Updates for GSFLOW version 1.1.6
March 2013

Version 1.1.6 includes a number of enhancements, modifications, and bug fixes that are summarized in this document. The initial release of GSFLOW (version 1.0) is documented in Markstrom and others (2008); additional updates made to the software since its initial release are described in the "release.txt" file located in the main directory and additional update files located in the gsflow documentation subdirectory.

Modifications to GSFLOW and PRMS Modules

(a) General Changes

A consistent declaration of all PRMS/GSFLOW modules is now done so that an organized list of available and active modules is always output to the user's screen.

Changed value checked for a missing temperature value as specified in the Data File from less than -89 to less than -99. Affected modules**: temp_laps**, **temp_1sta**, **temp_dist2**, **xyz_dist**, and **climateflow**. This change may affect some previously developed models.

Some variables have been changed from single precision to double precision in modules **precip_dist2**, **temp_dist2**, **srunoff_carea**, **srunoff_smidx**, **xyz_dist**, **basin_sum**, **map_results**, **climateflow**, **gsflow_setconv**, and **gsflow_budget**. These changes may cause a very slight change to some of the calculations because of round-off error.

Changes to the Data File and Climate-by-HRU Distribution Files: Input values are checked to see if any are specified as NaN (not a number), which results in an error message and stop of the execution. Also, if any values in a CBH file are missing, the number of missing values and data type are output to the user's screen and the execution stops.

Module **hru_sum_prms** (Hydrologic-Response-Unit Summary Module) was removed from the code. As a consequence, parameters `moyrsum` and `pmo` are not needed and are ignored by the code if specified.

(b) GSFLOW Modules

Computational-Sequence Control for MODFLOW Module (gsflow_modflow)
Merged with MODFLOW 1.9.01 and MODFLOW-NWT 1.0.7.

PRMS to MODFLOW Integration Module (gsflow_prms2mf)
BUG FIX: Modified code to check that `mxsziter` is specified less than `mnsziter`; if this is the case, `mxsziter` is set equal to `mnsziter`. Previously, this condition resulted in an array bounds being exceeded, which might have caused incorrect results.

(c) PRMS Modules

Cascading-Flow Module (cascade)

BUG FIX: when more than two cascade links were specified that originated from a source to the same destination, one or more of these cascade links could have been ignored and the associated fraction of cascade computed incorrectly. This would be a rare occurrence and was true for both HRU and GWR cascade specifications.

Observed-Data Module (obs)

Bug fix: negative values of observed runoff were set to -11; this might cause problems with automated calibration programs. Observed runoff values are now left unchanged from the values specified in the Data File.

Precipitation-Interception Module (intcp)

BUG FIX: if pan evaporation data are in Data File (`nevap`>0) and the evapotranspiration module is not **potet_pan**, then the data are ignored rather than used as potential evaporation.

BUG FIX: allow winter cover density to be greater than summer cover density; previously, if winter cover density was specified to be greater than summer cover density, it was set to the summer value.

Soil-Zone Module (soilzone)

BUG FIX: set available potential evapotranspiration used in soil zone evapotranspiration computations to be based on the average depth over the pervious portion instead of the whole HRU; this could increase the soil zone contribution to ET compared to previous versions in which impervious surfaces are present in an HRU.

BUG FIX: The code now limits the flows produced in each reservoir to maximum capacities instead of antecedent storage plus all inflow to a reservoir to be consistent with the soil zone conceptualization as documented in the GSFLOW manual. This change may affect calculated rates of streamflow because the cascading flow increases primarily due to increased Dunnian runoff. The change might also affect gravity drainage and slow interflow computations for some models.

BUG FIX: *basin_recharge* was computed incorrectly; it was incorrectly set to equal only the recharge value of the last HRU.

Map Results Module (map_results)

Added check to be sure the mapping specification for each GVR is valid (`gvr_cell_id`(i)>0, `gvr_hru_id`(i)>0, and `gvr_cell_pct`>1.0E-10).

Added checks for complete mapping (sum of gvr_cell_pct equals 1 for each cell). If the mapping is less than 1 or greater than 1 a warning message is printed. Note, in some cases it might be desirable to map only a portion of an HRU/cell, such as at a model boundary where the cell and HRU map have different spatial extents.

Climate by HRU Distribution Module (climate_hru)

New functionality: users can now input whether an HRU is in a transpiration day in a CBH file as a 0=no or 1=yes integer values. See file ‘Climate_hru.pdf’ in the gsflow documentation subdirectory for details.

PARAMETER NAME CHANGE: Parameters rain_adj, snow_adj, tmax_adj, and tmin_adj are now named rain_cbh_adj, snow_cbh_adj, tmax_cbh_adj, tmin_cbh_adj, respectively. The new parameters have the same dimensions and definitions as the original parameters; their names were changed to differentiate them from other climate distribution modules.

The value of solrad_tmax and solrad_tmin is now always set to basin_tmax and basin_tmin instead of using tmax(basin_tsta) and tmin(basin_tsta) when ntemp>0. This code modification may cause noticeable changes to model results for large model domains.

A check for any errors opening and finding the simulation start time for all CBHs files was added.

Modifications to MODFLOW Packages

Several relatively minor modifications and bug fixes were made to some of the MODFLOW Packages since the previous release of the code. These changes are described below. Users should also check the release notes for MODFLOW versions 1.9 and 1.9.01 to review additional changes that have been made to some of the MODFLOW Packages supported by GSFLOW.

Streamflow-Routing Package (gwf2sfr7_NWT.f and gwfsfrmodule.f)

SFR2 release with GSFLOW 1.1.6 now supports both the key word option and a negative value for NSTRM for activating alternate options for specifying stream information by reach and for simulating unsaturated flow beneath streams. Versions 1.1.3 – 1.1.5 of GSFLOW only allowed the use of key words.

A small bug was fixed that stopped the stream width from being set equal to the wetted perimeter for ICALC=2. This change only affects the printout of stream width, and calculations dependent on stream width were made using the correct value in previous versions of SFR2.

Changes were made to print out all stream reaches with streambed altitudes below the cell bottom before the model stops due to this error. Previous versions of the code printed out the first reach encountered with an altitude error and stopped. An example of this error print out extracted from the List File is shown below:

```
  REACHES WITH ALTITUDE ERRORS:
    LAY          ROW       COL        SEG     REACH          STR.ELEV.       CELL-BOT.
      1           4         57          1        57         -1.7500000      0.0000000
      1           4         58          1        58         -4.2500000      0.0000000
      1           4         59          1        59         -6.7500000      0.0000000
      1           4         60          1        60         -9.2500000      0.0000000
      1           4         61          1        61         -11.7500000     0.0000000
      1           4         62          1        62         -14.2500000     0.0000000
      1           4         63          1        63         -16.7500000     0.0000000
      1           4         64          1        64         -19.2500000     0.0000000
      1           4         65          1        65         -21.7500000     0.0000000
 MODEL STOPPING DUE TO REACH ALTITUDE ERROR
```

Some variables were made double precision and the precision used in calculations was made consistent. Some minor calculations were modified for solution efficiency. Allocation of some variables was changed to reduce the amount of random access memory (RAM) required for simulations. These changes did not affect simulation results. Initialization of some local variables was added.

Lake Package (gwf2lak7_NWT.f)

In versions of MODFLOW-NWT prior to 1.0.6, when the Lake Package was used simultaneously with the HUF Package the effective (combined) aquifer-lakebed conductances were not calculated correctly. In this update, the Lake Package has been modified to compute effective lake-aquifer conductance solely on the basis of the user-specified value of lakebed leakance; aquifer hydraulic conductivities are not used in this calculation. An appropriate informational message is now printed after the lakebed conductances are written to the main output file. There have also been several minor changes to format statements to improve the information content of the output file.

An updated set of input instructions for the Lake Package has been added to the release documents (subdirectory \doc\modflow) titled 'Lake3_Input_Modified.pdf.'

Unsaturated-Zone Flow Package (gwf2uzf1_NWT.f and gwfuzfmodule.f)

The package specific version of the variable LAYTYP (variable internal to the source code of MODFLOW) was replaced with the global MODFLOW variable LAYHDT. Some work arrays were modified to be single dimension instead of double dimension. Previous versions of GSFLOW set the extinction depth (EXTDP) to 1 if EXTDP was specified as zero in the UZF1 input file. ET is no longer simulated by UZF1 for cells with EXTDP set equal to zero. Some of the unsaturated-flow budget information that is printed to UZF1 GAGE files was modified to correct some inconsistencies in budget items.

Newton Solver (several source files, each beginning with 'NWT1_')

Changes were made to fix a bug that caused `HDRY` to be printed for confined cells that have heads below the cell-bottom altitude. `HDRY` only will be printed for unconfined layers.

Changes were made to the default input values when the key word options are used. These changes reflect information gained from testing numerous groundwater models. The defaults values for "`SIMPLE`," "`MODERATE`," and "`COMPLEX`" are now as follows:

"`SIMPLE` "
`IACL = 1, NORDER = 0, LEVEL = 3, NORTH = 5, IREDSYS = 1, RRCTOLS = 0.0, IDROPTOL = 1, EPSRN = 1.0e-3, HCLOSEXMD = 1.0e-4, MXITERXMD = 50`, All other values remain the same.

"`MODERATE` "
`DBDTHETA = 0.9, IACL = 2, NORDER = 0, LEVEL = 3, NORTH = 5, IREDSYS = 1, RRCTOLS = 0.0, IDROPTOL =1, EPSRN = 1.0e-3, HCLOSEXMD = 1.0e-4, MXITERXMD = 50`, All other values remain the same.

"`COMPLEX` "
`DBDTHETA = 0.85, BACKFLAG=1, MAXBACKITER=50, BACKTOL=1.1, BACKREDUCE=0.7, IACL = 2, NORDER = 1, LEVEL = 5, NORTH = 7, IREDSYS = 1, RRCTOLS = 0.0, IDROPTOL = 1, EPSRN = 1.0e-5, HCLOSEXMD = 1.0e-5, MXITERXMD = 100`, All other values remain the same.

xMD Matrix Solver (NWT1_xmd.f)

Some initialization issues associated with Bi-cgstab and Orthomin were resolved, and some minor changes were made.

Upstream Weighting Package (gwf2upw1.f)

Some variables were made double precision and the precision used in calculations was made consistent. An option was added to turn off the checking that a value is defined for all cells when parameters are used to define layer data. This option is implemented by specifying the keyword "NOPARCHECK" as one of the options in input Item 1 of the UPW input file.

Well Package (gwf2wel7_NWT.f)

Changes were made to report wells with reduced pumping rates due to dewatered conditions to a separate output file or to the main listing file. If the wells with reduced pumping rates are written to a separate output file then a file of type "DATA" must be included in the Name File with a unit number that matches the unit number specified in the Well File (following the variable PHIRAMP in Item 2b). For example, a value of PHIRAMP (see MODFLOW-NWT documentation report) of 0.3 and a unit number of 50 can be specified in the second line of the Well File using the key word "SPECIFY" as:

```
SPECIFY  0.3  50
```

The following line must be added to the Name File:

```
DATA  50  Reduced_wells.out
```

Thus, wells with reduced pumping rates will be written for each time step to the output file "Reduced_wells.out" with unit number 50. For example, wells with reduced pumping rates will be reported to file "reduced_wells.out" as:

```
 WELLS WITH REDUCED PUMPING FOR STRESS PERIOD     6 TIME STEP     2
   LAY   ROW   COL          APPL.Q           ACT.Q         GW-HEAD       CELL-BOT
     4    91    69  -0.104400E+04  -0.104399E+04   0.208142E+04   0.205380E+04
     4    91    69  -0.208800E+04  -0.208798E+04   0.208142E+04   0.205380E+04
     4    91    69  -0.208800E+04  -0.208798E+04   0.208142E+04   0.205380E+04

 WELLS WITH REDUCED PUMPING FOR STRESS PERIOD     6 TIME STEP     3
   LAY   ROW   COL          APPL.Q           ACT.Q         GW-HEAD       CELL-BOT
     4    91    69  -0.104400E+04  -0.967118E+03   0.207686E+04   0.205380E+04
     4    91    69  -0.208800E+04  -0.193424E+04   0.207686E+04   0.205380E+04
     4    91    69  -0.208800E+04  -0.193424E+04   0.207686E+04   0.205380E+04
```

Multi-Node Well Package, Version 1 (gwf2mnw17_NWT.f, lmt7_NWT.f, and lmt7_NWT.inc)

The name of the data module for MNW1 was changed from GWFMNWMODULE to GWFMNW1MODULE to discriminate it from the module in the MNW2 package. This change was required because data used in the lmt7_NWT and lmt7_NWT.inc source files were being confused with data in the MNW2 Package module. Both the lmt7_NWT.f and lmt7_NWT.inc files were changed to reflect the new module name.

Multi-Node Well Package, Version 2 (gwf2mnw27_NWT.f)

Changes were made to the MNW2 Package by the authors of the package (Konikow and others, 2009) for the version 1.9 release of MODFLOW-2005. These changes also were made to this release of GSFLOW. These changes are:

- A bug was fixed that affected simulations when both MNW2 and the HUF Package were used in the same simulation in conjunction with the partial penetration correction. The variable KY is now declared as a Double Precision variable instead of being implicitly assumed (incorrectly) to be an Integer variable.
- A number of minor changes were made in Format statements to produce a cleaner output file.
- In Subroutines GWF2MNW27BCF and GWF2MNW27HUF, corrections were made to assure the correct check is made for steady-state or transient conditions and to prevent a divide by zero error if a cell is dry.
- A bug was fixed for the calculation of angles theta and omega for slanted wells with an orientation into the southwest directional quadrant.
- A bug was fixed that caused erroneous values to be written to the compact budget file (specifically, for inactive MNW wells), although the numerical solution itself was accurate, as were the budget numbers written to the main listing file.

Additional changes were made to the MNW2 Package for MODFLOW-NWT (and GSFLOW). These changes do not affect simulations using the MNW2 Package with solvers other than the NWT solver within MODFLOW-NWT. These changes were required to solve instabilities created by seepage-face conditions within an MNW2 well and when a cell containing an MNW2 well becomes dry. The first change resets the head in a well to the bottom of the cell when it falls below the bottom of the cell for each node; for certain circumstances this was not occurring. The second change applies smoothing of the cell-to-well conductance as a cell dries. These changes may cause small changes to simulation results if these conditions arise (that is, cell drying or seepage-face conditions).

A bug was fixed that affected simulations in which a composite well screen was generated when specifying multiple open intervals by elevation. In this case, some nodes were inadvertently excluded from the second interval. With the fix, all nodes of the multi-node well will be represented. Some output format adjustments were also made.

If a single-node multi-node well with a nonzero specified discharge was located in an inactive cell (IBOUND=0), it could generate a divide-by-zero error and halt execution of the program. The code was fixed to preclude such a floating-point error from occurring. A new warning message is now also written to the output file if this condition is detected.

If the well yield (and pumping rate) was reduced because of the seepage-face calculations, an incorrect message (indicating erroneously that the cause was the head constraint) was written to the output file. The code was fixed so that possible causes of reduced pumping rates are accurately printed.

The code was modified to eliminate separate processing for single-node MNW2 wells, which eliminated some inconsistencies in handling single-node wells. If the computed value for the head in single-node wells drops below the bottom of the cell, it invokes the seepage-face calculation, which will reduce or eliminate the desired pumping rate (Qdes) from the well. In cases where the Qdes is thereby reduced, the actual head in the well is indeterminate, but will be reported in separate MNWI output files as the limiting value of the bottom elevation of the cell together with an information note that the actual value may be lower than that reported value. If

Qdes is reduced to zero, the well is deactivated and that information is reported in the MNWI optional MNW2 observation well file.

At the end of the first paragraph on p. 32 of the MNW2 documentation report, it states that the alternate calculations for CWC for nonvertical wells will be performed automatically when LOSSTYPE = THIEM, SKIN, or GENERAL. Unfortunately, the code did not check this condition, and erroneously performed these calculations when LOSSTYPE = SPECIFYCWC. The corrected code now uses the specified values of CWC for nonvertical wells when it is supposed to.

The code automatically estimates the maximum number of nodes (NODTOT) as required for allocation of arrays. However, if a large number of horizontal wells are being simulated, or possibly for other reasons, this default estimate proves to be inadequate, a new input option has been added to allow the user to directly specify a value for NODTOT. If this is a desired option, then it can be implemented by specifying a negative value for "MNWMAX"--the first value listed in Record 1 (Line 1) of the MNW2 input data file. If this is done, then the code will assume that the very next value on that line will be the desired value of "NODTOT". The model will then reset "MNWMAX" to its absolute value. The value of "IWL2CB" will become the third value on that line, and so forth.

The code included several errors in the calculation of cell-to-well conductances for nonvertical wells. There was also an error in the calculation of the length of closed casing between sequential, but non-adjacent, active nodes of a nonvertical MNW2 well (a value only used for informational purposes in the output file). All of these errors have now been fixed.

General-Head Boundary Package (gwf2ghb7_NWT.f)

A check was added for general-head boundaries set to altitudes below the cell bottom. If this occurs, an error message is printed to the List File and the model is stopped. Changes also were made to be consistent with the version 1.9 release of MODFLOW-2005.

Hydrogeologic-Unit Flow Package (gwf2huf7.f)

Small changes were made to make RHS and HCOF double precision when passed as subroutine arguments.

Basic (gwf2bas7_NWT.f), Strongly Implicit Procedure (sip7_NWT.f), Preconditioned Conjugate-Gradient (pcg7_NWT.f), and Direct Solver (de47_NWT.f) Packages

The variables RHS and HCOF were made double precision.

References Cited

Markstrom, S.L., Niswonger, R.G., Regan, R.S., Prudic, D.E., and Barlow, P.M., 2008, GSFLOW—Coupled ground-water and surface-water flow model based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005): U.S. Geological Survey Techniques and Methods 6-D1, 240 p.

Konikow, L.F., Hornberger, G.Z., Halford, K.J., and Hanson, R.T., 2009, Revised multi-node well (MNW2) package for MODFLOW ground-water flow model: U.S. Geological Survey Techniques and Methods 6–A30, 67 p.