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

This documentation describes the changes to the SFR Package (Prudic and others, 2004; Niswonger and Prudic, 2005) for conversion to MODFLOW-2005. See Chapter 9 of Harbaugh (2005) for further information about the MODFLOW-2005 program.

1. FORTRAN module GWFSFRMODULE was created to store the shared data for the SFR Package; GWFSFRMODULE incorporates the capability to support Local Grid Refinement. The following table describes the data. An input variable not defined in the following table is defined as followed: icalc = method used to compute stream depth. Dimensions not defined in the following table are defined as follows: nssar = the greater of NSS and 1; nstrmar = the greater of NSTRM and 1; nsegdim = NSS + nparseg; nparseg = number of stream segments defined using parameters <input>; Nsol = number of solutes being simulated.

Table 1. List of variables defined in FORTRAN module GWFSFRMODULE

Variable Name	Size	Description
NSS	Integer	<input> Number of stream segments.
NSTRM	Integer	<input> Number of stream reaches.
NSFRPAR	Integer	<input> Number of stream parameters.
ISTCB1	Integer	<input> Output unit to save unformatted stream reach leakages when > 0. Output is saved for stress periods and time steps specified in Output Control (Harbaugh, 2005, p. 8-17). Formatted information on reach inflows and outflows, stream depth, width, streambed conductance, and gradient across the streambed and unsaturated zone information are printed to the main listing file when <0. No information is saved or printed when = 0.
ISTCB2	Integer	<input> Output unit to save formatted information on reach inflows and outflows, stream depth, width, streambed conductance, and gradient across the streambed and unsaturated zone information when >0. Output is printed to the main listing file for stress periods and time steps specified in Output Control (Harbaugh, 2005, p. 8-17). Unformatted stream reach outflows are saved to the absolute value of the negative value when <0. No information is printed or saved when =0.
IUZT	Integer	Flag to indicate if unsaturated flow is active (0=inactive, 1=active).
MAXPTS	Integer	Dimension for tabulated discharge verses flow and width relations (set to 150).
IRTFLG	Integer	<input> Flag to indicate whether surface leakage will be routed to streams and lakes.
ISFROPT	Integer	<input> Flag for input and for the simulation of unsaturated flow beneath streams. (0=no, 1=yes with streambed top elevation and slope specified in SFR file, 2=yes with streambed top elevation and slope calculated from segment data)
NSTRAIL	Integer	<input> Number of trailing wave increments used to represent a trailing wave.
ISUZN	Integer	<input> Number of vertical cells to define unsaturated zone beneath a stream.
NSFRSETS	Integer	<input> Maximum number of trailing waves (used to dimension arrays).
NUZST	Integer	Dimension, set to 1 if unsaturated flow is inactive, to NSTRM if active.
NSTOTRL	Integer	Dimension, set to 1 if unsaturated flow is inactive, to 500 if active.

NUMAVE	Integer	Dimension, set to 1 if unsaturated flow is inactive, to 21 if active.
ITMP	Integer	<input> Flag for reusing or reading stream segment data that can change each stress period.
IRDFLG	Integer	<input> Flag for printing input data specified for this stress period.
IPTFLG	Integer	<input> Flag for printing streamflow-routing results during this stress period.
NP	Integer	<input> Number of parameters used in the current stress period.
CONST	Real	<input> Constant used for calculating reach stream depth with Manning's equation. Constant is 1.0 for units of cubic meters per second and 1.486 for units of cubic feet per second. The values are multiplied by 86,400 when time units are in days.
DLEAK	Real	<input> Maximum error (tolerance) of stream depth used in computing leakage between each stream reach and active model cell.
IOTSG	Integer (nsegdim)	<input> Number used to identify stream segment that receives outflow from a particular segment.
NSEGCK	Integer (nssar)	Stores segment numbers used for checking errors in segment number input.
ITRLSTH	Integer (NSTOTRL)	Stores temporary values of the array ITRLST.
ISEG	Integer (4,nsegdim)	Stores segment variables that can be read each stress period. Variables are ICALC, NSTRPTS, segment type (5=no tributary inflows, 6=diversions, and 7=tributary inflows), and total number of reaches in segment. Variables ICALC and NSTRPTS are defined in Prudic and others (2004, p. 43-45).
IDIVAR	Integer (2,nsegdim)	Stores diversionary variables that can be read each stress period. Variables are segment number to which flow is diverted and IPRIOR. The variable IPRIOR is defined in Prudic and others (2004, p. 44).
ISTRM	Integer (5,nstrmar)	Stores indices relating a stream segment and reach to a layer, row, and column in the finite-difference grid.
LTRLIT	Integer (NSTOTRL,NUZST)	Stores type of unsaturated flow wave during the formulate procedure.
LTRLST	Integer (NSTOTRL,NUZST)	Stores type of unsaturated flow wave during the budget procedure.
ITRLIT	Integer (NSTOTRL,NUZST)	Stores number of waves within a trail wave during the formulate procedure.
ITRLST	Integer (NSTOTRL,NUZST)	Stores number of waves within a trail wave during the budget procedure.
NWAVST	Integer (ISUZN,NUZST)	Stores total number of waves in a model cell.
STRIN	Real (nssar)	Stores segment outflow that is tributary to a lake.
STROUT	Real (nssar)	Stores lake outflow that is inflow to a stream segment.
FXLKOT	Real (nssar)	Stores specified flow into a stream segment from a lake.
UHC	Real (NUZST)	<input> Vertical saturated hydraulic conductivity of the unsaturated zone.
SGOTFLW	Real (nssar)	Stores outflow from segments that can be tributary to downstream segments.
DVRSFLW	Real (nssar)	Stores streamflow diverted into a diversionary segment.
SFRUZBD	Real (6)	Stores unsaturated zone budget terms.
SEG	Real (26,nsegdim)	<input> Physical and hydraulic properties of upstream and downstream end of stream segments. Variables stored in SEG are listed in table 2.
STRM	Real (31,nstrmar)	Combination of input variables read for each stream reach or computed from input variables by stream segment (SEG) and computed stream depth, inflows, outflows, streambed leakages, unsaturated storage, and recharge to ground water. Variables stored in STRM are listed in table 3.
SFRQ	Real (5,nstrmar)	Stores flow at midpoint of stream reach, flow in channel, leakage across streambed, stream width, and flow into stream reach for use with parameters.
HSTRM	Real (nstrmar,NUMTIM)	Stores stream head at the midpoint of a stream reach. This variable is used in routing flow down the channel

HWDTH	Real (nstrmar,NUMTIM)	Stores stream width at the midpoint of a stream reach. This variable is used in routing flow down the channel
HWTPRM	Real (nstrmar,NUMTIM)	Stores wetted perimeter at the midpoint of a stream reach. This variable is used in routing flow down the channel
QSTAGE	Real (MAXPTS,nsegdim)	<input> Table of values that relate streamflow to stream depth and width.
XSEC	Real(16,nsegdim)	<input> Depth and width relation using an eight-point cross-section for a selected stream segment.
AVDPT	Real (NUMAVE,NUZST)	Parameter for general power-law relation between flow and depth.
AVWAT	Real (NUMAVE,NUZST)	Parameter for general power-law relation between flow and depth.
WAT1	Real (NUMAVE,NUZST)	Parameter for general power-law relation between flow and depth.
CONCQ	Real (nsegdim,Nsol)	<input> The solute concentration associated with "FLOW"
CONCRUN	Real (nsegdim,Nsol)	<input> The solute concentration in the overland runoff entering the stream segment.
CONCPPT	Real (nsegdim,Nsol)	<input> The solute concentration in precipitation that directly falls onto the stream surface.
THTS	Double Precision (NUZST)	<input> the saturated volumetric water content in the unsaturated zone.
THTR	Double Precision(NUZST)	Residual water content used for unsaturated flow.
EPS	Double Precision(NUZST)	<input> The Brooks and Corey exponent used in the relation between water content and hydraulic conductivity within the unsaturated zone.
SUMLEAK	Double Precision(nstrmar)	Stores streambed leakage for each stream reach.
SUMRCH	Double Precision(nstrmar)	Stores recharge to ground water from unsaturated zone beneath each stream reach.
FOLDFLBT	Double Precision (nstrmar)	Seepage from previous time step.
THTI	Double Precision(NUZST)	<input> Initial volumetric water content.
UZFLWT	Double Precision (ISUZN,NUZST)	Volume of water added to ground water from the unsaturated zone.
UZSTOR	Double Precision(ISUZN,NUZST)	Volume of water stored in the unsaturated zone
UZWDTH	Double Precision(ISUZN,NUZST)	Width of unsaturated flow columns beneath stream reaches.
UZSEEP	Double Precision(ISUZN,NUZST)	Seepage rate per unit area of streambed entering the unsaturated zone beneath a stream reach.
DELSTOR	Double Precision(ISUZN,NUZST)	Volumetric change in unsaturated-zone storage beneath stream reaches
WETPER	Double Precision (ISUZN,NUZST)	Wetted perimeter of a stream reach used for calculating infiltration in the unsaturated zone.
UZDPIT	Double Precision (NSTOTRL,NUZST)	Depth of unsaturated flow waves during formulate procedure.
UZDPST	Double Precision(NSTOTRL,NUZST)	Depth of unsaturated flow waves during budget procedure.
UZTHIT	Double Precision(NSTOTRL,NUZST)	Water content of unsaturated flow waves during formulate procedure.
UZTHST	Double Precision(NSTOTRL,NUZST)	Water content of unsaturated flow waves during budget procedure.
UZSPIT	Double Precision(NSTOTRL,NUZST)	Speed of unsaturated flow waves during formulate procedure.
UZSPST	Double Precision(NSTOTRL,NUZST)	Speed of unsaturated flow waves during budget procedure.
UZFLIT	Double Precision(NSTOTRL,NUZST)	Flux of unsaturated flow waves during formulate procedure.
UZFLST	Double Precision(NSTOTRL,NUZST)	Flux of unsaturated flow waves during budget procedure.
UZOLSFLX	Double Precision(ISUZN,NUZST)	Seepage rate per unit area of streambed during the previous time step.
QSTRM	Double Precision (nstrmar,NUMTIM)	Average flow at the center of reach.

SLKOTFLW	Double precision (200,nssar)	Stores lake outflow for a range in lake stage for use in computing lake stage in the Lake Package (Merritt and Konikow, 2000).
DLKOTFLW	Double precision (200,nssar)	Stores the derivative of lake outflow for a range in lake stage for use in computing lake stage in the Lake Package (Merritt and Konikow, 2000).
DLKSTAGE	Double precision (200,nssar)	Stores lake stage used for interpolating lake outflow from streams for use in computing lake stage in the Lake Package (Merritt and Konikow, 2000).

2. All subroutines were changed to designate 2 for the process version and 7 for the package version: GWF2SFR7.

3. Subroutines GWF1SFR7DF, GWF1SFR7ALP, and GWF1SFR7RPP were combined to form GWF2SFR7AR and subroutine GWF1SFR7RPS was changed to GWF2SFR7RP.

4. GWF2SFR7AR was modified to use ALLOCATE statements to reserve memory for the data in GWFSFRMODULE rather than reserving space in the X, RX, RZ, 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 GWF2SFR7DA was created to deallocate memory.

7. To support the Local Grid Refinement capability, subroutine SGWF2SFR7PNT was created to set pointers to a grid, and subroutine SGWF2SFR7PSV 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 SGWF2SFR7PSV and SGWF2SFR7PNT are called as appropriate.

8. Subroutine GWF2SFR7LAKOUTFLW was added to SFR in version 1.17 of MODFLOW-2000 and in version 1.2 of MODFLOW-2005. The subroutine was written to compute the variables SLKOTFLW, DLKOTFLW, and DLKSTAGE described in table 1.

9. The code was reformatted using a FORTRAN restructuring tool called SPAG by PlusFORT. The letter case of the code was changed to reflect function of the code. All FORTRAN language features and FORTRAN module variables are in uppercase letters. Local variables are in lower case letters. Format statements were renumbered and most collected at the end of subroutines. Spacing was made consistent, with two spaces to indent loops and conditional clauses. All variables are explicitly declared. Redundant RETURN statements were removed. Variables not initialized were initialized. Double precision constants were used where appropriate. References to do loop variables outside of their scope were replaced with variables set inside the do loop.

Table 2. List of variables stored in the SEG array

Location	Variable name	Description
SEG(1,nsegdim)	SEGLEN	Stream segment length.
SEG(2,nsegdim)	FLOW	Specified streamflow into segment.
SEG(3,nsegdim)	RUNOF	Specified segment runoff.
SEG(4,nsegdim)	ETSW	Surface water evapotranspiration rate.
SEG(5,nsegdim)	PPTSW	Surface water precipitation rate.
SEG(6,nsegdim)	Hc1fact or HCOND1	Hydraulic conductivity at beginning of segment.
SEG(7,nsegdim)	THICKM1	Streambed thickness at beginning of segment.
SEG(8,nsegdim)	ELEVUP	Streambed elevation at beginning of segment.
SEG(9,nsegdim)	WIDTH1	Stream width at beginning of segment.
SEG(10,nsegdim)	DEPTH1	Stream depth at beginning of segment.
SEG(11,nsegdim)	Hc2fact or HCOND2	Hydraulic conductivity at end of segment.
SEG(12,nsegdim)	THICKM2	Streambed thickness at end of segment.
SEG(13,nsegdim)	ELEVDN	Streambed elevation at end of segment.
SEG(14,nsegdim)	WIDTH2	Stream width at end of segment.
SEG(15,nsegdim)	DEPTH2	Stream depth at end of segment.
SEG(16,nsegdim)	ROUGHCH	Mannings roughness coefficient for channel.
SEG(17,nsegdim)	ROUGHBK	Mannings roughness coefficient for bank.
SEG(18,nsegdim)	THTS1	Saturated water content beneath streambed at beginning of segment.
SEG(19,nsegdim)	THTI1	Initial water content beneath streambed at beginning of segment.
SEG(20,nsegdim)	EPS1	Brooks-Corey exponent used in the relation between water content and hydraulic conductivity for unsaturated flow at beginning of segment.
SEG(21,nsegdim)	UHC1	Vertical saturated hydraulic conductivity of unsaturated zone beneath streambed at beginning of segment.
SEG(22,nsegdim)	THTS2	Saturated water content beneath streambed at end of segment.
SEG(23,nsegdim)	THTI2	Initial water content beneath streambed at end of segment.
SEG(24,nsegdim)	EPS2	Brooks-Corey exponent used in the relation between water content and hydraulic conductivity for unsaturated flow at end of segment.
SEG(25,nsegdim)	UHC2	Vertical saturated hydraulic conductivity of unsaturated zone beneath streambed at end of segment.
SEG(26,nsegdim)	RUNOFF	Overland runoff from Unsaturated Zone Flow (UZF1) Package (Niswonger and others, 2006).

Table3. List of variables stored in the STRM array

Location	Variable name	Description
STRM(1,nstrmar)	RCHLEN	Length of stream reach.
STRM (2,nstrmar)	SLOPE	Streambed slope of stream reach.
STRM (3,nstrmar)	STRTOP	Streambed top elevation at midpoint of stream reach.
STRM (4,nstrmar)	SBOT	Streambed bottom elevation at midpoint of stream reach.
STRM (5, nstrmar)	WIDTH	Average streambed width of stream reach.
STRM (6, nstrmar)	AVHC	Streambed hydraulic conductivity of stream reach.
STRM (7, nstrmar)	DEPTH	Average stream depth of stream reach.
STRM (8, nstrmar)	SBDTHK	Average streambed thickness of stream reach.
STRM (9, nstrmar)	FLOWOT	Streamflow out of stream reach.
STRM (10, nstrmar)	FLOWIN	Streamflow into stream reach.
STRM (11, nstrmar)	FLOBOT	Computed leakage across streambed of stream reach.
STRM (12, nstrmar)	RUNOF	Specified volumetric rate of overland runoff into stream reach.
STRM (13, nstrmar)	ETSTR	Volumetric rate of evapotranspiration from stream reach.
STRM (14, nstrmar)	PRECIP	Volumetric rate of precipitation to stream reach.
STRM (15, nstrmar)	HSTR	Stream head or stage at midpoint of stream reach.
STRM (16, nstrmar)	CSTR	Streambed conductance of stream reach.
STRM (17, nstrmar)	HDIFF	Head difference across streambed at midpoint of stream reach.
STRM (18, nstrmar)	GRAD	Head gradient across streambed at midpoint of stream reach.
STRM (19, nstrmar)	H	Head in underlying active cell.
STRM (20, nstrmar)	WETPERM	Wetted perimeter of streambed at midpoint of stream reach.
STRM (21, nstrmar)	TOTFLWT/DELTINC	Total volumetric unsaturated flow rate to water table.

STRM (22, nstrmar)	TOTDELSTOR/DELTINC	Change in unsaturated storage rate beneath stream reach.
STRM (23, nstrmar)	TOTUZSTOR	Total unsaturated storage beneath stream reach.
STRM (24, nstrmar)	RUNOFF	Overland runoff from Unsaturated Zone Flow (UZF1) Package (Niswonger and others, 2006) for a stream segment. The overland runoff is divided into stream reaches on basis of percentage of stream length in each stream.
STRM (25, nstrmar)	QB	Streamflow out of reach for previous time step with channel-flow routing (array element not implemented in version 1.2)
STRM (26, nstrmar)	QA	Streamflow into reach for previous time step with channel-flow routing (array element not implemented in version 1.2)
STRM (27, nstrmar)	QD	Streamflow out of reach for current time step with channel-flow routing (array element not implemented in version 1.2)
STRM (28, nstrmar)	QC	Streamflow into reach for current time step with channel-flow routing (array element not implemented in version 1.2)
STRM (29, nstrmar)	TOTDELSTOR	Total change in unsaturated zone storage.

References

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