DOCUMENTATION FOR CONVERSION OF THE MODFLOW-2000 LAK PACKAGE TO MODFLOW-2005

This documentation describes the changes to the Lake (LAK3) Package (Merritt and Konikow, 2000) for conversion to MODFLOW-2005. This version of the Lake Package includes several changes that have been made to the Package since it was originally released (see LAK7_Read_Me.txt file for a description of changes that have been made to LAK3). See Chapter 9 of Harbaugh (2005) for further information about the MODFLOW-2005 program.

1. FORTRAN module GWFLAKMODULE was created to store the shared data for the Lake Package; GWFLAKMODULE incorporates the capability to support Local Grid Refinement. The following table describes the data. Dimensions not defined in the following table are defined as follows: nlakesar = the greater of NLAKES and 1; nssar = the greater of nss and 1; nss = the number of stream segments specified in the Streamflow Routing (SFR) Package (Prudic and others, 2004; Niswonger and Prudic, 2005); mxlkar = the greater of MXLKND and 1; nuzfar = the greater of NLAKES and 1. NLAY, NROW, NCOL and NODES are global integers that are defined in Harbaugh (2005).

Variable Name	Size	Description
NLAKES	Integer	<input> Number of separate lakes.
ILKCB	Integer	<input> Flag for writing cell-by-cell flows. If >0, it is the unit number to which unformatted seepage rates are stored. If<0, seepage rates are printed to the main listing file. Seepage rates are stored or printed whenever "Save Budget" or ICBCFL is not zero in Output Control (Harbaugh, 2005, p. 8-18 to 8-21).
NSSITR	Integer	<input> Number of Newton iterations for computing lake depth.
MXLKND	Integer	Estimate of the number of lake-aquifer interfaces used for memory allocation.
LKNODE	Integer	Number of lake-aquifer interfaces.
ICMX	Integer	Maximum number of sublakes that can coalesce into a single lake. It is the largest value of the input variable IC (Merritt and Konikow, 2000, p. 55).
NCLS	Integer	Number of sublake systems in which lakes can coalesce and divide. It is the same as the input variable NSLMS (Merritt and Konikow, 2000, p. 55).
LWRT	Integer	<input> Flag for suppressing printout.
NDV	Integer	Number of stream diversions from a lake in which outflow is specified or computed on basis of stream channel geometry and lake stage.
NTRB	Integer	Number of tributary inflows to lakes.
THETA	Real	<input> Time weighting factor for solution of lake stage. This value is limited to a range between 0.5 and 1.0. A value of 0.5 averages the lake stage from the last time step with the current iteration lake stage. If a value less than 0.5 is specified, theta is automatically reset to 0.5.
SSCNCR	Real	<input> Convergence criterion for solution of a steady-state lake stage. If a simulation includes multiple steady-state and transient simulations, the value will be used for both. If only transient simulations are simulated, a value of 1E-06 is automatically assigned.
ICS	Integer (NLAKES)	Stores number of sublakes in each sublake system. The number of sublakes in each sublake system is defined by the input variable IC (Merritt and Konikow, 2000, p. 55).

NCNCVR	Integer (NLAKES)	Flag that determines the Newton iteration method for computing lake stage for a lake that has converged to less than a value specified by SSCNCR.
LIMERR	Integer (NLAKES)	Number of times lake stage is outside the specified maximum and minimum lake stage for a steady-state simulation. The steady-state simulation is stopped if LIMERR exceeds 10.
ILAKE	Integer (5,MXLKND)	Stores layer, row, column, lake id, and cell face number of cell that interfaces a lake.
ITRB	Integer (NLAKES,nssar)	Stores stream segment numbers that are tributary to a lake. Outflows from all stream segments entering a lake are added as inflow to a lake.
IDIV	Integer (NLAKES,nssar)	Stores stream segment numbers that are diversions from a lake. Outflows from a lake are either specified or computed on the basis of lake stage and stream channel geometry (Prudic and others, 2004, p. 9).
ISUB	Integer (NLAKES,NLAKES)	<input> Identification number of sublakes in a sublake system. Center lake is listed first.
IRK	Integer (2,NLAKES)	Total number of stream segments that are tributary to [IRK(1,NLAKES)] and diversionary from [IRK(1,NLAKES)] each lake.
LKARR1	Integer (NCOL,NROW,NLAY)	<input> Lake identification number read for each column, row, and layer. A value of zero means grid cell is not a lake. A value greater than zero means it is a lake. The lake identification number for a cell cannot exceed the value of NLAKES.
STAGES	Real (nlakesar)	<input> Initial stage of lake.
STGNEW	Double precision (nlakesar)	Lake stage after Newton iteration.
STGOLD	Double precision (nlakesar)	Lake stage from end of previous time step.
STGITER	Double precision (nlakesar)	Lake stage from previous Newton iteration.
VOL	Real (nlakesar)	Lake volume.
FLOB	Real (mxlkar)	Cell by cell flux between lake and aquifer.
DSRFOT	Real (NLAKES)	Stores derivatives of the lake outflow function with respect to lake stage for a lake with stream outflow.
PRCPLK	Real (NLAKES)	<input> Lake precipitation per unit area of lake.
EVAPLK	Real (NLAKES)	<input> Lake evaporation per unit area of lake.
BEDLAK	Real (MXLKND)	Lakebed leakance for each cell.
WTHDRW	Real (NLAKES)	<input> Volumetric rate of artificial withdrawal (positive value) from or augmentation (negative value) to a lake.
RNF	Real (NLAKES)	<input> Overland runoff to a lake. It is a volumetric rate to a lake if positive. It is a dimensionless multiplier applied to the product of lake precipitation rate per unit area (PRCPLK) and the lake surface area at its full stage.
CUMRNF	Real (NLAKES)	Stores cumulative volumetric runoff to each lake.
CUMPPT	Real (NLAKES)	Stores cumulative volumetric precipitation to each lake.
CUMEVP	Real (NLAKES)	Stores cumulative volumetric evaporation from each lake.
CUMGWI	Real (NLAKES)	Stores cumulative volumetric ground-water inflow to each lake.
CUMGWO	Real (NLAKES)	Stores cumulative volumetric ground-water outflow from each lake.
CUMSWI	Real (NLAKES)	Stores cumulative volumetric stream inflow to each lake.
CUMSWO	Real (NLAKES)	Stores cumulative volumetric stream outflow to each lake.
CUMWDR	Real (NLAKES)	Stores cumulative volumetric withdrawals from each lake.
CUMFLX	Real (NLAKES)	Stores cumulative volumetric exchange among connected lakes.
CNDFCT	Real (MXLKND)	Stores conductance factor needed for seepage calculations for each aquifer cell face with a lake cell.
VOLINIT	Real (NLAKES)	Stores initial lake volume.
STGOLD2	Real (NLAKES)	Stores lake stage from previous time step for each lake and is used to print previous time step lake stage to Gage Package.
BOTTMS	Real (NLAKES)	Stores lake bottom elevation for each lake.
BGAREA	Real (NLAKES)	Stores lake bed area for each lake.

SSMN	Real (NLAKES)	<input> Minimum lake stage of each lake for a steady-state simulation.
SSMX	Real (NLAKES)	<input> Maximum lake stage of each lake for a steady-state simulation.
EVAP	Real (NLAKES)	Stores volumetric rate of lake evaporation for each lake.
PRECIP	Real (NLAKES)	Stores volumetric rate of lake precipitation for each lake.
SEEP	Real (NLAKES)	Stores volumetric rate of lake seepage to and from ground water for each lake (summed over all aquifer cells interfacing a lake).
SEEP3	Real (NLAKES)	Stores total lake seepage when an incremental change is added to lake stage for each lake. The seepage value is used in computing lake stage using the Newton method.
SURFA	Real (NLAKES)	Stores surface area of lake (summed over all aquifer cells interfacing a lake excluding lake-wall cells).
SURFIN	Real (NLAKES)	Stores volumetric inflow from all tributary streams to a lake
SURFOT	Real (NLAKES)	Stores volumetric outflow to all diversionary streams from a lake.
SUMCNN	Real (NLAKES)	Stores the sum of all conductance values for lake-aquifer interfaces of each lake.
SUMCHN	Real (NLAKES)	Stores the sum of the product of all conductance values and ground-water heads for lake-aquifer interfaces of each lake.
CLAKE	Real (nlakesar,Nsol)	<input> Initial solute concentration of each lake.
CRNF	Real (NLAKES,Nsol)	<input> Solute concentration of specified runoff directly to a lake.
SILLVT	Real (NLAKES,NLAKES)	<input> Sill elevation that determines the connection among the center lake with sublakes.
CAUG	Real (NLAKES,Nsol)	<input> Concentration of solute in water used to augment the lake volume.
CPPT	Real (NLAKES,Nsol)	<input> Concentration of solute in precipitation onto the lake surface.
CLAKINIT	Real (nlakesar,Nsol)	Stores initial concentration of solute in each lake.
BDLKN1	Real (NCOL,NROW,NLAY)	<input> Lake bed leakances for each lake-aquifer interface.
OVRLNDRNF	Real (nuzfar)	Stores overland runoff from Unsaturated-Zone Flow (UZF1) Package.
CUMLNDRNF	Real (nuzfar)	Stores cumulative overland runoff from Unsaturated-Zone Flow (UZF1) Package.
EVAPO	Real (NLAKES)	Stores volumetric rate of lake evaporation for each lake that is limited by inflow to the lake when the lake is dry.
WITHDRW	Real (NLAKES)	Stores volumetric rate of withdrawal for each lake limited by inflow to the lake when the lake is dry.
FLWIN	Real (NLAKES)	Stores volumetric inflow in excess of withdrawals and lake evaporation and is used for keeping a water budget of the lake when the lake is dry.
FLWITER	Real (NLAKES)	Stores volumetric inflow in excess of lake evaporation and withdrawal during each Newton iteration for computing lake stage and stream outflow.
GWRATELIM	Real (NLAKES)	Stores the maximum volumetric rate of water available for seeping through lakebed when lake is dry, there is inflow to the lake from surface water, and the head in the aquifer is below the bottom-most elevation of the lakebed.
DEPTHTABLE	Real (151,NLAKES)	Stores increments of lake depth (lake stage less bottom elevation) starting from bottom-most elevation of lake to depth at maximum lake surface area.
AREATABLE	Real (151,NLAKES)	Stores lake areas corresponding to the increments of lake depth in DEPTHTABLE.
XLAKES	Real (NLAKES,1)	Stores a zero value for each lake and is used for passing to the GAGE Package when Solute Transport is inactive.
XLAKINIT	Real (NLAKES,1)	Stores a zero value for each lake and is used for passing to the GAGE Package when Solute Transport is inactive.
XLKOLD	Real (NLAKES,1)	Stores a zero value for each lake and is used for passing to the GAGE Package when Solute Transport is inactive.
LDRY	Integer (NODES)	Flag to indicate dry lake cells.
NCNT	Integer (NLAKES)	Flag for identifying connections to sublakes.

NCNST	Integer (NLAKES)	Flag that indicates lake stage of a lake is higher than the sill elevation that connects to a sublake.
KSUB	Integer (NLAKES)	Stores lake number of connected sublakes in a sublake system.
MSUB	Integer (NLAKES,NLAKES)	Stores lake numbers of connected sublakes for each sublake system.
MSUB1	Integer (NLAKES)	Stores total number of connected sublakes for a sublake system.
FLXINL	Real (NLAKES)	Stores changes in volumes when sublakes connect. It is the product of the combined surface area of the connected sublakes and the lake stage adjustment (STGADJ).
VOLOLD	Real (NLAKES)	Stores volume in each lake at end of previous time step.
GWIN	Real (NLAKES)	Stores volumetric inflow rate to lake from ground water at end of current time step.
GWOUT	Real (NLAKES)	Stores volumetric outflow rate to lake from ground water at end of current time step.
DELH	Real (NLAKES)	Stores change in lake stage between end of current time step and previous time step for each lake.
TDELH	Real (NLAKES)	Stores cumulative change in lake stage from beginning of simulation.
SVT	Real (NLAKES)	Stores sill elevations of sublakes.
STGADJ	Real (NLAKES)	Stores lake stage adjustment when sublakes connect so lake connected lake has one stage.

2. All subroutines were changed to designate 2 for the process version and 7 for the package version: GWF2LAK7.

3. Subroutines GWF1LAK3DF, GWF1LAK3ALP and GWF1LAK3RPP were combined to form GWF2LAK7AR and subroutine GWF1LAK3RPS was changed to GWF2LAK7RP.

4. GWF2LAK7AR was modified to use ALLOCATE statements to reserve memory for the data in GWFLAKMODULE rather than reserving space in the X, RX, IR, IG, and GX arrays used by MODFLOW-2000.

5. Subroutine arguments that are contained in FORTRAN modules were replaced with USE statements in all subroutines.

6. Subroutine GWF2LAK7DA was created to deallocate memory.

7. To support the Local Grid Refinement capability, subroutine SGWF2LAK7PNT was created to set pointers to a grid, and subroutine SGWF2LAK7PSV was created to save the pointers for a grid. The grid number, IGRID, was added as a subroutine argument to all of the primary subroutines, and subroutines SGWF2LAK7PSV and SGWF2LAK7PNT are called as appropriate.

8. The subroutine GWF2LAK7FM was modified to calculate lake stage as a function of outflow from a lake using a different Newton solution scheme than had been originally programmed for steady-state simulations. This change was made because outflow from a lake could oscillate between MODFLOW iterations that could affect stream seepage losses downstream and prevent MODFLOW from converging. Because lake stage is now a function of outflow from a lake, the Newton solution scheme is also used for transient simulations. The time weighting factor variable (THETA) used for computing ground water seepage rates to and from lakes using either the lake stage from the previous time step (THETA= 0.0) or lake stage from the most recent iteration of the current time step (THETA=1.0) or a combination of lake stage between the previous and current time step, is now limited to the range 0.5 to 1.0 for convergence.

9. Functions FINTERP, DERIVTERP, and OUTFLWTERP were added to linearly interpolate lake area, the derivative of stream outflow, and stream outflow as a function of lake stage. These were added to calculate lake-stage dependent sources and sinks during the Newton iteration of the lake stage.

10. A lake water budget is maintained even when the lake is dry. Five arrays (EVAPO, WITHDRW, FLWIN, FLWITER, and GWRATELIM) are used to limit specified withdrawals and evaporation to the lake inflow (both surface and subsurface). If there is more inflow than can be removed by the specified withdrawal and evaporation rates, then excess water can seep into the bottom area of the lake provided that ground-water heads are below the bottom-most elevation of the lake or the lake can begin to fill whenever inflow exceeds outflow.

References

Harbaugh, A.W., 2005, MODFLOW-2005, the U.S. Geological Survey modular ground-water model—the Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods 6-A16, variously paginated.

Merritt, M.L., and Konikow, L.F., 2000, Documentation of a computer program to simulate lake-aquifer interaction using the MODFLOW ground-water flow model and the MOC3D solute-transport model: Water-Resources Investigations Report 00-4167, 146 p.

Niswonger, R.G., and Prudic, D.E., 2005, Documentation of the Streamflow-Routing (SFR2) Package to include unsaturated flow beneath streams—a modification to SFR1: U.S. Geological Techniques and Methods Book 6, Chapter A13, 47 p.

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