Map Results Module

The Map Results Module (`map_results`) replaces the Grid Report Module initially released with GSFLOW version 1.1.3. This module writes simulated results for each hydrologic response unit (HRU) in a gridded format, summarized at four temporal frequencies—weekly, monthly, yearly, and total simulation time period, depending on the value specified for parameter **mapvars_freq i**n the Parameter File (see Table 2 below). The control parameter **mapOutON_OFF** (see table 1 below) is used to activate the Map Results Module for a PRMS-only simulation (control parameter **model_mode** set to PRMS). This control parameter is ignored for integrated and MODFLOW-only simulations. Summarized results can be written in units of inches/day, feet/day, centimeters/day, or meters/day, depending on the value specified for parameter **mapvars_units** in the Parameter File. If the value of **mapvars_units** is specified as 0, the output units for each variable are the units as computed by PRMS. If **mapvars_units** is specified as 1, 2, or 3, the units of each output variable as computed by PRMS must be inches/day.

Input parameter **prms_warmup** specifies the number of years the PRMS-only simulation executes prior to computing summarized results. For example, if the simulation start date (control parameter **start_time**) is specified to be 10/1/1980, the end date (control parameter **end_time**) is specified to be 9/30/1996, and **prms_warmup** is specified to be 2, then the `map_results` module computations begin on 10/1/1982. For this example, the first weekly results will be for October 1 to 7, 1982; the first monthly results will be for October 1982 and the last monthly results will be for September 1996; yearly results will be for the 14 water years 1983, 1984, and so forth through 1996 (where a water year extends from October 1 of the previous calendar year to September 30 of the water year of interest); and total results will be the average of the 14 water years extending from 10/1/1982 through 9/30/1996. If a user wants results for calendar years, the simulation start time should be specified with a start day of January 1. Results for each time period are preceded by a line that indicates the last day of the averaging period and the mean recharge rate over the basin; results for each time period are followed by a line of #s.

Summaries of mapped results are written to one or more output files as time series for each selected variable averaged over the temporal frequency(ies) selected, as specified by parameter **mapvars_freq**. Results can be written for average weekly rates (output file ‘*variable*.weekly’); monthly rates (output file ‘*variable*.monthly’); average yearly rates (output file ‘*variable*.yearly’); and (or) the average rate over the total simulation period (output file ‘*variable*.total’). The prefix *variable* of each output file is set to the variable(s) specified by control parameter **mapOutVar_names**. The number of output variables is specified by control parameter **nmapOutVars**. To determine the list of available variable names for a particular model, execute GSFLOW in PRMS-only mode using the –print option, for example:

```
gsflow control_name –print
```

The value of `control_name` is the path and name to the Control File. The list of available variables in the model will then be found in the `control_name.var_name` file in the directory in which GSFLOW is executed. Information that is provided for each variable includes a description of the variable, its dimension(s), data type, and number of values. Any declared output variable dimensioned by **nhru**, **nssr**, and **ngw** can be specified in the **mapOutVar_names** list. The following is an example of an entry in a `control_name.var_name` file for the variable recharge for a simulation with 829 HRUs.

```
Name: recharge
Module: soilzone
Ndimen: 1
Dimensions: nhru - 829
Size: 829
Type: float
Desc: Recharge to the associated GWR as sum of soil_to_gw and ssr_to_gw for each HRU
Units: inches
```

Simulated results can be summarized as a grid of HRU values from 1 to **nhru**, with the number of columns of values per row specified by parameter **ncol**. The first value (upper-left corner) is the simulated result for HRU 1 and the last value (lower-right corner) is the result for HRU with identification number **nhru**. For example, if there are 40 HRUs and the user specifies 4 as the value of **ncol**, the output will be a grid that has 10 rows and 4 columns; HRU 1 would correspond to row 1, column 1 and HRU 40 would correspond to row 10, column 4. This option is most useful when the target map is coincident with the HRU map and the upper left corner of the target map is row 1, column 1. The `map_results` module uses this method when the dimension **ngwcell** is specified with a value equal to **nhru** and control parameter **mapOutON_OFF** with the value 1.

Optionally, the module can interpolate PRMS output-variable(s) values for each HRU to a target map, such as a grid of cells from a grid-based model, using an area-weighted scheme and topological mapping parameters to relate HRUs to the target map. The HRU map and target map can be of different spatial extents; for example, the target map can extend beyond the HRU map or be fully or partially coincident with the HRU map (Markstrom and others, 2008, fig. 16). This option is activated by two conditions when **mapOutON_OFF** is greater than 0: (1) dimension **ngwcell** does not equal **nhru** and/or (2) specifying control parameter **mapOutON_OFF** with the value 2. The second condition must be used when the numbering scheme of the HRU identification numbers is different than that for the target map. For example, if the HRU map and the target map are the same grid of cells and the upper left corner of the target grid does not correspond to row 1, column 1 of the HRU map the second condition must be used.

The topological mapping parameters, which are specified in the Parameter File, are determined based on the intersection of the HRU map and target map. These parameters are dimensioned by the number of unique intersections between the HRU-map and target- map spatial units, **nhrucell**. Each intersection is identified by the associated HRU identification number, **gvr_hru_id**, the associated target-map, spatial-unit identification number, **gvr_cell_id**, and the associated portion of the target-map spatial unit, **gvr_cell_pct**, expressed as a decimal fraction. The topological parameters are named based on the USGS coupled Groundwater and Surface-Water Flow Model (GSFLOW), as described on pages 25-27 and tables A1-25 of the GSFLOW documentation report (Markstrom and others, 2008).

If the target map is different than a MODFLOW finite-difference grid, a second set of these topological parameters can be specified in a separate Parameter File, which is specified as the last Parameter File for the control parameter **param_file**. (IMPORTANT: be sure NOT to include this additional Parameter File for an integrated GSFLOW simulation.)

The primary use of the `map_results` module is for a PRMS-only simulation to provide an estimate of recharge, summarized at the temporal frequency required as input for a MODFLOW-only simulation. For this use, control parameter **mapOutON_OFF** is set based on the description above to either 1 or 2, **nmapOutVars** is set to 1, and **mapOutVar_names** is specified with the single value `recharge`. For example, include the following in the Control File.

```
####
mapOutON_OFF
1
1
1
####
nmapOutVars
1
1
1
####
mapOutVar_names
1
4
recharge
```

The gridded recharge rates can be used as initial estimates of the infiltration rates at land surface in a MODFLOW-only simulation (defined using variable *FINF* in the Unsaturated-Zone Flow Package, Niswonger and others, 2006); that is, as initial estimates of recharge to the subsurface zone. The values of recharge can be used for calibration purposes for any MODFLOW model because `map_results` output files are written in a format that is compatible for use in MODFLOW input files.

Recharge estimates computed by PRMS have been used as input for MODFLOW models in various applications (see, Bjerklie and others, 2010; Jeton and Maurer, 2007; Lee and Risley, 2002; Steuer and Hunt, 2001; Vaccaro, 1992; and Vaccaro, 2007). GSFLOW users have found these recharge estimates to be useful in a three-step calibration process (1) the PRMS model is calibrated; (2) values of recharge calculated by the `map_results` module are then used to aide calibration of the MODFLOW model; and (3) the GSFLOW model can be calibrated using as a starting point the individually calibrated PRMS and MODFLOW models. This calibration process typically is an iterative process.

Note, however, that the recharge estimates computed in a PRMS-only simulation do not reflect interactions with the underlying unsaturated and saturated zones that would be computed by an integrated GSFLOW simulation. Variable `recharge` is the sum of variables `soil_to_gw` and `ssr_to_gw`, as computed within the soilzone module. The calculated flow rates are similar to the potential gravity drainage computed for the first iteration of a GSFLOW time step. The flow rate `soil_to_gw` is based on soil infiltration and cascading surface runoff and interflow and the antecedent storage in the capillary reservoir of each HRU. The flow rate `ssr_to_gw` is computed based on the flow from the capillary reservoir into, and antecedent storage within, each gravity reservoir (GVR) associated with an HRU. In PRMS-only simulations, the available water to compute `ssr_to_gw` (see equation 59, page 58 in Markstrom and others, 2008) is the same for each associated GVR. In an integrated GSFLOW simulation, the available water in each GVR associated with an HRU can vary due to interactions with the underlying unsaturated and saturated zones (see page 58 of Markstrom and others, 2008). These interactions include groundwater discharge and rejected potential gravity drainage from the associated MODFLOW cell of the GVR, which affects the available water in each GVR. Thus, the potential gravity drainage written by the map_results module in a PRMS-only simulation will most likely be different than the potential gravity drainage computed during an integrated GSFLOW simulation.

References:

Bjerklie, D.M., Starn, J.J., and Tamayo, C., 2010, Estimation of the effects of land-use and ground-water withdrawals on ground-water recharge and streamflow using the Precipitation Runoff Modeling System (PRMS) watershed model and the Modular Ground-Water Flow Model (MODFLOW) for the Pomperaug River, Connecticut: U.S. Geological Survey Scientific Investigations Report 2010–5114, 81 p.

Jeton, A.E., and Maurer, D.K., 2007, Precipitation and runoff simulations of the Carson Range and Pine Nut Mountains, and updated estimates of ground-water inflow and the ground-water budget for basin-fill aquifers of Carson Valley, Douglas County, Nevada, and Alpine County, California: U.S. Geological Survey Scientific Investigations Report 2007–5205, 56 p.

Lee, K.K. and Risley, J.C., 2002, Estimates of groundwater recharge, base flow, and stream reach gains and losses in the Willamette River Basin, Oregon: U.S. Geological Survey Water-Resources Investigations Report 01–4215, 52 p.

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.

Niswonger, R.G., Prudic, D.E., and Regan, R.S., 2006, Documentation of the Unsaturated-Zone Flow (UZF1) Package for modeling unsaturated flow between the land surface and the water table with MODFLOW-2005: U.S. Geological Survey Techniques and Methods 6-A19, 62 p.

Steuer, J.J., and Hunt, R.J., 2001, Use of a watershed-modeling approach to assess hydrologic effects of urbanization, North Fork Pheasant Branch basin near Middleton, Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 2001-4113, 49 p.

Vaccaro, J.J., 1992, Sensitivity of groundwater recharge estimates to climate variability and change, Columbia Plateau, Washington: Journal of Geophysical Research, v. 97, no. D3, p. 2821–2833.

Vaccaro, J.J., 2007, A deep percolation model for estimating ground-water recharge—Documentation of modules for the modular modeling system of the U.S. Geological Survey: U.S. Geological Survey Scientific Investigations Report 2006-5318, 30 p.

Table 1. Input parameters specified in the Control File for the Map Results Module: map_results.

[Data type: 1, integer; 4, character string]

Parameter name	Definition	Number of values	Data type	Default value
Parameters related to model execution				
model_mode	Model to run (GSFLOW, PRMS, MODFLOW, WRITE_CLIMATE)	1	4	GSFLOW
start_time	Simulation start date and time specified in order as: year, month, day, hour, minute, second	6	4	2000, 10, 1, 0, 0, 0
end_time	Simulation end date and time specified in order as: year, month, day, hour, minute, second	6	4	2001, 9, 30, 0, 0, 0
Parameters related to model output				
mapOutON_OFF	Switch to specify whether or not mapped output file(s) by a specified number of columns (**ncol**) of weekly, monthly, yearly, or total simulation results is generated (0=no; 1=yes; 2=force use of topological mapping parameters)	1	1	0
mapOutVar_names	List of variable names for which output is written to mapped output files(s); required only when **mapOutON_OFF** > 0	**nmapOutVars**	4	none
nmapOutVars	Number of variables to write mapped output resuts; required only when **mapOutON_OFF** > 0	1	1	0

Table 2. Input parameters specified in the Parameter File for the Map Results Module: map_results.

[HRU: hydrologic response unit; **one**: a constant (1); **nhrucell**: number of unique intersections between gravity reservoirs and mapped spatial units]

Parameter name	Description	Dimension parameter	Units	Type	Range	Default value
Input from the Parameter File						
gvr_cell_id	Index of the spatial unit of target map associated with each gravity reservoir	**nhrucell**	none	integer	0 to number of mapped spatial units	0
gvr_cell_pct	Fraction of the spatial area unit of target map associated with each gravity reservoir	**nhrucell**	decimal fraction	real	0.0 to 1.0	0.0
gvr_hru_id	Index of the HRU associated with each gravity reservoir	**nhrucell**	none	integer	1 to **nhrucell**	1
mapvars_freq	Flag to specify the output frequency (0= none; 1=monthly; 2=yearly; 3=total; 4=monthly and yearly; 5=monthly, yearly, and total; 6=weekly)	**one**	none	integer	0-6	1
mapvars_units	Flag to specify the output units of mapped results (0= no units conversion; 1=converts inches/day to feet/day; 2= converts inches/day to centimeters/day; 3= converts inches/day to meters/day)	**one**	none	integer	0 to 3	0
ncol	Number of columns for each row of the mapped results	**one**	none	integer	1 to user determined	1
prms_warmup	Number of years to simulate before writing mapped results	**one**	years	integer	0 to user determined	1