

GWM Addendum – August 2006

A supplement to : Ahlfeld, D.P., Barlow, P.M., and Mulligan, A.E., 2005, GWM—A ground-water management process for the U.S. Geological Survey modular ground-water model (MODFLOW-2000): U.S. Geological Survey Open-File Report 2005-1072, 124 p.

Beginning with Version 1.1 of GWM, new features are available for output control and control of the SLP algorithm. The meaning of several existing GWM input variables have been extended beyond that described in the original GWM documentation (OFR 2005-1072). In addition, one new input variable has been added to GWM Version 1.1 (variable GWMWFILE, described below). Finally, the SUPPLY sample problem distributed with GWM has been changed.

IRM: Response Matrix Input/Output

GWM Version 1.1 allows the user to read a pre-computed response matrix or write the response matrix in a formatted or non-formatted structure. (Note that the non-formatted file may be either a FORTRAN BINARY or UNFORMATTED file depending on the settings in the openspec.inc file. GWM is distributed with UNFORMATTED specified.) These options are controlled with the existing IRM parameter and listed below. IRM is read from line 4a of the GWM SOLN file. Prior to Version 1.1, values of 0, 1 or 2 could be specified for IRM. These meanings have not changed, but are repeated here for comparison with the three additional meanings of IRM that have been added in Version 1.1.

IRM=0; an existing non-formatted file containing the response matrix will be read and the LP solved

IRM=1: the response matrix is computed and saved to a non-formatted file. The LP is then solved.

IRM=2: the response matrix is computed and the LP solved. The response matrix is not saved or printed.

IRM=3: the response matrix is computed and printed to a formatted file. The LP is then solved.

IRM=4: the response matrix is computed, saved to a non-formatted file and printed to a formatted file. The LP is then solved.

IRM=5: an existing non-formatted file containing the response matrix is read and the LP solved. The response matrix is printed to a formatted file.

If IRM is set to 0, 1 or 3 a file name needs to be specified. This is defined in the SOLN file on line 4f of the GWM SOLN file. If IRM is set to 4 or 5 two file names need to be specified. In this case, two names are read from line 4f of the SOLN file. The first file name is the non-formatted file and the second file name is the formatted file. The response matrix is written row-by-row using a format similar to that used to write the MODFLOW head solution. Each row represents one of the simulation-based constraints (e.g. heads or streamflows). The rows are in read-order; the order in which the constraints were read. First the head constraints are listed in the order in which they were

read from the HEDCON file and then the stream constraints are listed in the order they appear in the STRMCON file. Each column of the response matrix represents a decision variable. These are also listed in read-order, the same order in which they appear in the DECVAR file.

NPGNMX: Testing of the GWF Process Results

The GWM RMS package performs a series of tests on the outcome of each run of the GWF process. These tests include checking for flow process convergence, adequate response coefficient precision and dewatering at cells that are included in head constraints. These tests are discussed in more detail on pages 32 and 33 of OFR 2005-1072 and are controlled by user-specified parameters NSIGDIG, AFACT, PGFACT and NPGNMX in the SOLN input file. Based on the results of these tests, GWM may automatically re-run the flow process simulation. Under some circumstances the user may prefer to bypass these tests and continue with perturbation calculations regardless of response coefficient precision, dewatered status or other possible problems. This might arise, for example, if dewatering occurs at a constrained head cell, but the user prefers to retain the constraint with a trivially satisfied right hand side. In this case, the response coefficients would be erroneous but the constraint would be satisfied anyway. This can be accomplished by setting NPGNMX to a value of zero. If NPGNMX is set to zero GWM will continue to test for convergence of the GWF process for any base or perturbation run and will terminate the run if the GWF process fails to converge.

SLPITPRT: Solution Status at Every SLP Iteration

The level of detail provided on the progress of the SLP algorithm is controlled by variable SLPITPRT, which is read on line 5d of the GWM SOLN file. A new possible value of SLPITPRT has been added in Version 1.1 so that the possible values and meaning of SLPITPRT are as follows:

SLPITPRT = 0: no information on progress of SLP algorithm is printed to GLOBAL file.

SLPITPRT = 1: constraint status and convergence status at each iteration of the SLP algorithm is printed to GLOBAL file.

SLPITPRT = 2: the optimal solution, constraint status, and convergence status at each iteration of the SLP algorithm is printed to GLOBAL file.

GWMWFILE: Output of Solution to Separate File

Version 1.1. has added a feature so that the value of the flow variables in the optimal solution can be written to a separate file called GWMWFILE. The flow variables are written in a format similar to that used as input by the MODFLOW WEL package. For each stress period, the number of cells at which optimal flows are non-zero are written, along with the layer, row, column location of the cell. When a flow variable is applied over multiple cells, each of the cells is identified along with its proportion of optimal pumping. When a flow variable is applied over multiple stress periods, its flow rate and cell location is written at each stress period during which it is active. For problems with no unmanaged wells, the completed GWMWFILE can be used as the basis for a WEL file that would reproduce the optimal results; if unmanaged wells are present,

then the user will need to merge GWMWFILE with the unmanaged WEL file to reproduce optimal results.

Output to GWMWFILE is activated by providing a positive integer value in the DECVAR file after variable IPRN on line 1. This is a new GWM input variable which is called GWMWFILE. The value of GWMWFILE is the unit number of the file to which output will be written. The unit number should be associated with a file that is defined in the MODFLOW NAME file using the DATA file type. If the value is non-positive or blank then the output will not be written. If SLPITPRT=2, then GWMWFILE will be written at the end of each SLP iteration with only the most recent solution appearing in the file.

An example of the use of GWMWFILE is provided for the Seawater example problem distributed with GWM Version 1.1:

(a) the NAME file includes a DATA file type to which the optimal pumping rates are written:

```
DATA 20 ..\data\seawater.gwmw
```

(b) the DECVAR file includes a value of 20 for GWMWFILE on line 1:

```
#SEAWATER Sample Problem, DECVAR file
#August 14, 2006
1 20                                #1-IPRN  GWMWFILE
```

(c) the output file 'seawater.gwmw' contains the optimal flow rates for each non-zero managed well in the solution. Compare these optimal flow rates to those given on page 77 of original GWM report by Ahlfeld and others, 2005:

10	0		Stress Period:	1	
1	7	12 -0.1000000E+05	Flow Variable:W1	NC=	1
1	10	13 -0.3300918E+04	Flow Variable:W2	NC=	1
1	15	11 -0.8387307E+03	Flow Variable:W5	NC=	1
2	15	11 -0.8387307E+03	Flow Variable:W5	NC=	2
1	7	27 0.3146982E+02	Flow Variable:I1	NC=	1
2	7	27 0.3146982E+02	Flow Variable:I1	NC=	2
1	11	27 0.2660578E+03	Flow Variable:I2	NC=	1
2	11	27 0.2660578E+03	Flow Variable:I2	NC=	2
1	15	27 0.1477542E+03	Flow Variable:I3	NC=	1
2	15	27 0.1477542E+03	Flow Variable:I3	NC=	2

New SUPPLY Sample Problem

Sample problem 3 in OFR 2005-1072 describes a water supply problem with the objective to maximize withdrawals subject to streamflow constraints. Experience with this problem has shown that it can have numerical stability problems. For this reason it has been simplified. One of the decision variables (Q3) has been removed and a number of constraints have been removed. These are stream constraints in stress periods 1-8 and summation constraints in stress periods 5-8. This new version (named supply2) is distributed with GWM V1.1. The solution obtained is identical to that published in OFR 2005-1072. The reasons for the instability and the resolution of the problem are instructive for proper formulation of groundwater management problems and are described next.

The supply problem is setup to run for 12 3-month periods to simulate three successive years. The recharge varies from season to season but is identical in each year. The upstream inflows are identical for all periods. There are no unmanaged wells. While the problem is transient, the initial conditions and the storage coefficient was such that the problem quickly reached a dynamic equilibrium. This can be seen by noting that the impact of the initial conditions, as measured by the flows in and out of storage, is negligible after the second stress period and the storage flows become nearly identical after the first year. Thus, the unmanaged simulation achieves a dynamic equilibrium after the first year.

In the original SUPPLY problem, all wells except for Q3, pump in the same pattern each year. The objective is to maximize pumping. With the coefficients the same it is most beneficial to not operate Q3 since its operation would preclude operation of other wells in different years. Hence, with Q3 not operating, the system is nearly identical from year to year. So, with the managed wells pumping the same in each year, the optimized managed system is also at dynamic equilibrium.

Constraints on streamflow are imposed in each year. Their use in the case of a dynamic equilibrium means that the response coefficients for these constraints will be nearly identical. For example, when SO4.8 and SO4.12 are binding, SO4.4 is nearly binding, since the pumping rates during stress periods 4,8, and 12 are the same. Constraints that are identical or nearly-identical can cause problems during solution of the linear program when the basis matrix, which is built from the constraint equations, is inverted. This can occur when the basis is degenerate, that is, at least one of the basic variables takes a value of zero. In the original SUPPLY problem, the presence of these near-redundant constraints produced linear program solution failure in some cases and produced a range analysis that was flawed.

By eliminating streamflow depletion constraints in all but the last year, the potential for redundant constraints is removed. With these constraints removed, flow rate variable Q3 becomes relatively unconstrained (since it does not operate in the last year) and is removed to retain the same solution to the problem. Finally, with Q3 removed, the summation constraints in the second year become redundant with those in the first year and are removed.