USG distribution. The example uses one stream segment that consists of 100 reaches:

```
# SFR2 Package input file for hypothetical test simulation
# Example using keyword options
REACHINPUT Item 1a
TABFILES 1 50 Item 1b
100 1 0 0 1.0 0.00001 -1 0 5 10 5 20 0 Item 1c: NSTRM NSS NSFRPAR NPARSEG
CONST DLEAK ISTCB1 ISTCB2 {ISFROPT} {NSTRAIL} {ISUZN} {NSFRSETS} {IRTFLG}
1 4 1 1 1 200.0                               Item 2
1 4 2 1 2 200.0
1 4 3 1 3 200.0
     … (97 lines of input deleted here)
1 0 0 0                                       Item 3: stress period 1
1 2 0 0 .3 0.0 0.0 0.0 0.030 .04       Item 4a:
.00000035 0.5 140. .3 .1 3.5 6.0e-6    Item 4b:
.00000035 0.5 110. .3 .1 3.5 6.0e-6    Item 4c:
0. 2. 4. 6. 8. 10. 12. 14. Item 4d:
6.0 4.5 3.5 0. 0.3 3.5 4.5 6.           Item 4d:
1 50 55                                 Item 4f: SEGNUM NUMVAL IUNIT
```

The tabular flow file has been assigned IUNIT 55 and Fname 'testsfr2.tab' in the Name File:

```
data 55 testsfr2.tab
```

File 'testsfr2.tab' has 50 lines of data, the first five of which are:

```
0 0.30                                         TIME INFLOW
2592000 2.53
5184000 3.84
7776000 17.85
10368000 20.26
```

The time and inflow values specified in each tabular flow file are echoed to the MODFLOW-USG LIST file.

Stream Gaging (Monitoring) Station File (GAGE)

Cells of the model grid can be designated as "stream gaging station" locations. At each designated cell (or stream reach), the time, stage, streamflow out of that reach, the streambed seepage, unsaturated storage, change in unsaturated storage, and ground-water recharge will be written to a separate output file to facilitate model output evaluation and graphical post processing of the calculated data. Several options are available to print additional information. The input file for specifying gaging station locations is read if the file type (Ftype) "GAGE" is included in the MODFLOW name file. The output file will contain two header lines that provide relevant information (the text will be contained within quotes).

For Each Simulation, if Gage Package is Used:

1. `Data: NUMGAGE`

NUMGAGE   Number of gaging stations.

For Each Gaging Station:

2. `Data: {GAGESEG GAGERCH} {LAKE} UNIT OUTTYPE`

GAGESEG   An integer value that is the stream segment number where gage is located. This value only is specified for stream gages.

GAGERCH   An integer value that is the stream reach number where gage is located. This value only is specified for stream gages.

LAKE An integer value equal to the negative of the lake number. This value only is specified for lake gages.

UNIT   An integer value that is the unit number of output file for this gage. For a gaging station on a lake, a minus sign on the unit number is a flag indicating that OUTTYPE for a lake will be read.

OUTTYPE   An integer value that is a flag for type of expanded listing desired in output file.

If UNIT>0 then OUTTYPE specifies the following output options for streams:

0	Use standard default listing of time, stage, and outflow.
1	Default values plus depth, width, and flow at midpoint.
2	Default values plus streambed conductance for the reach, head difference across streambed, and hydraulic gradient across streambed.
3	This option was originally created for printing output related to the Groundwater Transport Process (GWT), which is not supported in MODFLOW-USG. Thus, this option is identical to option 2.
4	All of the above.
5	Used for diversions to provide a listing of time, stage, flow diverted, maximum assigned diversion rate, and flow at end of upstream segment prior to diversion.

If UNIT<0 then OUTTYPE specifies the following output options for **lakes:**

0	Use standard default listing of time, stage, and volume.
1	Standard default listing plus precipitation, ET, runoff, groundwater inflow, groundwater outflow, surface water inflow, surface water outflow, specified withdrawal, volume change, total conductance, and percent error in lake budget.

2   Default values plus change in lake stage over time step, change in lake volume over time step, cumulative change in lake stage, cumulative change in lake volume, and cumulate percent error in lake budget.

3   Default values plus precipitation, ET, runoff, groundwater inflow, groundwater outflow, surface water inflow, surface water outflow, specified withdrawal, change in stage and volume, cumulative change in stage and volume, cumulative error in lake budget.

4   Standard default listing plus the rate of change in lake volume, precipitation, ET, runoff, groundwater inflow, groundwater outflow, surface water inflow, surface water outflow, specified withdrawal, volume change, total conductance, and percent error for lake budget for the time step.

Note 1: A unique unit number must be specified for each stream gaging station and the MODFLOW name file (see Harbaugh and others, 2000, p. 42-44) must specify the file for each unit. The file type in the name file must be "DATA".

Note 2: If the LAK3 Package is also active, a gaging station may be placed on a lake. In this case, only two required variables and one optional variable are read. The first variable should be the negative value of the lake number and the second is the unit number for the output. The original description of the Gage Package (Merritt and Konikow, 2000, p. 57) did not include additional print options listed for OUTTYPE. For a gaging station on a lake, a minus sign on the unit number is a flag indicating that OUTTYPE for a lake will be read.

Note 3: Data Set 2 must include exactly NUMGAGE lines (records) of data. If NUMGAGE > 1, it is permissible to interleaf the Item 2 lines for stream gaging stations with lines for lake gages. Data lines (records) within Item 2 can be listed in any arbitrary order.

Note 4: The GWT process and the UZF1 package are not supported in MODFLOW-USG. Thus, values of OUTTYPE greater than 5 are not supported in MODFLOW-USG.

Lake (LAK) Package

Lake Package

MODFLOW Name File

The simulation of the interaction of lakes with the aquifer is activated by including a record in the MODFLOW name file using the file type (Ftype) "LAK" to indicate that such calculations are to be made in the model and to specify the related input data file. The user can optionally specify that lake stages are to be written using the Gage Package by including a record in the MODFLOW name file using the file type (Ftype) "GAGE" that specifies the selected input data file identifying the lakes.

Lake Package Input Data

The lake package of MODFLOW-USG can currently be used only with vertically stacked grids. Thus, if nesting or irregular grids are used in the lateral direction, the same grid is used in all layers. If that is not the case, MODFLOW-USG will print a statement indicating so, and exit.

Input for the Lake Package is read from the unit specified in the MODFLOW name file. The input consists of nine separate data sets, each consisting of one or more records, as described in detail below. These data are used to specify information about the physical geometry of the lakes, hydraulic properties of the lakebeds, and the degree of hydraulic stress originating from atmospheric and anthropogenic sources, as well as specifying certain output control parameters. Spatial and temporal units of input data specifications should be consistent with other data input for the MODFLOW run.

In the following section, parameters are indicated as being optional by their enclosure in brackets. All input variables are read using free formats, unless specifically indicated otherwise. In free format, variables are separated by one or more spaces, or by a comma and, optionally, one or more spaces. It is important to note that, in free format, blank spaces are not read as zeroes and a blank field cannot be used to set a parameter value to zero.

For Each Simulation:

These data are read by module LAK3AL.

Record 1a. Data: TABLEINPUT

TABLEINPUT An optional character variable used for activating the option to specify text files containing relationships between lake stage, surface area and volume. A separate text file is specified for each lake, each file contains exactly 151 lines, and each line consists of one value for lake stage, volume and surface area, respectively. If the keyword "TABLEINPUT" is entered on the first line (record) of the data set, then Record 4 (described below) will be read. These tables are used for calculating water balances within lakes; however, calculation of seepage between lakes and groundwater is unchanged from the original LAK3 Package on the basis of the lake and groundwater discretization (Merritt and Konikow, 2000).

Record 1b. Data: NLAKES   ILKCB

NLAKES   Number of separate lakes.
ILKCB   Whether or not to write cell-by-cell flows (yes if ILKCB> 0, no otherwise). If ILKCB< 0 and ICBCFL is not equal to 0, the cell-by-cell flows will be printed in the standard output file.

Notes:

1. Sublakes of multiple-lake systems are considered separate lakes for input purposes. The variable NLAKES is used, with certain internal assumptions and approximations, to dimension arrays for the simulation.

2. If data are being read using the fixed format mode, then each field should be entered using I10 format.

3. ICBCFL is specified in the input to the Output Control Package of MODFLOW.

Record 2. Data: THETA {NSSITR SSCNCR SURFDEP}

THETA   A new method of solving for lake stage uses only the time-weighting factor THETA (Merritt and Konikow, 2000, p. 52) for transient simulations. THETA is automatically set to a value of 1.0 for all steady-state stress periods. For transient stress periods, Explicit (THETA = 0.0), semi-implicit (0.0 < THETA < 1.0), or implicit (THETA = 1.0) solutions can be used to calculate lake stages. The option to specify negative values for THETA is supported to allow specification of additional variables (NSSITER, SSCNCR, SURFDEP) for simulation that only include transient stress periods. If THETA is specified as a negative value then it is converted to a positive value for calculations of lake stage.

NSSITR   Maximum number of iterations for Newton's method solution for equilibrium lake stages in each
              MODFLOW iteration for steady-state aquifer head solution. Only read if ISS (option flag input to
              BCF Package of MODFLOW indicating steady-state solution) is not zero or if THETA is
              specified as a negative value.

SSCNCR   Convergence criterion for equilibrium lake stage solution by Newton's method. Only read if ISS
is not zero or if THETA is specified as a negative value.

SURFDEP   The height of small topological variations (undulations) in lake-bottom elevations that can affect groundwater discharge to lakes. SURFDEPTH decreases the lakebed conductance for vertical flow across a horizontal lakebed caused both by a groundwater head that is between the lakebed and the lakebed plus SURFDEPTH and a lake stage that is also between the lakebed and the lakebed plus SURFDEPTH. This method provides a smooth transition from a condition of no groundwater discharge to a lake, when groundwater head is below the lakebed, to a condition of increasing groundwater discharge to a lake as groundwater head becomes greater than the elevation of the dry lakebed. The method also allows for the transition of seepage from a lake to groundwater when the lake stage decreases to the lakebed elevation. Values of SURFDEPTH ranging from 0.01 to 0.5 have been used successfully in test simulations. SURFDEP is read only if THETA is specified as a negative value.

Notes:

1. If data are being read using the fixed format mode, then the data should be entered using a F10.4 format statement for floating point numbers and I10 format statement for integer numbers.

2. If the model simulation includes a steady-state stress period, then the number of iterations (NSSITER) and the closure tolerance (SSCNCR) defined by Merritt and Konikow (2000, p. 52) for ending the Newton iteration method is used for all subsequent transient or steady-state stress periods. If the model simulation only includes transient stress periods, a default value of 0.0001 is assigned to SSCNCR and a default value of 100 is assigned to NSSITR. An option was added in which values of SSCNCR and NSSITR can be read for a transient only simulation by specifying a negative value for THETA. If THETA is specified as a negative value then it is converted to a positive value for calculations of lake stage.

For the First Stress Period Only:

These data are read by module LAK3RP.

Record 3. Data: STAGES {SSMN SSMX} {IUNITAB}

STAGES   The initial stage of each lake at the beginning of the run.

SSMN   Minimum stage allowed for each lake in steady-state solution. Omit for transient simulations.

SSMX   Maximum stage allowed for each lake in steady-state solution. Omit for transient simulations.

IUNITAB   The unit number of the text file containing relationships between lake stage, surface area and volume. Only read if the keyword "TABLEINPUT" is entered on the first line (record) of the input file.

Notes:

1. This data set should consist of one line for each lake, where line 1 includes data for lake 1, and line *n* includes data for lake *n*. There must be exactly NLAKES lines of data.

2. SSMN and SSMX are not specified for a transient run and must be omitted when the solution is transient. For simulations that do not include a steady state stress period, the minimum and maximum values of lake stage for calculated based on the lowest elevation of the lakebed and the and highest elevation of the cell tops for all lake cells for a particular lake, respectively.

3. If data are being read using the fixed format mode, then each field should be entered using F10.4 format statement.

Record 4. Data: {STAGELAKE   VOLUMELAKE   AREALAKE}

STAGELAKE   are the lake stage values. These values should include lake stage values over the range that could occur in the simulation. This variable only is read when the keyword "TABELINPUT" is specified in item 1a.

VOLUMELAKE are the lake volume values corresponding to the values specified for STAGELAKE. This variable only is read when the keyword "TABELINPUT" is specified in item 1a.

AREALAKE are the lake surface area values corresponding to the values specified for STAGELAKE. This variable only is read when the keyword "TABELINPUT" is specified in item 1a.
Notes:

1. Record 4 must be repeated NLAKES times if the keyword "TABLEINPUT" is specified, otherwise Record 4 is excluded.

For Each Stress Period:

These data are read by module LAK3RP.

Record 5. Data: ITMP   ITMP1   LWRT

ITMP   > 0, read lake definition data (records 5-7, and, optionally, records 8 and 9);
                   = 0, no lake calculations this stress period;
                   < 0, use lake definition data from last stress period.

ITMP1   > 0 or = 0, read new recharge, evaporation, runoff, and withdrawal data for each lake, and
                   associated concentrations if needed for MOC3D runs;
                   < 0, use recharge, evaporation, runoff, and withdrawal data, and concentrations, if needed, from
                   last stress period.

LWRT   > 0, suppresses printout from the lake package.

Notes:

1. ICBCFL < 0 or = 0 also suppresses printout from the lake package. ICBCFL is specified in the input to the Output Control Package of MODFLOW.

2. If data are being read using the fixed format mode, then each field should be entered using I10 format.

3. Lake definition data are restricted to cells for which IBOUND and WETDRY values have been set to zero.
If ITMP > 0:

Record 6. Data: LKARR(NCOL,NROW) or LKARR(NDSLAY)

A NCOL by NROW array is read for each layer in the grid by MODFLOW module U2DINT for structured grids. For unstructured grids, an array of length NDSLAY is read for each layer in the grid where NDSLAY, the number of nodes per layer may vary for the different layers. Hence, Record 6 is repeated for each of the NLAY layers of the grid for structured or unstructured grids.

LKARR   A value is read in for every grid cell. If LKARR(I,J,K) = 0, the grid cell is not a lake volume cell.
              If LKARR(I,J,K) > 0, its value is the identification number of the lake occupying the grid cell.
              LKARR(I,J,K) must not exceed the value NLAKES. If it does, or if LKARR(I,J,K) < 0,
              LKARR(I,J,K) is set to zero.
Notes:

1. Lake cells cannot be overlain by non-lake cells in a higher layer.

Record 7. Data: BDLKNC(NCOL,NROW) or BDLKNC(NDSLAY)

A NCOL by NROW array is read for each layer in the grid by MODFLOW module U2DREL for structured grids. For unstructured grids, an array of length NDSLAY is read for each layer in the grid where NDSLAY, the number of nodes per layer may vary for the different layers. Hence, Record 7 is repeated for each of the NLAY layers of the grid for structured or unstructured grids.

BDLKNC   A value is read in for every grid cell. The value is the lakebed leakance that will be assigned to
              lake/aquifer interfaces that occur in the corresponding grid cell.

Notes:

1. If the wet-dry option flag (IWTFLG) is not active (cells cannot rewet if they become dry), then the BDLKNC values are assumed to represent the combined leakances of the lakebed material and the aquifer material between the lake and the centers of the underlying grid cells, i. e., the vertical conductance values (CV) will not be used in the computation of conductances across lake/aquifer boundary faces in the vertical direction.

2. IBOUND in the input to the Basic Package of MODFLOW and, if the IWTFLG option is active, WETDRY in the input to the BCF or other flow package of MODFLOW, should be set to zero for every cell for which LKARR is not equal to zero.

If ITMP > 0:

Record 8. Data: NSLMS

NSLMS   The number of sublake systems if coalescing/dividing lakes are to be simulated (only in transient runs). Enter 0 if no sublake systems are to be simulated.

Notes:

1. If data are being read using the fixed format mode, then NSLMS should be entered using format I5.

If ITMP > 0 and NSLMS > 0:

Record 9a. Data: IC   ISUB(1)   ISUB(2)   .... ISUB(IC)

Record 9b. Data: SILLVT(2)   .... SILLVT(IC)

IC   The number of sublakes, including the center lake, in the sublake system being described in this record.
ISUB   The identification numbers of the sublakes in the sublake system being described in this record. The center lake number is listed first.
SILLVT   Sill elevation that determines whether the center lake is connected with a given sublake. One value is entered in this record for each sublake in the order the sublakes are listed in the previous record.

Notes:

1. A pair of records (records 9a and 9b) is read for each multiple-lake system, i.e., NSLMS pairs of records. However, IC = 0 will terminate the input.

2. If data are being read using the fixed format mode, then each field of Record 9a should be entered using I5 format and each field of Record 9b should be entered using F10.4 format.

If ITMP1 > 0 or = 0.

Record 10. Data: PRCPLK   EVAPLK   RNF   WTHDRW

PRCPLK   The rate of precipitation per unit area at the surface of a lake (L/T).

EVAPLK   The rate of evaporation per unit area from the surface of a lake (L/T).

RNF   Overland runoff from an adjacent watershed entering the lake. If RNF > 0, it is specified directly
                as a volumetric rate, or flux (L3/T). If RNF < 0, its absolute value is used as a dimensionless
                multiplier applied to the product of the lake precipitation rate per unit area (PRCPLK) and the
                surface area of the lake at its full stage (occupying all layer 1 lake cells).

WTHDRW   The volumetric rate, or flux (L3/T), of water removal from a lake by means other than rainfall,
                evaporation, surface outflow, or ground-water seepage. A negative value indicates augmentation.
                Normally, this would be used to specify the rate of artificial withdrawal from a lake for human
                water use, or if negative, artificial augmentation of a lake volume for esthetic or recreational
                purposes.

Notes:

When RNF is entered as a dimensionless multiplier (RNF < 0), it is considered to be the product of two proportionality
factors. The first is the ratio of the area of the basin contributing runoff to the surface area of the lake when it is at full stage.
The second is the fraction of the current rainfall rate that becomes runoff to the lake. This procedure provides a means for the
automated computation of runoff rate from a watershed to a lake as a function of varying rainfall rate. For example, if the
basin area is 10 times greater than the surface area of the lake, and 20 percent of the precipitation on the basin becomes
overland runoff directly into the lake, then set RNF = -2.0.

**If keyword "TABLEINPUT" is specified in item 1a then the following data are required, where 1 file is
required for each lake:**

Data: {STAGELAKE   VOLUMELAKE   AREALAKE}

STAGELAKE   are the lake stage values. These values should include lake stage values over the range that could
occur in the simulation.

VOLUMELAKE are the lake volume values corresponding to the values specified for STAGELAKE.

AREALAKE are the lake surface area values corresponding to the values specified for STAGELAKE.

Notes:

1. Exactly 151 lines must be included within each lake bathymetry input file and each line must contain 1 value of
lake stage, volume, and area (3 numbers per line) if the keyword "TABLEINPUT" is specified in item 1a. A
separate file is required for each lake. Thus, if there are 4 lakes in a simulation then 4 lake bathymetry files are
required.

Example LAK3 input file demonstrating the use of the TABLEINPUT functionality

The following is part of an example LAK3 input file that demonstrates the TABLEINPUT functionality. The
example was developed from the 'l1b2k' example that is provided with the MODFLOW-2005 distribution. The
example consists of 1 lake within a 2 layer groundwater model.

```
# Modified version of LAK3 test problem "l1b2k"
# Example input for specifying lake bathymetry information using external
# text files using key word option "TABLEINPUT"
TABLEINPUT               Item 1a: KEY WORD
     1     0              Item 1b: NLAKES,ILKCB
```

```
 0.00     50   0.001        Item 2:  THETA,NSSITER,SSCNCR
110.    100.    170.  22   Item 3:STAGES,SSMN,SSMX,IUNITLAKTAB
   1     0      0
```
.

.

.

The rest of the 46 lines of 'l1b2k_bath.lak' were omitted.

The lake bathymetry file has been assigned IUNIT 22 and Fname 'l1b2k_bath.lak' in the Name File:

DATA 22 lak1b_bath.txt

File 'lak1b_bath.txt' has 151 lines of data, the first five of which are:

```
9.70000E+01  0.00000E+00  2.25000E+06
9.96867E+01  6.04500E+06  2.25000E+06
1.02373E+02  1.20900E+07  2.25000E+06
1.05060E+02  1.81350E+07  2.25000E+06
1.07747E+02  3.49267E+07  6.25000E+06
```

Subsidence (SUB) Package

Input for the SUB Package is read from the file that has the type "SUB" in the name file. Optional variables are shown in brackets. All single-valued variables in data items 1, 15, and 16, layer assignments for systems of interbeds in data items 2 and 3, and material properties in data item 9 are read in free format. Data items 1, 2, 3, and 15 consist of at most one record. For structured grids, the two-dimensional arrays in data items 4-8 and 10-14 are read with MODFLOW-2000 utility array readers U2DREL and U2DINT. For instructions on use of array readers, refer to Harbaugh and others (2000). For unstructured grids, the one-dimensional arrays in data items 4-8 and 10-14 are read with MODFLOW-USG utility array readers U1DREL and U1DINT.

FOR EACH SIMULATION

1. ISUBCB ISUBOC NNDB NDB NMZ NN AC1 AC2 ITMIN IDSAVE IDREST
(Enter integers for variables other than AC1 and AC2, which are floating-point variables.)

2. [LN(NNDB)] if NNDB > 0
(Enter NNDB integers separated by one or more spaces or by commas.)

3. [LDN(NDB)] if NDB > 0
(Enter NDB integers separated by one or more spaces or by commas.)

If *UNSTRUCTURED* option is used then read item 4a, or for structured grid read item 4b.
4a. [RNB(NODLAY(1))] U1DREL if NDB > 0, where NODLAY(1) is the number of nodes in layer 1.

4b. [RNB(NCOL,NROW)] U2DREL if NDB > 0
(One array for each of the NDB systems of interbeds)

The following four arrays are needed to describe the initial conditions and properties of each of the NNDB systems of no-delay interbeds. All of the arrays (items 5–8) for system 1 are read first; then all of the arrays for the remaining systems.

If *UNSTRUCTURED* option is used then read item 5a, or for structured grid read item 5b.
5a. [HC(NODLAY(1))] U1DREL if NNDB > 0, where NODLAY(1) is the number of nodes in layer 1.

5b. [HC(NCOL,NROW)] U2DREL if NNDB > 0

If *UNSTRUCTURED* option is used then read item 6a, or for structured grid read item 6b.
6a. [Sfe(NODLAY(1))] U1DREL if NNDB > 0, where NODLAY(1) is the number of nodes in layer 1.

6b. [Sfe(NCOL,NROW)] U2DREL if NNDB > 0

If *UNSTRUCTURED* option is used then read item 7a, or for structured grid read item 7b.
7a. [Sfv(NODLAY(1))] U1DREL if NNDB > 0, where NODLAY(1) is the number of nodes in layer 1.

7b. [Sfv(NCOL,NROW)] U2DREL if NNDB > 0

If *UNSTRUCTURED* option is used then read item 8a, or for structured grid read item 8b.
8a. [Com(NODLAY(1))] U1DREL if NNDB > 0, where NODLAY(1) is the number of nodes in layer 1.

8b. [Com(NCOL,NROW)] U2DREL if NNDB > 0

9. [DP(NMZ,3)] if NDB > 0
(Use one record for each material zone. Data item includes NMZ records, each with a value of vertical hydraulic conductivity, elastic specific storage, and inelastic specific storage)

The following five arrays are needed to describe the initial conditions and properties of each of the NDB systems of delay interbeds. All of the arrays (items 10-14) for system 1 are read first; then all of the arrays for the remaining systems.

If *UNSTRUCTURED* option is used then read item 10a, or for structured grid read item 10b.
10a. [Dstart(NODLAY(1))] U1DREL if NDB > 0, where NODLAY(1) is the number of nodes in layer 1.

10b. [Dstart(NCOL,NROW)] U2DREL if NDB > 0

If *UNSTRUCTURED* option is used then read item 11a, or for structured grid read item 11b.
11a. [DHC(NODLAY(1))] U1DREL if NDB > 0, where NODLAY(1) is the number of nodes in layer 1.

11b. [DHC(NCOL,NROW)] U2DREL if NDB > 0

If *UNSTRUCTURED* option is used then read item 12a, or for structured grid read item 12b.
12a. [DCOM(NODLAY(1))] U1DREL if NDB > 0, where NODLAY(1) is the number of nodes in layer 1.

12b. [DCOM(NCOL,NROW)] U2DREL if NDB > 0

If *UNSTRUCTURED* option is used then read item 13a, or for structured grid read item 13b.
13a. [DZ(NODLAY(1))] U1DREL if NDB > 0, where NODLAY(1) is the number of nodes in layer 1.

13b. [DZ(NCOL,NROW)] U2DREL if NDB > 0

If *UNSTRUCTURED* option is used then read item 14a, or for structured grid read item 14b.
14a. [NZ(NODLAY(1))] U1DINT if NDB > 0, where NODLAY(1) is the number of nodes in layer 1.

14b. [NZ(NCOL,NROW)] U2DINT if NDB > 0

15. [Ifm1 Iun1 Ifm2 Iun2 Ifm3 Iun3 Ifm4 Iun4 Ifm5 Iun5 Ifm6 Iun6] if ISUBOC > 0
(Data item 15 consists of one record with 12 integers separated by one or more spaces or by commas)

16. [ISP1 ISP2 ITS1 ITS2 Ifl1 Ifl2 Ifl3 Ifl4 Ifl5 Ifl6 Ifl7 Ifl8 Ifl9 Ifl10 Ifl11 Ifl12 Ifl13] if ISUBOC > 0.
Data item 16 consists of ISUBOC records with 17 integers separated by one or more spaces or by commas. Please see the section entitled "Package Output" for a detailed explanation of the use of data item 16.

Explanation of Variables Read by the SUB Package:

ISUBCB   is a flag and unit number.
          If ISUBCB > 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 MODFLOW-2000 Output Control (see Harbaugh and others, 2000, p. 52–55).
          If ISUBCB ≤ 0, cell-by-cell flow terms will not be recorded.

ISUBOC   is a flag used to control output of information generated by the Sub Package
          If ISUBOC > 0,   it is the number of repetitions of item 16 to be read, each repetition of which defines a set of times steps and associated flags for printing and saving subsidence, compaction, vertical displacement, preconsolidation head and volumetric budget.
          If ISUBOC ≤ 0,   volumetric budgets for systems of delay interbeds will be printed at the end of each stress period. Subsidence, compaction, vertical displacement, preconsolidation head will not be printed or saved.

NNDB   is the number of systems of no-delay interbeds.

NDB   is the number of systems of delay interbeds.

NMZ   is the number of material zones that are needed to define the hydraulic properties of systems of delay interbeds. Each material zone is defined by a combination of vertical hydraulic conductivity, elastic specific storage, and inelastic specific storage.

NN   is the number of nodes used to discretize the half space to approximate the head distributions in systems of delay interbeds.

AC1   is an acceleration parameter. This parameter ($\omega 1$ in equation 25) is used to predict the aquifer head at the interbed boundaries on the basis of the head change computed for the previous iteration. A value of 0.0 results in the use of the aquifer head at the previous iteration. Limited experience indicates that optimum values may range from 0.0 to 0.6.

AC2   is an acceleration parameter. This acceleration parameter is a multiplier for the head changes to compute the head at the new iteration ($\omega 2$ in equation 27). Values are normally between 1.0 and 2.0, but the optimum is probably closer to 1.0 than to 2.0. However, as discussed following equation 27, this parameter also can be used to help convergence of the iterative solution by using values between 0 and 1.

ITMIN   is the minimum number of iterations for which one-dimensional equations will be solved for flow in interbeds when the Strongly Implicit Procedure (SIP) is used to solve the ground-water flow equations. If the current iteration level is greater than ITMIN and the SIP convergence criterion for head closure (HCLOSE) is met at a particular cell, the one-dimensional equations for that cell will not be solved. The previous solution will be used. The value of ITMIN is not used if a solver other than SIP is used to solve the ground-water flow equations.

IDSAVE   is a flag and a unit number.
         If IDSAVE > 0,   it is the unit number on which restart records for delay interbeds will be saved at the end of the simulation. The unit number must be associated with a BINARY data file specified in the MODFLOW Name File.
         If IDSAVE ≤ 0,   restart records for delay interbeds will not be saved.

IDREST   is a flag and a unit number.
         If IDREST > 0,   it is the unit number on which restart records for delay interbeds will be read in at the start of the simulation. The unit number must be associated with a BINARY data file specified in the MODFLOW Name File.
         If IDREST ≤ 0,   restart records for delay interbeds will not be read in.

LN   is a one-dimensional array specifying the model layer assignments for each system of no-delay interbeds. The array has NNDB values.

LDN   is a one-dimensional array specifying the model layer assignments for each system of delay interbeds. The array has NDB values.

RNB   is an array specifying the factor *nequiv* (equation 20) at each cell for each system of delay interbeds. The array also is used to define the areal extent of each system of interbeds. For cells beyond the areal extent of the system of interbeds, enter a number less than 1.0 in the corresponding element of this array.

HC   is an array specifying the preconsolidation head or preconsolidation stress in terms of head in the aquifer for systems of no-delay interbeds. For any model cells in which specified HC is greater than the corresponding value of starting head, the value of HC will be set to that of starting head.

Sfe   is an array specifying the dimensionless elastic skeletal storage coefficient for systems of no-delay interbeds. Values may be estimated using equation 17.

Sfv   is an array specifying the dimensionless inelastic skeletal storage coefficient for systems of no-delay interbeds. Values may be estimated using equation 17.

COM is an array specifying the starting compaction in each system of no-delay interbeds. Compaction values computed by the package are added to values in this array so that printed or stored values of compaction and land subsidence may include previous components. Values in this array do not affect calculations of storage changes or resulting compaction. For simulations in which output values are to reflect compaction and subsidence since the start of the simulation, enter zero values for all elements of this array.

DP is an array containing a table of material properties for systems of delay interbeds. For each of the NMZ zones of material properties, vertical hydraulic conductivity, elastic specific storage, and inelastic specific storage are read.

Dstart is an array specifying starting head in interbeds for systems of delay interbeds. For a particular location in a system of interbeds, the starting head is applied to every node in the string of nodes that approximates flow in half of a doubly draining interbed.

DHC is an array specifying the starting preconsolidation head in interbeds for systems of delay interbeds. For a particular location in a system of interbeds, the starting preconsolidation head is applied to every node in the string of nodes that approximates flow in half of a doubly draining interbed. For any location at which specified starting preconsolidation head is greater than the corresponding value of the starting head, Dstart, the value of the starting preconsolidation head will be set to that of the starting head.

DCOM is an array specifying the starting compaction in each system of delay interbeds. Compaction values computed by the package are added to values in this array so that printed or stored values of compaction and land subsidence may include previous components. Values in this array do not affect calculations of storage changes or resulting compaction. For simulations in which output values are to reflect compaction and subsidence since the start of the simulation, enter zero values for all elements of this array.

DZ is an array specifying the equivalent thickness for a system of delay interbeds (*bequiv* in equation 19).

NZ is an array specifying the material zone numbers for systems of delay interbeds. The zone number for each location in the model grid selects the hydraulic conductivity, elastic specific storage, and inelastic specific storage of the interbeds.

Ifm1 is a code for the format in which subsidence will be printed. Format codes for variables Ifm1, Ifm2, Ifm3, Ifm4, Ifm5, Ifm6 are as follows:

0 - (10G11.4)	7 - (20F5.0)
1 - (11G10.3)	8 - (20F5.1)
2 - (9G13.6)	9 - (20F5.2)
3 - (15F7.1)	10 - (20F5.3)
4 - (15F7.2)	11 - (20F5.4)
5 - (15F7.3)	12 - (10G11.4)
6 - (15F7.4)	

Iun1 is the unit number to which subsidence will be written if it is saved on disk.

Ifm2 is a code for the format in which compaction by model layer will be printed.
Iun2 is the unit number to which compaction by model layer will be written if it is saved on disk.
Ifm3 is a code for the format in which compaction by interbed system will be printed.

Iun3 is the unit number to which compaction by interbed system will be written if it is saved on disk.

Ifm4 is a code for the format in which vertical displacement will be printed.

Iun4 is the unit number to which vertical displacement will be written if it is saved on disk.

Ifm5   is a code for the format in which no-delay preconsolidation head will be printed.

Iun5   is the unit number to which no-delay preconsolidation head will be written if it is saved on disk.
Ifm6   is a code for the format in which delay preconsolidation head will be printed.

Iun6   is the unit number to which delay preconsolidation head will be written if it is saved on disk.

The variables ISP1, ISP2, ITS1, ITS2, and Ifl1 through Ifl13 are used to control printing and saving of information generated by the SUB Package during program execution. The use of some of these variables is explained in more detail in the section entitled Package Output. The default condition for flags Ifl1 through Ifl13 is to not print or save the indicated information, except for printing budgets for no-delay interbeds for the last time step of each stress period.

ISP1   is the starting stress period in the range of stress periods to which output flags Ifl1 through Ifl13 apply. If the value of ISP1 is less than 1, the SUB Package will change the number to 1.

ISP2   is the ending stress period in the range of stress periods and time steps to which output flags Ifl1 through Ifl13 apply. If the value of ISP1 is greater than NPER (the number of stress periods in the simulation), the SUB Package will change the number to NPER.

ITS1   is the starting time step in the range of time steps in each of the stress periods ISP1 through ISP2 to which output flags Ifl1 through Ifl13 apply. If the value of ITS1 is less than 1, the SUB Package will change the number to 1.

ITS2   is the ending time step in the range of time steps in each of stress periods ISP1 through ISP2 to which output flags Ifl1 through Ifl13 apply. If the value of ITS2 is greater than the number of time steps in a given stress period, the SUB Package will change the number to the number of time steps in that stress period.

Ifl1   is the output flag for printing subsidence for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.
       If Ifl1 < 0,   use default or previously defined settings of Ifl1 for printing subsidence.
       If Ifl1 = 0,   do not print subsidence.
       If Ifl1 > 0,   print subsidence.

Ifl2   is the output flag for saving subsidence to an unformatted disk file for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.
       If Ifl2 < 0,   use default or previously defined settings of Ifl2 for saving subsidence.
       If Ifl2 = 0,   do not save subsidence.
       If Ifl2 > 0,   save subsidence.

Ifl3   is the output flag for printing compaction by model layer for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.
       If Ifl3 < 0,   use default or previously defined settings of Ifl3 for printing compaction by model layer.
       If Ifl3 = 0,   do not print compaction by model layer.
       If Ifl3 > 0,   print compaction by model layer.

Ifl4   is the output flag for saving compaction by model layer to an unformatted disk file for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.
       If Ifl4 < 0,   use default or previously defined settings of Ifl4 for saving compaction by model layer.
       If Ifl4 = 0,   do not save compaction by model layer.
       If Ifl4 > 0,   save compaction by model layer.

Ifl5   is the output flag for compaction by interbed system printout for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.

If Ifl5 < 0, use default or previously defined settings of Ifl5 for printing compaction by interbed system.
If Ifl5 = 0, do not print compaction by interbed system.
If Ifl5 > 0, print compaction by interbed system.

Ifl6 is the output flag for saving compaction by interbed system to an unformatted disk file for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.
If Ifl6 < 0, use default or previously defined settings of Ifl6 for saving compaction by interbed system.
If Ifl6 = 0, do not save compaction by interbed system.
If Ifl6 > 0, save compaction by interbed system.

Ifl7 is the output flag for vertical displacement printout for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.
If Ifl7 < 0, use default or previously defined settings of Ifl7 for printing vertical displacement.
If Ifl7 = 0, do not print vertical displacement.
If Ifl7 > 0, print vertical displacement.

Ifl8 is the output flag for saving vertical displacement to an unformatted disk file for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.
If Ifl8 < 0, use default or previously defined settings of Ifl8 for saving vertical displacement.
If Ifl8 = 0, do not save vertical displacement.
If Ifl8 > 0, save vertical displacement.

Ifl9 is the output flag for critical head for no-delay interbeds printout for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.
If Ifl9 < 0, use default or previously defined settings of Ifl9 for printing critical head for no-delay interbeds.
If Ifl9 = 0, do not print critical head for no-delay interbeds.
If Ifl9 > 0, print critical head for no-delay interbeds.

Ifl10 is the output flag for saving critical head for no-delay interbeds to an unformatted disk file for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.
If Ifl10 < 0, use default or previously defined settings of Ifl10 for saving critical head for no-delay interbeds.
If Ifl10 = 0, do not save critical head for no-delay interbeds.
If Ifl10 > 0, save critical head for no-delay interbeds.

Ifl11 is the output flag for critical head for delay interbeds printout for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.
If Ifl11 < 0, use default or previously defined settings of Ifl11 for printing critical head for delay interbeds.
If Ifl11 = 0, do not print critical head for delay interbeds.
If Ifl11 > 0, print critical head for delay interbeds.

Ifl12 is the output flag for saving critical head for delay interbeds to an unformatted disk file for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.
If Ifl12 < 0, use default or previously defined settings of Ifl12 for saving critical head for delay interbeds.
If Ifl12 = 0, do not save critical head for delay interbeds.
If Ifl12 > 0, save critical head for delay interbeds.

Ifl13 is the output flag for volumetric budget for delay interbeds printout for the set of time steps specified by ISP1, ISP2, ITS1, and ITS2.

If Ifl13 < 0,   use default or previously defined settings of Ifl13 for printing volumetric budget for delay interbeds.

If Ifl13 = 0,   do not print volumetric budget for delay interbeds.

If Ifl13 > 0,   print volumetric budget for delay interbeds.

Segmented Evapotranspiration (ETS) Package

The Segmented Evapotranspiration (ETS) Package for MODFLOW-USG was developed by modifying the MODFLOW-2005 ETS Package, Version 7, to be compatible with, and include the flexibility of unstructured grids.

Input to the Segmented Evapotranspiration (ETS) 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 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* NPETS]
This optional item must start with the word "PARAMETER".

2a. NETSOP IETSCB NPETS NETSEG

Item 2b is read only for an unstructured grid and NETSOP = 2
2b. MXNDETS

3. [PARNAM PARTYP Parval NCLU [INSTANCES NUMINST]]
Repeat Item 3 combined with the indicated repetitions of Item 4 NPETS times. Items 3 and 4 are not read if NPETS is negative or 0.
If PARNAM is to be a time-varying parameter, the keyword "INSTANCES" and a value for NUMINST must be entered.

4a. [INSTNAM]

4b. [Mltarr Zonarr IZ]
After each Item 3 for which the keyword "INSTANCES" is not entered, read Item 4b and not Item 4a.
After each Item 3 for which the keyword "INSTANCES" is entered, read Item 4a and Item 4b for each instance.
NCLU repetitions of Item 4b are required. Each repetition of Item 4 is called a parameter cluster. The NCLU repetitions of Item 4b follow each repetition of Item 4a when PARNAM is time varying.

FOR EACH STRESS PERIOD

5. INETSS INETSR INETSX [INIETS [INSGDF]]

If *UNSTRUCTURED* option is used, then read items 6 through 12.
6. [ETSS(INIETS)] -- U2DREL If INETSS ≥ 0

7. [ETSR(INIETS)] -- U2DREL If NPETS = 0 and if INETSR ≥ 0

8. [Pname [Iname] [IETSPF]] -- if NPETS > 0 and if INETSR > 0
Either Item 7 or Item 8 may be read, but not both. Item 8, if read, is repeated INETSR times. Iname is read if Pname is a time-varying parameter.

9. [ETSX(INIETS)] -- U2DREL If INETSX ≥ 0

10. [IETS(INIETS)] -- U2DINT If NETSOP = 2 and if INIETS ≥ 0

Read items 11 and 12 below only if NETSEG > 1. (i.e., there are more than one segment to the ET function), and INSGDF ≥ 0
11. [PXDP(INIETS)] -- U2DREL If NETSET > 1 and INSGDF ≥ 0

`12. [PETM(INIETS)] -- U2DINT If  NETSET > 1 and INSGDF` ≥ 0

Note in items 6 through 12 that INIETS is equal to the number of nodes in the top layer if NETSOP = 1 or 3. Items 6 through 12 are read for unstructured input only.

If NETSEG > 1, (NETSEG − 1) repetitions of items 11 and 12 are read. If NETSEG > 2, items 11 and 12 are read for the uppermost segment intersection, followed by repetitions of items 11 and 12 for successively lower intersections.

Otherwise, if *UNSTRUCTURED* option is not used, then read items 13 through 19 for structured input
`13. [ETSS(NCOL,NROW)] -- U2DREL If INETSS` ≥ 0

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

`15. [Pname [Iname] [IETSPF]] -- if NPETS > 0 and if INETSR > 0`
Either Item 15 or Item 16 may be read, but not both. Item 13, if read, is repeated INETSR times. Iname is read if Pname is a time-varying parameter.

`16. [ETSX(NCOL,NROW)] -- U2DREL If INETSX` ≥ 0

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

`Read items 18 and 19 below only if NETSEG > 1. (i.e., there are more than one segment to the ET function), and INSGDF` ≥ 0
`18. [PXDP(NCOL,NROW)] -- U2DREL If  NETSET > 1 and INSGDF` ≥ 0

`19. [PETM(NCOL,NROW)] -- U2DINT If  NETSET > 1 and INSGDF` ≥ 0
If NETSEG > 1, (NETSEG − 1) repetitions of items 18 and 19 are read. If NETSEG > 2, items 18 and 19 are read for the uppermost segment intersection, followed by repetitions of items 18 and 19 for successively lower intersections.

Explanation of Variables Read by the ETS 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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

NPETS—is the number of evapotranspiration parameters.

NETSOP—is the evapotranspiration (ET) option code. ET variables (ET surface, maximum ET rate, and extinction depth) are specified in layer variables, SURF, ETSR, 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 IETS.
      3—ET is applied to the highest active cell in each vertical column. A constant-head node supplies the required ET and prevents ET from occurring from ?the domain. Note that if the top-most layer is inactive for unstructured grids, this option assigns all ET flux to the first active node in the layers below. Hence if there is a vertical nesting involved, with multiple active nodes underlying an inactive node then the ET is not spread over all of these active underlying nodes. The quantity of water however, is conserved for the prescribed ET rate if the cell can provide the ET rate without becoming dry.

IETSCB—is a flag and a unit number.

If IETSCB > 0, cell-by-cell flow terms will be written to this unit number when "SAVE BUDGET" or a nonzero value for ICBCFL is specified in Output Control.

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

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.

MXNDETS—is the maximum number of nodes on which ET is applied in a simulation. This parameter is read only for an unstructured grid with NETSOP=2 (whereby the nodes on which ET is applied are a user input).

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

Parval—is the parameter value. This parameter value may be overridden by a value in the Parameter Value File.

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). Usually only one cluster is used to define an ETS non-time-varying parameter or an instance of a time-varying parameter; however, more than one cluster is acceptable.

INSTANCES—is an optional keyword that designates a parameter as time varying. The keyword is not case sensitive; that is, any combination of the same characters with different case can be used. 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 for a time-varying parameter, where each instance is a list of river reaches and associated properties. If the keyword *INSTANCES* is present, it must be followed by a value for NUMINST. If *INSTANCES* is absent, NUMINST should not be present.

INSTNAM—is the name of an instance associated with the parameter named in the corresponding Item 3. The instance name can be 1 to 10 characters and is not case sensitive. That is, any combination of the same characters with different case will be equivalent. Instance names must be unique for a parameter, but instance names may be reused for 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.

INETSS—is the ET surface (ETSS) read flag.
If INETSS≥ 0, a layer variable containing the ET surface elevation (ETSS) will be read.
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.
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 that will be used to define ETSR in the current stress period. Item 15 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 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.

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, An array containing the layer indicators (IETS) will be read for a structured grid. For an unstructured grid, INIETS is further equal to the number of nodes for which ET values are read in the simulation, with the nodes being identified in the array IETS.

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. This variable is read only if INETSS ≥ 0

ETSR—is the maximum ET flux [volumetric flow rate per unit area (LT^{-1})]. This variable is read only if INETSR ≥ 0 and if NPETS=0. Contrary to the usual convention in MODFLOW, ETSR values should be specified as positive values even though they represent an outflow from the groundwater system.

Pname—is the name of a parameter that will be used to define the ETSR variable in the current stress period. Read INETSR values if NPETS > 0 and INETSR > 0.

Iname—is an instance name that is read only if Pname is a time-varying parameter. Multiple instances of the same 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 subroutine.

ETSX—is the ET extinction depth. 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 when a structured MODFLOW grid is used. For an unstructured grid, IETS is the node number to which the ET is applied, where the list includes INIETS number of nodes. Read only if NETSOP is two and if INIETS is greater than or equal to zero.

Drain with Return Flow (DRT) Package

The Drain with Return Flow (DRT) Package for MODFLOW-USG was developed by modifying the MODFLOW-2005 DRT Package, Version 7, to be compatible with, and include the flexibility of unstructured grids. Details of the package formulation are provided in Banta (2000). [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), USGS Open File Report 00-466.]

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 multiple times.
```
1. MXADRT IDRTCB NPDRT MXL [Option]
2. [PARNAM PARTYP Parval NLST]
```
Item 3a is read only for a structured grid
```
3a. Layer Row Column Elevation Condfact [LayR RowR ColR Rfprop] [xyz]
```
Item 3b is read only for an unstructured grid
```
3b. Node Elevation Condfact [NodeR 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
```
Item 5a is read only for a structured grid
```
5a. Layer Row Column Elevation Cond [LayR RowR ColR Rfprop] [xyz]
```
Item 5b is read only for an unstructured grid
```
5b. Node Elevation Cond [NodeR 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 DRT 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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

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.

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.
Node—is the layer number of the cell containing the drain.
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.
NodR—is a flag and, if greater than 0, a node number. If auxiliary variables are being read, NodR must be greater than zero, so that Rfprop is read. NodR is not read if "RETURNFLOW" is not listed as an option in item 1.
If NodR > 0, it is the node number of the recipient cell.
If NodR = 0, there is no return flow for the drain cell, and Rfprop are not read.
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.

Connected Linear Network (CLN) Process

Input for the Connected Linear Network (CLN) Process is read from the file that is type "CLN" in the Name File.

FOR EACH SIMULATION

`0. [OPTIONS opt, …]`
This optional item must start with the keyword "OPTIONS"

`1. NCLN ICLNNDS ICLNCB ICLNHD ICLNDD ICLNIB NCLNGWC NCONDUITYP`
These variables are free format if the option "FREE" is specified in the Basic Package input file; otherwise, the variables all have 10-character fields.

If NCLN is greater than zero, then read item 2.
`2. NNDCLN(NCLN) — U1DREL`

If NCLN is greater than zero and ICLNNDS is greater than zero, then read item 3. Item 3 is read NCLN times, once for each CLN segment in the simulation. The number of entries for each line of item 3 is the number of CLN cells associated with each CLN segment, as input in item 2 above.
`3. CLNCON[NNDCLN(NCLN)]`
The variables of item 3 are free format if the option "FREE" is specified in the Basic Package input file; otherwise, the variables all have 10-character fields.

If NCLN is equal to zero, then read items 4, 5, and 6.
`4. NJA_CLN`
`5. IAC_CLN(ICLNNDS) — U1DINT`
`6. JA_CLN(NJA_CLN) — U1DINT`

`7. IFNO IFTYP IFDIR FLENG FELEV FANGLE IFLIN ICCWADI`
Item 7 is read for each CLN node in the domain. Therefore, item 7 is repeated NCLNNDS times for each of the NCLNNDS Connected Linear Network nodes or ICLNNDS if NCLN is zero.

If the GWF Process model is *UNSTRUCTURED* then read item 8.
`8. IFNOD IGWNOD IFCON FSKIN FLENGW FANISO  ICGWADI`
Item 5 is read for each CLN node to porous medium grid-block connection in the domain. Therefore, item 5 is repeated NCLNGWC times for each of the NCLNGWC connections.

Otherwise, if the GWF Process model is *STRUCTURED* then read item 9 for structured input
`9. IFNOD IGWLAY IGWROW IGWFCOL IFCON FSKIN FLENGW FANISO  ICGWADI`
Item 9 is read for each CLN node to porous medium grid-block connection in the domain. Therefore, item 9 is repeated NCLNGWC times for each of the NCLNGWC connections.

`10. ICONDUITYP FRAD CONDUITK`
Item 10 is read for each conduit categorized in the model. Therefore, item 10 is repeated NCONDUITYP times for each of the NCONDUITYP types of conduit-geometries in the model.

`11. IBOUND(NCLNNDS) — U1DINT`

`12. STRT(NCLNNDS) — U1DREL`

FOR EACH STRESS PERIOD (only if the "TRANSIENT" keyword is listed for OPTIONS)

13.   NIB0 NIB1 NIBM1

Read item 14 only if NIB0 is greater than zero
14.   IB0(NIBO) — U1DINT

Read item 15 only if NIB1 is greater than zero
15.   IB1 [HEADOPT]
Note that item 15 is read NIB1 times, one record for each node for which IBOUND is activated.

Read item 16 only if NIBM1 is greater than zero
16.   IBM1 [HEADOPT]
Note that item 16 is read NIBM1 times, one record for each node for which IBOUND is made into a prescribed head.

Explanation of Variables Read by the CLN Package:

OPTIONS are keyword options. "OPTIONS" must be listed as the first keyword in order to specify any options. The following options are supported:

> TRANSIENT indicates that transient IBOUND information will be read for each stress period.

> PRINTIAJA will print the IA_CLN and JA_CLN arrays to the listing file. These arrays correspond with the CLN-CLN flows that are written to the CLN cell-by-cell output file.

NCLN—is a flag or the number of CLN segments simulated in the model.

> If NCLN = 0, then this flag indicates that the CLN domain connectivity is input in a general IA-JA manner as is used for the GWF Process.

> If NCLN > 0, linear CLN segments (for instance multi-aquifer wells) or simple CLN networks are simulated and NCLN is the total number of CLN segments in the domain.

ICLNNDS—is a flag or number of CLN-nodes simulated in the model. Multiple CLN-nodes constitute a segment.

> If ICLNNDS < 0, the CLN-nodes are ordered in a sequential manner from the first CLN node to the last CLN node. Therefore, only linear CLN segments are simulated since a CLN segment does not share any of its nodes with another CLN segment.

> If ICLNNDS > 0, CLN networks can be simulated and ICLNNDS is the total number of CLN-nodes simulated by the model. CLN nodes can be shared among CLN segments in the network and therefore, the CLN-nodal connectivity for the network is also required as input. Note that if NCLN is zero, then ICLNNDS is the total number of CLN nodes in the model (even if the sign is negative).

ICLNCB—is a flag and a unit number.
> If ICLNCB > 0, cell-by-cell flow terms will be written to this unit number when "SAVE BUDGET" or a nonzero value for ICBCFL is specified in Output Control. The terms that are saved are storage, and flow between adjacent cells.

> If ICLNCB = 0, cell-by-cell flow terms will not be written.

If ICLNCB < 0, cell-by-cell flow for CLN cells will be written in the listing file when "SAVE BUDGET" or a non-zero value for ICBCFL is specified in Output Control.

ICLNHD—is a flag and a unit number.
If ICLNHD > 0, head output for CLN-nodes will be written to this unit number.

If ICLNHD = 0, head output for CLN-nodes will not be written.

If ICLNHD < 0, head output for CLN-nodes will be written to the same unit number (IHEDUN) as used for head output for the porous matrix nodes.

ICLNDD—is a flag and a unit number.
If ICLNDD > 0, drawdown output for CLN-nodes will be written to this unit number.

If ICLNDD = 0, drawdown output for CLN-nodes will not be written.

If ICLNDD < 0, drawdown output for CLN-nodes will be written to the same unit number (IDDNUN) as used for drawdown output for the porous matrix nodes.

ICLNIB—is a flag and a unit number.
If ICLNIB > 0, IBOUND output for CLN-nodes will be written to this unit number.

If ICLNIB = 0, IBOUND output for CLN-nodes will not be written.

If ICLNIB < 0, IBOUND output for CLN-nodes will be written to the same unit number (IBOUUN) as used for IBOUND output for the porous matrix nodes.

NCLNGWC—is the number of CLN to porous-medium grid-block connections present in the model. A CLN node need not be connected to any groundwater node. Conversely, a CLN node may be connected to multiple groundwater nodes, or multiple CLN nodes may be connected to the same porous medium mode. .

NCONDUITYP—is the number of conduit-geometry types that are present within the model.

NNDCLN—is the number of CLN-nodes that are associated with each CLN segment.
NCLNNDS—is the total number of CLN-nodes. This parameter is computed internally by the code.

$$NLFFNDS = ICLNNDS \qquad for \qquad ILCLNDS \geq 0$$
$$NCLNNDS = \sum_{NCLN} NNDCLN(NCLN) \qquad for \qquad ICLNNDS < 0$$

CLNCON—are the CLN-node numbers associated with each CLN segment.

IFNO—is the node number for the CLN node. CLN-nodes are numbered from 1 to the total number of CLN-nodes, NCLNNDS.

IFTYP—is the type-index for the CLN node. The type-index identifies this CLN segment type from the catalogue of CLN elements in a simulation. CLN types include different cross-section shapes (currently only circular conduit geometries are included) of different sizes.

IFDIR—is a directional index for the CLN-node orientation.

If IFDIR = 0, the CLN-node is oriented in the vertical direction

If IFDIR = 1, the CLN-node is oriented in the horizontal direction

If IFDIR = 2, the CLN-node is oriented at an angle to the horizontal and the angle is read in parameter FANGLE.

Note that the parameter IFDIR is utilized only to determine a CLN-node's fractional saturation to determine transients or dry conditions.

FLENG—is the length of the CLN-node.

FELEV—is the elevation of the bottom of the CLN-node.

FANGLE—is the angle made by a CLN-node segment from the horizontal. FANGLE is ignored if the parameter IFDIR is not equal to 2.

IFLIN—is a flag indicating if flow within the CLN network is to be treated as linear.

If IFLIN = 0, flow in the CLN network at this cell is treated in a nonlinear manner as per the governing equations.

If IFLIN = 1, the CLN-node is treated as linear and if this is an upstream location, it's relative permeability is fixed at unity and does not diminish to zero as the CLN cell becomes dry. This is similar to the "confined flow" option in the GW domain of MODFLOW.

ICCWADI—is a flag indicating if vertical flow correction is applied to CLN-CLN flow at this node if it is dry.

If ICCWADI = 0, flow in the CLN network at this cell is treated without vertical flow correction.

If ICCWADI = 1, vertical flow correction is applied for flow within the CLN network to this node if it is dry.

IFNOD—is the node number for the CLN node that is connected to the groundwater node.

IGWNOD—is the node number of the connecting subsurface node for unstructured grid input.

IGWLAY—is the layer number of the connecting subsurface node, for structured input.

IGWROW—is the row number of the connecting subsurface node, for structured input.

IGWCOL—is the column number of the connecting subsurface node, for structured input.

IFCON—is an index for determining the connectivity equation between CLN-node and its associated matrix node.

If IFCON = 0, the Thiem equation is used to provide the connection between CLN-node and matrix node as was done in the Multi-Node Well Package of MODFLOW-2005, without any skin effects.

If IFCON = 1, the Thiem equation is used to provide the connection between CLN-node and matrix node as was done in the Multi-Node Well Package of MODFLOW-2005, with inclusion of skin effects.

If IFCON = 2, the connection between CLN-node and matrix node is computed across a leakance term as done in the Conduit Flow Process Package of MODFLOW-2005, with leakance input to the model.

If IFCON = 3, the connection between CLN-node and matrix node is computed across a leakance term as done in the Conduit Flow Process Package of MODFLOW-2005, with skin conductivity and skin thickness input to the model and leakance computed internally as per CLN cross-sectional geometry.

FSKIN—This parameter determines the leakance across a skin, depending on which equation is selected to represent the flow between CLN cell and matrix.

If IFCON=0, the value of FSKIN is ignored and the skin resistance is taken as zero.

If IFCON=1, the value of FSKIN is the skin factor for a CLN-matrix connection that uses the Thiem Equation with skin resistance,

If IFCON=2, the value of FSKIN is the leakance of the sediments (skin) between the CLN and the matrix node for a CLN-matrix connection as used in the Conduit Flow Process Package of MODFLOW-2005.

If IFCON=3, the value of FSKIN is the hydraulic conductivity of the sediments (skin) between the CLN node and the matrix for computing the CLN-matrix leakance as used in the Conduit Flow Process Package of MODFLOW-2005.

FLENGW—is the length of the CLN segment connected to the GW cell.

FANISO—This parameter is used in computation of leakance across a skin, depending on which equation is selected to represent the flow between CLN node and matrix.

If IFCON=0 or 1, the value of FANISO is the anisotropy factor of the porous matrix block that is connected to the CLN-node, used for computations related to the Thiem Equation. The Kx/Ky value is provided here for a vertically oriented CLN cell, and Kx/Kz is provided here for a horizontally oriented CLN cell. These anisotropies may or may not be read in the BCF or LPF packages depending on the selected simulation options, and are therefore input here to accommodate anisotropic computations for flow to wells. This input therefore provides independent control of flow to wells in anisotropic media.

If IFCON=2, the value of FANISO is not used.

If IFCON=3, the value of FANISO is the thickness of sediments (skin) between the CLN and matrix nodes for computing the CLN-matrix leakance as used in the Conduit Flow Process Package of MODFLOW-2005.

ICGWADI—is a flag indicating if vertical flow correction is applied to CLN-GW flow at this node if either cell is dry.

If ICGWADI = 0, CLN-GW flow at this cell is treated without vertical flow correction.

If ICGWADI = 1, vertical flow correction is applied for CLN-GW flow at this node if it is dry.

FLENGW—is the length of the CLN-node's connection with the groundwater node.

ICONDUITYP—is the index for the conduit type

FRAD—is the radius of the conduit type

CONDUITK—is the hydraulic conductivity factor for the conduit type. Note that CONDUITK times radius squared is used to compute the conductivity of the conduit, as per laminar flow equations.

IBOUND—is the boundary array for CLN-nodes.
     If IBOUND(IFN) < 0, CLN-cell IFN has a constant head.
     If IBOUND(IFN) = 0, CLN-cell IFN is no flow.
     If IBOUND(IFN) > 0, CLN-cell IFN is variable head.

STRT—is initial (starting) head—that is, head at the beginning of the simulation. STRT must be specified for all simulations, including steady-state simulations. One value is read for every CLN cell.

NIB0—is the number of IBOUND values that will be turned to zero in this stress period.

NIB1—is the number of IBOUND values that will be turned to active (one) in this stress period.

NIBM1—is the number of IBOUND values that will be turned to prescribed head (minus one) in this stress period.

IB0—is the array of cell numbers for which IBOUND values will be set to zero.

IB1—is the cell number for which IBOUND is set to active (one).

HEADOPT are keywords to indicate how head values will be set for nodes that are activated. The following options are supported:

     HEAD hvalue – indicates that the head value is input and the number following the keyword HEAD is the value to be used as the initial head at the given cell.

     AVHEAD – indicates that the average head of all active connected cells will be used as the initial head at the given cell.

Note that if no HEADOPT options are provided, then the head from the previous stress period will be used at this node, which is turned active. If the node was inactive in the previous stress period, an option is required to provide a head value to the cell that is made active or prescribed head, otherwise the simulation will be aborted.

IBM1—is the cell number for which IBOUND is set to prescribed head (minus one). Note that the same HEADOPT options for IB1 can be used for IBM1.

Ghost Node Correction (GNC) Package

Input for the Ghost Node Correction (GNC) Package is read from the file that has file type "GNC" in the Name File. All variables are read in free format. The GNC package is not needed and is therefore inactivated, for a structured finite-difference grid. If the GNC contribution to sub-grid scale displacements for CLN nodes is required, the problem should be run as unstructured.

The GNC package allows for any user defined maximum number of adjacent contributing nodes and associated contributing fractions. If it is determined that unconfined simulations are more accurate with contributing factors that are function of the unconfined conductance, then the user can set the appropriate flag (IFLALPHAn = 1) and input effective saturated conductance instead of contributing factors for all the contributing nodes to the ghost node, and the code will internally compute the nonlinear contributing factors depending on the upstream water levels. This option may also be used for confined flow situations however, there is no benefit to doing so as the factors would be linear and constant.

FOR EACH SIMULATION

`0. [#Text]`
Item 0 is optional—"#" must be in column 1. Item 0 can be repeated multiple times.

`1. NPGNCn MXGNn NGNCNPn MXADJn I2Kn ISYMGNCn IFLALPHAn` *`[NOPRINT]`*
The optional keyword "NOPRINT" specifies that lists of GNC cells will not be written to the Listing File.

`2. [PARNAM PARTYP Parval NLST ]`

`3. [NodeN NodeM (NodeJ, J=1,MXADJn) (FactorJ, J=1,MXADJn] FactorN`
These variables are free format. Note that FactorN is not required and is ignored if IFLALPHAn = 0.

Repeat Items 2 and 3 NPGNCn times. Items 2 and 3 are not read if NPGNCn is negative or zero.
NLST repetitions of Item 3 are required; they are read by subroutine ULSTRD. (SFAC of the ULSTRD utility subroutine applies to FactorJ to each of the additional J contributing nodes).

`4. NodeN NodeM (NodeJ, J=1,MXADJn) (AlphaJ, J=1,MXADJn) AlphaN`
These variables are free format. Note that AlphaN is not required and is ignored if IFLALPHAn = 0.

`5. NACTGNCn`

`6. Pname`
NACTGNCn repetitions of Item 6 are read. Item 6 is not read if NACTGNCn is negative or zero.

Explanation of Variables Read by the GNC 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. Lines beginning with # are restricted to the first lines of the file. Text is written to the Listing File.

NPGNCn—is the number of ghost node parameters to be defined in Items 2 and 3. Note: A GNCn parameter must be defined in Items 2 and 3, and made active using Item 6, to have an effect in the simulation.

MXGNn—is the maximum number of GNC cells that will be defined using parameters.

NGNCNPn—is the number of GNC cells defined without using parameters.

MXADJn—is the maximum number of adjacent contributing nodes that will be present in the simulation. Every ghost node in the simulation will have entries for each of the adjacent contributing nodes. If a ghost node has less contributing nodes than this maximum, then additional dummy contributing nodes should be inserted with a contributing factor of zero. A value of negative or zero cannot be used for the dummy node number. The dummy node number should be set as the node number of the cell on which the Ghost Node resides (n) or the node number of the cell to which flow occurs (m), so that the connectivity matrix is not expanded, the consequence of which would be a larger matrix requiring more storage.

I2Kn—is a flag indicating if second-order correction is also applied to the unconfined transmissivity term by using $\bar{h}$ to compute the transmissivity of node $\bar{n}$ instead of h.

      If I2Kn = 0, second-order correction is not applied to the unconfined transmissivity term.

      If I2Kn = 1, second-order correction is applied to the unconfined transmissivity term.

ISYMGNCn—is a flag indicating if the GNC formulation is applied in an implicit manner on the left-hand side matrix for an asymmetric system, or in an explicit manner on the right-hand side vector with iterative updates as is required for symmetric systems.

      If ISYMGNCn = 0, use implicit update for asymmetric formulation.

      If ISYMGNCn = 1, use explicit update for symmetric formulation.

IFLALPHAn—is a flag that indicates the meaning of input coefficients AlphaJ

      If IFLALPHAn = 0, the coefficients AlphaJ represent the contributing factors α_j from all adjacent contributing nodes.

      If IFLALPHAn = 1, the coefficients AlphaJ represent the saturated conductances between the ghost node location and node j, and the contributing factors are computed internally using the equations in the report for the unconfined conductances.

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 GNC Package, the only allowed parameter type is GNC, which defines values of the ghost node coefficient of the cell.

Parval—is the parameter value. This parameter value may be overridden by a value in the Parameter Value File.

NLST—is the number of ghost node cells included in the parameter.

NodeN—is the node number of the cell in which the ghost node is located, $\bar{n}$.

NodeM—is the node number of the connecting cell, m, to which flow occurs from the ghost node $\bar{n}$.

NodeJ—is the node number of a contributing cell j, which contributes to the interpolated head value at the ghost node, $\bar{n}$. This Item is repeated for each of the MXADJn adjacent contributing cells of the ghost node. Note that if the number of adjacent contributing cells is less than MXADJn for any ghost node, then dummy node numbers should be inserted with an associated contributing factor of zero. As mentioned earlier, the dummy node number

should be set as the node number of the cell on which the Ghost Node resides (n) or the node number of the cell to which flow occurs (m), so that the connectivity matrix is not expanded

FactorJ—is the factor used to calculate the contributing factor (α_j) from the parameter value. The term α_j is the product of FactorJ and the parameter value, for each of the J=1,MXADJn contributing nodes.

FactorN—is the factor used to calculate conductance between the ghost node and node n from the parameter value. The calculated conductance is the product of FactorN and the parameter value.

AlphaJ—is the contributing factor α_j of the ghost node. This Item is repeated for each of the MXADJn adjacent contributing cells of the ghost node. Note that if the number of adjacent contributing cells is less than MXADJn for any ghost node, then dummy node numbers should be inserted with an associated contributing factor of zero. Also note that AlphaJ represents the conductance between cell j and the Ghost Node location when the flag IFLALPHAn=1.

AlphaN—is the conductance between the ghost node and node n. This value is used only if the flag IFLALPHAn=1.

NACTGNCn—is the number of active GNC parameters.

Pname—is the name of a parameter to be used in the simulation. NACTGNCn parameter names will be read.

Sparse Matrix Solver (SMS) Package

Input for the Sparse Matrix Solver (SMS) Package is read from the file that is type "SMS" in the Name File. The SMS Package input instructions include flags, indices and tolerances for the nonlinear solution of the unconfined groundwater flow equation as well as for the matrix solution scheme selected for solution of the matrix equations. Guidance for selection of appropriate solution schemes is provided in the main document under the section "Guidance for Applying MODFLOW-USG". Recommended values for of numerical parameters used by the SMS package are provided below. The input is read in as free format.

FOR EACH SIMULATION

```
1a. OPTIONS

1b. HCLOSE HICLOSE MXITER ITER1 IPRSMS NONLINMETH LINMETH

If NONLINMETH ≠ 0 and OPTIONS is not specified then read item 2
2. THETA AKAPPA GAMMA AMOMENTUM NUMTRACK BTOL BREDUC RESLIM

If LINMETH = 1 and OPTIONS is not specified then read item 3 for the χMD
solver
3. IACL NORDER LEVEL NORTH IREDSYS RRCTOL IDROPTOL EPSRN

If LINMETH = 2 and OPTIONS is not specified then read item 4 for the PCGU
solver
4. [CLIN] IPC ISCL IORD RCLOSEPCGU [RELAXPCGU]
```

Explanation of Variables Read by the SMS Package:

OPTIONS— are keywords that activate options:

> SIMPLE indicates that default solver input values will be defined that work well for nearly linear models. This would be used for models that do not include nonlinear stress packages and models that are either confined or consist of a single unconfined layer that is thick enough to contain the water table within a single layer.

> MODERATE indicates that default solver input values will be defined that work well for moderately nonlinear models. This would be used for models that include nonlinear stress packages and models that consist of one or more unconfined layers. The "MODERATE" option should be used when the "SIMPLE" option does not result in successful convergence.

> COMPLEX indicates that default solver input values will be defined that work well for highly nonlinear models. This would be used for models that include nonlinear stress packages and models that consist of one or more unconfined layers representing complex geology and sw/gw interaction. The "COMPLEX" option should be used when the "MODERATE" option does not result in successful convergence.

The values of solver parameters for the various options are shown below in Tables 1 and 2.
HCLOSE—is the head change criterion for convergence of the outer (nonlinear) iterations, in units of length. When the maximum absolute value of the head change at all nodes during an iteration is less than or equal to HCLOSE, iteration stops. Commonly, HCLOSE equals 0.01.

HICLOSE—is the head change criterion for convergence of the inner (linear) iterations, in units of length. When the maximum absolute value of the head change at all nodes during an iteration is less than or equal to HICLOSE, the matrix solver assumes convergence. Commonly, HICLOSE is set an order of magnitude less than HCLOSE.

MXITER—is the maximum number of outer (nonlinear) iterations -- that is, calls to the solution routine. For a linear problem MXITER should be 1.

ITER1—is the maximum number of inner (linear) iterations. The number typically depends on the characteristics of the matrix solution scheme being used. For nonlinear problems, ITER1 usually ranges from 60 to 600; a value of 100 will be sufficient for most linear problems.

IPRSMS—is a flag that controls printing of convergence information from the solver:
     0 – print nothing
     1 – print only the total number of iterations and nonlinear residual reduction summaries
     2 – print matrix solver information in addition to above

NONLINMETH—is a flag that controls the nonlinear solution method and under-relaxation schemes
     0 – Picard iteration scheme is used without any under-relaxation schemes involved
     > 0 – Newton-Raphson iteration scheme is used with under-relaxation. Note that the Newton-Raphson linearization scheme is available only for the upstream weighted solution scheme of the BCF and LPF packages.
     < 0 – Picard iteration scheme is used with under-relaxation.

     The absolute value of NONLINMETH determines the underrelaxation scheme used.

     1 or -1 – Delta-Bar-Delta under-relaxation is used.
     2 or -2 – Cooley under-relaxation scheme is used.

     Note that the under-relaxation schemes are used in conjunction with gradient based methods, however, experience has indicated that the Cooley under-relaxation and damping work well also for the Picard scheme with the wet/dry options of MODFLOW.

LINMETH—is a flag that controls the matrix solution method
     1 – the χMD solver of Ibaraki (2005) is used.
     2 – the unstructured pre-conditioned conjugate gradient solver of White and Hughes (2011) is used.

THETA—is the reduction factor for the learning rate (under-relaxation term) of the delta-bar-delta algorithm. The value of THETA is between zero and one. If the change in the variable (head) is of opposite sign to that of the previous iteration, the under-relaxation term is reduced by a factor of THETA. The value usually ranges from 0.3 to 0.9; a value of 0.7 works well for most problems.

AKAPPA—is the increment for the learning rate (under-relaxation term) of the delta-bar-delta algorithm. The value of AKAPPA is between zero and one. If the change in the variable (head) is of the same sign to that of the previous iteration, the under-relaxation term is increased by an increment of AKAPPA. The value usually ranges from 0.03 to 0.3; a value of 0.1 works well for most problems.

GAMMA—is the history or memory term factor of the delta-bar-delta algorithm. Gamma is between zero and 1 but cannot be equal to one. When GAMMA is zero, only the most recent history (previous iteration value) is maintained. As GAMMA is increased, past history of iteration changes has greater influence on the memory term.

The memory term is maintained as an exponential average of past changes. Retaining some past history can overcome granular behavior in the calculated function surface and therefore helps to overcome cyclic patterns of non-convergence. The value usually ranges from 0.1 to 0.3; a value of 0.2 works well for most problems.

AMOMENTUM—is the fraction of past history changes that is added as a momentum term to the step change for a nonlinear iteration. The value of AMOMENTUM is between zero and one. A large momentum term should only be used when small learning rates are expected. Small amounts of the momentum term help convergence. The value usually ranges from 0.0001 to 0.1; a value of 0.001 works well for most problems.

NUMTRACK—is the maximum number of backtracking iterations allowed for residual reduction computations. If NUMTRACK = 0 then the backtracking iterations are omitted. The value usually ranges from 2 to 20; a value of 10 works well for most problems.

BTOL—is the tolerance for residual change that is allowed for residual reduction computations. BTOL should not be less than one to avoid getting stuck in local minima. A large value serves to check for extreme residual increases, while a low value serves to control step size more severely. The value usually ranges from 1.0 to 10^6; a value of 10^4 works well for most problems but lower values like 1.1 may be required for harder problems.

BREDUC—is the reduction in step size used for residual reduction computations. The value of BREDUC is between zero and one. The value usually ranges from 0.1 to 0.3; a value of 0.2 works well for most problems.

RESLIM—is the limit to which the residual is reduced with backtracking. If the residual is smaller than RESLIM, then further backtracking is not performed. A value of 100 is suitable for large problems and residual reduction to smaller values may only slow down computations.

For the χMD solver (Ibaraki, 2005):

IACL—is the flag for choosing the acceleration method.
      0 – Conjugate Gradient – select this option if the matrix is symmetric.
      1 – ORTHOMIN
      2 - BiCGSTAB

NORDER—is the flag for choosing the ordering scheme.
      0 – original ordering
      1 – reverse Cuthill McKee ordering
      2 – Minimum degree ordering

LEVEL—is the level of fill for ILU decomposition. Higher levels of fill provide more robustness but also require more memory. For optimal performance, it is suggested that a large level of fill be applied (7 or 8) with use of drop tolerance.

NORTH—is the number of orthogonalizations for the ORTHOMIN acceleration scheme. A number between 4 and 10 is appropriate. Small values require less storage but more iteration may be required. This number should equal 2 for the other acceleration methods.

IREDSYS—is the index for creating a reduced system of equations using the red-black ordering scheme.
      0 – do not create reduced system
      1 – create reduced system using red-black ordering

RRCTOL—is a residual tolerance criterion for convergence. The root mean squared residual of the matrix solution is evaluated against this number to determine convergence. The solver assumes convergence if either HICLOSE (the absolute head tolerance value for the solver) or RRCTOL is achieved. Note that a value of zero ignores residual tolerance in favor of the absolute tolerance (HICLOSE) for closure of the matrix solver.

IDROPTOL—is the flag to perform drop tolerance.
   0 – do not perform drop tolerance
   1 – perform drop tolerance

EPSRN—is the drop tolerance value. A value of 10^{-3} works well for most problems.

For PCGU Solver (White and Hughes, 2011):

CLIN— an option keyword that defines the linear acceleration method used by the PCGU solver.
   CLIN = 'CG', preconditioned conjugate gradient method.
   CLIN = 'BCGS', preconditioned bi-conjugate gradient stabilized method.

If CLIN is not specified the preconditioned conjugate gradient method is used. The preconditioned conjugate gradient method should be used for problems with a symmetric coefficient matrix. The preconditioned bi-conjugate gradient stabilized method should be used for problems with a non-symmetric coefficient matrix (for example, with problems using the Newton-Raphson linearization scheme).

IPC— an integer value that defines the preconditioner.
   IPC = 0, No preconditioning.
   IPC = 1, Jacobi preconditioning.
   IPC = 2, ILU(0) preconditioning.
   IPC = 3, MILU(0) preconditioning.
IPC=3 works best for most problems.

ISCL is the flag for choosing the matrix scaling approach used.
   0 – no matrix scaling applied
   1 – symmetric matrix scaling using the scaling method by the POLCG preconditioner in Hill (1992).
   2 – symmetric matrix scaling using the ℓ^2 norm of each row of $\mathbf{A}$ ($\mathbf{D_R}$) and the ℓ^2 norm of each row of $\mathbf{D_R}\mathbf{A}$.

If the ILU(0) or MILU(0) preconditioners (IPC = 2 or 3) are used and matrix reordering (IORD > 0) is selected, then ISCL must be 1 or 2.

IORD is the flag for choosing the matrix reordering approach used.
   0 – original ordering
   1 – reverse Cuthill McKee ordering
   2 – minimum degree ordering

If reordering is used, reverse Cuthill McKee ordering has been found to be a more effective reordering approach for the test problems evaluated.

RCLOSEPCGU—a real value that defines the flow residual tolerance for convergence of the PCGU linear solver. This value represents the maximum allowable residual at any single node. Value is in units of length cubed per time, and must be consistent with MODFLOW-USG length and time units. Usually a value of 1.0×10^{-1} is

sufficient for the flow-residual criteria when meters and seconds are the defined MODFLOW-USG length and time.

RELAXPCGU—a real value that defines the relaxation factor used by the MILU(0) preconditioner. RELAXPCGU is unitless and should be greater than or equal to 0.0 and less than or equal to 1.0. RELAXPCGU values of about 1.0 are commonly used, and experience suggests that convergence can be optimized in some cases with RELAXPCGU values of 0.97. A RELAXPCGU value of 0.0 will result in ILU(0) preconditioning. RELAXPCGU is only specified if IPC=3. If RELAXPCGU is not specified and IPC=3, then a default value of 0.97 will be assigned to RELAXPCGU.

SMS Output:

Diagnostic output from the SMS package includes the solver iteration details (or summary), residual reduction information, and the nonlinear (outer) iteration summary. Residual reduction information includes the incoming and final accepted residuals, the backtracking count (IBCOUNT) and a flag (IBFLAG) indicating the backtracking status for each nonlinear iteration as indicated below.

IBFLAG   = 0 – backtracking was not performed
              = 1 – backtracking was performed and the routine exited because the required residual reduction was achieved.
              = 2 – backtracking was performed and the routine exited because the maximum number of backtracks, NUMTRACK was exceeded.
              =3 – backtracking was performed and the routine exited because the new residual was less than the residual reduction limit, RES_LIM.
              =4 – backtracking was performed and the routine exited because the largest step-size was less than the convergence limit of HCLOSE.

The residual reduction information is provided if the solver print-flag IPRSMS is greater than or equal to one.

The nonlinear iteration summary includes the total number of nonlinear iterations required for convergence and the maximum head change at each nonlinear iteration (immediately after a matrix solve), along with the node number where the maximum head change occurs.. This information, along with the backtracking information may be used to tune the parameters for the delta-bar-delta algorithm and the residual reduction scheme to obtain convergence or improve robustness of the simulations. The summary at each iteration of the matrix solver is also provided in the output, if the value of IPRSMS is equal to two. This information is useful in tuning solver behavior if the matrix solver is stalling or failing.

Table 1 – Parameter Values for the Various Default XMD Solver Options

Parameter	Option		
	Simple	Moderate	Complex
IACL	1	2	2
NORDER	0	0	1
LEVEL	3	3	5
NORTH	5	5	7
IREDSYS	1	1	1
IDROPTOL	0	1	1
RRCTOL	0.00E+00	0.00E+00	0.00E+00
EPSRN	1.00E-03	1.00E-03	1.00E-05
THETA	1.00E+00	9.00E-01	8.00E-01
AKAPPA	0.00E+00	1.00E-04	1.00E-04

GAMMA	0.00E+00	0.00E+00	0.00E+00
AMOMENTUM	0.00E+00	0.00E+00	0.00E+00
NUMTRACK	0	0.00E+00	2.00E+01
BTOL	0.00E+00	0.00E+00	1.05E+00
BREDUC	0.00E+00	0.00E+00	1.00E-01
RES_LIM	0.00E+00	0.00E+00	2.00E-03

Table 2 – Parameter Values for the Various Default PCGU Solver Options

	Option		
Parameter	Simple	Moderate	Complex
CLIN	CG	BCGS	BCGS
IPC	2	3	3
ISCL	0	0	0
IORD	0	0	0
RCLOSEPCGU	1.00E-01	1.00E-01	1.00E-01
RELAXPCGU	0.0	0.97	0.97
THETA	1.00E+00	9.00E-01	8.00E-01
AKAPPA	0.00E+00	1.00E-04	1.00E-04
GAMMA	0.00E+00	0.00E+00	0.00E+00
AMOMENTUM	0.00E+00	0.00E+00	0.00E+00
NUMTRACK	0	0.00E+00	2.00E+01
BTOL	0.00E+00	0.00E+00	1.05E+00
BREDUC	0.00E+00	0.00E+00	1.00E-01
RES_LIM	0.00E+00	0.00E+00	2.00E-03

Input Instructions for Array Reading Utility Subroutines

The array reading utility subroutines provide a common way for all packages to read variables that have multiple values. The term "array" is simply a programming term for a variable that contains multiple values. There are three subroutines: U2DREL, U2DINT, and U1DREL. U2DREL reads real two-dimensional variables, U2DINT reads integer two-dimensional variables, and U1DREL reads real one-dimensional variables. All of these subroutines work similarly. They read one array-control line and, optionally, a data array in a format specified on the array-control line. Several alternate structures for the control line are provided. The original fixed-format control lines work as documented in McDonald and Harbaugh (1988), and four free-format versions have been added. The free-format versions are described first because they are easier to use.

FREE-FORMAT CONTROL LINES FOR ARRAY READERS:

Values in bold italics are keywords that can be specified as uppercase or lowercase. Each control line is limited to a length of 199 characters.

1. **CONSTANT** CNSTNT
All values in the array are set equal to CNSTNT.

2. **INTERNAL** CNSTNT FMTIN IPRN
The individual array elements will be read from the same file that contains the control line.

3. **EXTERNAL** Nunit CNSTNT FMTIN IPRN
The individual array elements will be read from the file unit number specified by Nunit. The name of the file associated with this file unit must be contained in the Name File.

4. **OPEN/CLOSE** FNAME CNSTNT FMTIN IPRN
The array will be read from the file whose name is specified by FNAME. This file will be opened on unit 99 just prior to reading the array and closed immediately after the array is read. This file should not be included in the Name File. A file that is read using this control line can contain only a single array.

FIXED-FORMAT CONTROL LINE FOR ARRAY READERS:

A fixed-format control line contains the following variables:

LOCAT   CNSTNT   FMTIN   IPRN

These variables are explained below. LOCAT, CNSTNT, and IPRN are 10-character numeric fields. For U2DREL and U1DREL, CNSTNT is a real number. For U2DINT, CNSTNT is an integer and must not include a decimal. FMTIN is a 20-character text field. All four variables are always read when the control line is fixed format; however, some of the variables are unused in some situations. For example when LOCAT = 0, FMTIN and IPRN are not used.

CNSTNT—is a real-number constant for U2DREL and U1DREL, and an integer constant for U2DINT. If the array is being defined as a constant, CNSTNT is the constant value. If individual elements of the

array are being read, the values are multiplied by CNSTNT after they are read. CNSTNT, when used as a multiplier and specified as 0, is changed to 1.

FMTIN—is the format for reading array elements. The format must contain 20 characters or less. The format must either be a standard Fortran format that is enclosed in parentheses, "(FREE)" which indicates free format, or "(BINARY)" which indicates binary (unformatted) data. When using a free-format control line, the format must be enclosed in apostrophes if it contains one or more blanks or commas. A binary file that can be read by MODFLOW may be created in only two ways. The first way is to use MODFLOW to create the file by saving heads in a binary file. This is commonly done when the user desires to use computed heads from one simulation as initial heads for a subsequent simulation. The other way to create a binary file is to write a special program that generates a binary file, and compile this program using a Fortran compiler that is compatible with the compiler used to compile MODFLOW. "(FREE)" and "(BINARY)" can only be specified in free-format control lines. Also, "(BINARY)" can be specified only when using U1DREL, U2DREL or U2DINT, and only when the control line is EXTERNAL or OPEN/CLOSE. When the "(FREE)" option is used, be sure that all array elements have a non-blank value and that a comma or at least one blank separates adjacent values.

IPRN—is a flag that indicates whether the array being read should be written to the Listing File after the array has been read and a code for indicating the format that should be used when the array is written. The format codes are different for each of the three array-reading subroutines as shown below. IPRN is set to zero when the specified value exceeds those defined. If IPRN is less than zero, the array will not be printed.

IPRN	U2DREL	U2DINT	U1DREL
0	10G11.4	10I11	10G12.5
1	11G10.3	60I1	5G12.5
2	9G13.6	40I2	
3	15F7.1	30I3	
4	15F7.2	25I4	
5	15F7.3	20I5	
6	15F7.4	10I11	
7	20F5.0	25I2	
8	20F5.1	15I4	
9	20F5.2	10I6	
10	20F5.3		
11	20F5.4		
12	10G11.4		
13	10F6.0		
14	10F6.1		
15	10F6.2		
16	10F6.3		
17	10F6.4		
18	10F6.5		
19	5G12.5		
20	6G11.4		
21	7G9.2		

Nunit—is the unit for reading the array when the ***EXTERNAL*** free-format control line is used.

LOCAT—indicates the location of the array values for a fixed-format array control line. If LOCAT = 0, all elements are set equal to CNSTNT. If LOCAT > 0, it is the unit number for reading formatted lines using FMTIN as the format. If LOCAT < 0, it is the unit number for binary (unformatted) lines, and FMTIN is ignored. Also, when LOCAT is not 0, the array values are multiplied by CNSTNT after they are read.

Examples of Free-Format Control Lines

The following examples use free-format control lines for reading an array. The example array is a real array consisting of 4 rows with 7 columns per row:

```
CONSTANT  5.7        This sets an entire array to the value "5.7".

INTERNAL  1.0  (7F4.0)  3      This reads the array values from the
 1.2 3.7 9.3 4.2 2.2 9.9 1.0  file that contains the control line.
 3.3 4.9 7.3 7.5 8.2 8.7 6.6  Thus, the values immediately follow the
 4.5 5.7 2.2 1.1 1.7 6.7 6.9  control line.
 7.4 3.5 7.8 8.5 7.4 6.8 8.8

EXTERNAL 52  1.0 (7F4.0)  3   This reads the array from the formatted
                              file opened on unit 52.

EXTERNAL 47 1.0 (BINARY)  3   This reads the array from the
                              binary file opened on unit 47.


OPEN/CLOSE  test.dat  1.0  (7F4.0)  3  This reads the array from the

                                       file named "test.dat".
```

Input Instructions for List Utility Subroutine (ULSTRD)

Subroutine ULSTRD reads lists that are any number of repetitions of an input item that contains multiple variables. Examples of packages that make use of this subroutine are the General-Head Boundary, Drain, River, and Well Packages.

1. [**EXTERNAL** IN] or [**OPEN/CLOSE** FNAME]
If Item 1 is not included, then the list is read from the package file. Item 1 must begin with the keyword "EXTERNAL" or the keyword "OPEN/CLOSE" (not both).

2. [**SFAC** Scale]

3. List

Explanation of Variables Read by the List Utility Subroutine:

IN—is the unit number for a file from which the list will be read. The name of the file associated with this file unit must be contained in the Name File, and its file type must be "DATA" in the Name File.

FNAME—is the name of a file from which the list will be read. This file will be opened on unit 99 just before reading the list and closed immediately after the list is read. This file should not be included in the Name File.

Scale—is a scale factor that is multiplied times the value of one or more variables within every line of the list. The input instructions that define a list, which will be read by ULSTRD, should specify the variables to which SFAC applies. If Item 2 is not included, then Scale is 1.0. If Item 2 is included, it must begin with the keyword "SFAC." The values of the list variables that are printed to the listing file include the effect of Scale.

List—is a specified number of lines of data in which each line contains a specified number of variables. The first three variables are always layer, row, and column. The other fields vary according to which package is calling this subroutine.

Description of Binary Output Files

The format of the binary output files written by MODFLOW-USG depends on whether or not the model is structured or unstructured. If the name file contains a "DIS" file type, then the model is structured; if the name file contains a "DISU" file type, then the model is unstructured. If the model is structured, then the format of the binary output files written by MODFLOW-USG is the same as the format used by MODFLOW-2005. If the model is unstructured, then the format of the binary files is different from the MODFLOW-2005 format.

Variable names that begin with the letters A to H and O to Z are of type REAL. If MODFLOW-USG is compiled using a compiler switch that sets all REAL variables to DOUBLE PRECISION, then all REAL output values will be of type DOUBLE PRECISION. Otherwise, all REAL output values will be of single precision. Variables that begin with the letters I to N are integers, and are written to the output file as integers. Some variables are character strings and are indicated as so in the following descriptions.

The file formats for head and drawdown data and for cell-by-cell flow data are described for both structured and unstructured grids in the following sections. The frequency of output and the types of output files that are created is described in the Output Control Option and in the individual package input files.

Structured Head and Drawdown File Format

For each stress period, time step, and layer for which data are saved to the binary output file, the following two records are written:

Record 1: KSTP,KPER,PERTIM,TOTIM,TEXT,NCOL,NROW,ILAY
Record 2: ((DATA(J, I), J=1,NCOL),I=1,NLAY)

where
  KSTP is the time step number;
  KPER is the stress period number;
  PERTIM is the time value for the current stress period;
  TOTIM is the total simulation time;
  TEXT is a character string (character*16);
  NCOL is the number of columns;
  NROW is the number of rows;
  ILAY is the layer number; and
  DATA is either the head or drawdown data.

In the present MODFLOW-USG version, TEXT can be "HEAD" or "DRAWDOWN".

Unstructured Head and Drawdown File Format

For each stress period, time step, and layer that is saved to the binary output file, the following two records are written:

Record 1: KSTP,KPER,PERTIM,TOTIM,TEXT,NSTRT,NNDLAY,ILAY
Record 2: (DATA(N), N=NSTRT,NNDLAY)

where
        KSTP is the time step number;
        KPER is the stress period number;
        PERTIM is the time value for the current stress period;
        TOTIM is the total simulation time;
        TEXT is a character string (character*16);
        NSTRT is the starting cell number for the layer;
        NNDLAY is the cell number of the last cell in the layer;
        ILAY is the layer number; and
        DATA is either the unstructured head or drawdown data.

In the present MODFLOW-USG version, TEXT can be:
"HEADU",
"DRAWDOWNU",
"CLN HEADS", or
"CLN DRAWDOWN".

The "U" character at the end of "HEADU" and "DRAWDOWNU" indicate that the grid is unstructured.

Structured Cell-by-Cell Flow File

The format for the cell-by-cell flow file is more complicated than the format for the head and drawdown data. The cell-by-cell flow file can be written in the regular legacy style, in which three-dimensional arrays are written for all packages, even if most of the values are zero. The cell-by-cell flow file can also be written in the compact budget style, which is the preferred format, because the cell-by-cell flow file is much smaller and because additional information, such as timing information and auxiliary variable values, is written. The compact budget style is activated by adding "COMPACT BUDGET" to the output control input file.

For each stress period and time step that is saved to the binary output file, the following records are written:

Record 1: KSTP,KPER,TEXT,NCOL,NROW,NLAY

If NLAY > 0: *The budget data is written in legacy style.*
      Record 2: (((DATA(J,I,K),J=1,NCOL),I=1,NROW),K=1,NLAY)

If NLAY < 0: *The budget data is written in the compact budget style.*
      Record 2: IMETH,DELT,PERTIM,TOTIM

      If IMETH=1: *The budget data is full grid array.*
            Record 3: (((DATA(J,I,K),J=1,NCOL),I=1,NROW),K=1,NLAY)

      If IMETH=2: *The budget data is a list.*
            Record 3: NLIST
            Record 4: ((NODE(N),Q(N)),N=1,NLIST)

      If IMETH=3: *The budget data is a two-dimensional array that has a layer indicator array.*
            Record 3: ((ILAYER(J,I),J=1,NCOL),I=1,NROW)
            Record 4: ((DATA(J, I), J=1,NCOL),I=1,NLAY)

      If IMETH=4: *The budget data is a two-dimensional array that applies to layer 1.*
            Record 3: ((DATA(J, I), J=1,NCOL),I=1,NLAY)

      If IMETH=5: *The budget data is a list with auxiliary data.*
            Record 3: NVAL
            Record 4: (AUXTXT(N),N=1,NVAL-1)
            Record 5: NLIST
            Record 6: ((NODE(N),(DATA(I,N),I=1,NVAL)),N=1,NLIST)

where
      KSTP is the time step number;
      KPER is the stress period number;
      TEXT is a character string (character*16) name of the budget term;
      NCOL is the number of columns;
      NROW is the number of rows;

NLAY is the layer number;

IMETH is a code that specifies the form of the remaining data;

DELT is the length of the timestep;

PERTIM is the time value for the current stress period;

TOTIM is the total simulation time;

DATA is a two- or three-dimensional array of the budget values. When IMETH=5, the budget value for each list entry is contained in the first DATA column;

NLIST is the number of values in the following list;

NODE is the one-dimensional node number;

Q is the budget value;

ILAYER is an two-dimensional layer indicator array corresponding to the subsequent DATA array;

NVAL is the number of values for each list entry, which is the number of auxiliary values plus 1; and

AUXTXT is an array of size NVAL - 1 containing character*16 text names for each auxiliary variable.

Unstructured Cell-by-Cell Flow File

For unstructured grids, the cell-by-cell flow file can also be written in the legacy style; however, in this case, the budget arrays are one-dimensional with the size equal to the number of nodes, in contrast to the three-dimensional budget arrays written for structured grids. Except for budget terms corresponding to flows between cells and storage, most of the budget terms will be zero for typical applications. The cell-by-cell flow file can also be written in the compact budget style for unstructured grids, which is the preferred format, because the cell-by-cell flow file is much smaller and because additional information, such as timing information and auxiliary variable values, is written.

For each stress period and time step for which budget data are requested to be saved to the binary output file, the following records are written:

Record 1: KSTP,KPER,TEXT,NVAL,1,ICODE

If ICODE > 0: *The budget data is written in legacy style.*
      Record 2: (DATA(I),I=1,NVAL)

If ICODE = -1: *The budget data is written in the compact budget style.*
      Record 2: IMETH,DELT,PERTIM,TOTIM

      If IMETH=1: *The budget data is full grid array.*
            Record 3: (DATA(I),I=1,NVAL)

      If IMETH=2: *The budget data is a list.*
            Record 3: NLIST
            Record 4: ((NODE(N),Q(N)),N=1,NLIST)

      If IMETH=3: *The budget data is a one-layer array that has a one-dimensional node indicator array.*
            Record 3: (INODE(I),I=1,NVAL)
            Record 4: (DATA(I),I=1,NVAL)

      If IMETH=4: *The budget data is a one-dimensional array that applies to layer 1.*
            Record 3: (DATA(I),I=1,NVAL)

      If IMETH=5: *The budget data is a list with auxiliary data.*
            Record 3: NDAT
            Record 4: (AUXTXT(N),N=1,NDAT-1)
            Record 5: NLIST
            Record 6: ((NODE(N),(DATA(I,N),I=1,NDAT)),N=1,NLIST)

where
      KSTP is the time step number;
      KPER is the stress period number;
      TEXT is a character string (character*16) name of the budget term;

NVAL is the number of data values (unless it is a list, then NVAL is the number of nodes in the grid);

ICODE indicates whether the file is legacy or compact style;

IMETH is a code that specifies the form of the remaining data;

DELT is the length of the timestep;

PERTIM is the time value for the current stress period;

TOTIM is the total simulation time;

DATA is a one- or two-dimensional array of the budget values. When IMETH=5, the budget value for each list entry is contained in the first DATA column;

NLIST is the number of values in the following list;

NODE is the node number indicating the location of the stress;

Q is the budget value;

INODE is a one-dimensional node indicator array corresponding to the subsequent DATA array

NDAT is the number of values for each list entry, which is the number of auxiliary values plus 1. Note that the first data value is the budget term. The remaining values in DATA are the values for the auxiliary variables.

AUXTXT is an array of size NDAT - 1 containing character*16 text names for each auxiliary variable.

MODFLOW-USG writes a special record for flow between connected cells. This record has a TEXT identifier equal to "FLOW JA FACE". For this record, NVAL is equal to NJAG, which is the total of the number of connections plus 1 for all of the cells. Therefore, this budget record corresponds to the JA array. A value of zero is written to the node positions in the "FLOW JA FACE" record.