Applied Hydrogeology Introduction to Modflow



Adam Říčka

Department of Geological Sciences, Faculty of Science, Masaryk University, Kotlarska 2, 611 37 Brno, Czech Republic

Modflow – introduction

The most widespread computer code for groundwater flow - **MODFLOW**

Modflow versions: 88, 96, 2000 and 2005

Software packages with modflow code: PMWIN (version 96), Processing modflow Pro (version 96), Visual Modflow (version 2000), GMS (version 2000)

PMWIN:

Finite differences, saturated flow, steady-state and transient flow, water budget, inverse modelling (PEST, UCODE), transport advective modelling (MT3D, MT3DMS, MOC3D), advective modelling (PMPATH)

New model – crate new folder choose simple path (e.g. C: Document: My model folder)

🤋 Pi	Processing Modflow						
ile	Grid	Parameters	Models	Tools	Help		
Ne	w Mo	del					
Ор	en Me	odel					
Col	nvert	Model					
Model Information							
Save Plot As							
Print Plot							
Animation							
1 c:\čerťák1-střední stav\čerťák.pm5 2 c:\pm5_3\mb - brezen 2003.pm5 3 c:\documents and s…b - brezen 2003.pm5							
Exi	Exit						
	_			_	_	_	

Modeled area discretization

Keep the mine basical principles and rules in the grid preaparation! (see previous presentation)

Grid creation – define modeled area extent and consequently define number and size of rows, columns and layers

Define the layer type – preferable is the confined/unconfined layer with transmissivity varies



Environment and Maps

Environment

Find out:

- Extent of modeled area discretized by grid
- Extent of the underlying map set up the same size for the worksheet
- Define X and Y coordinates Universal Trasnverse mercator – UTM – depiction of elipsoid's parts in plan

Latitude – 60 zones marked by numbers

Longitude – 20 zones marked by letter of the alphabet



🗗 Processing Modflow - [ČERŤÁK.PM5]

Environment... Ctrl+E

Ctrl+M

Maps..

Display Mode

Input Method

File Value Options Help





Environment and Maps

Maps

Underlying map – vector map (DXF) or raster map (bmp, jpg)

• Define the left-lower and right-upper edge of the map (Ctrl + left mouse button - decrease the map view, Shift + left mouse button - increase the map view)

Environment

move and rotate the model grid to desired position according to underlaid map

😌 Environment Options	×
Appearance Coordinate System) Contours)
Grid Position	Worksheet / Coordinate System
Xo= -543892	(X2, Y2)
Yo= -1179544	Your model grid
A= 27	(Xo, Yo)
Worksheet Size	HHAT A
×1= -544100	
Y1= -1182700	x x
×2= -535900	(A=Rotation angle in degree)
Y2= -1176300	(×1, Y1)
Display zones in the cell-by-cell r	ode
	OK Cance Help
Maps Options	
Vector Graphics Baster Graphics	
Filename: C:\man.ing	
Point 1	Point 2
Raster X= √-544100	Set X= -535900 Set
Visible Y= 1182700	Y= -1176300
FULATIONSA	2- 200
Koora	H.shhninaks
and the second s	The second se
20 Parks	
	STARE MESTO
Ziachoz	The hast
Starting 1 - 12 to the starting	
1 the	Summer and State
	Kenning and Andrewski and Andr
UHERS	KE WAR
UHERS	Arrest Ar

Define the boundary conditions –

assign number:

- Active cell = 1
- Inactive cell = 0 (II. type)
- Constant cell = -1 (I. type)



Define the top and bottom of layers:

- Manual cell by cell or zonal input method
- Interpolation Digitizer, Field interpolator



Input parameters – time, observations, starting

heads and hydraulic parameters

Time:

Steady state flow type - steady-state flow even for several Stress periods

Transient flow type – time is discretizated to Time steps in Stress periods Choose time unit

Initial starting heads:

- Steady-state flow require exactly determined heads only in boundary conditions
- Transient flow require exactly determined heads in the whole model





Boreholes and Observations - insert name, coordinate system and observed hydraulic head

~	Bore	holes and C)bservat	ions			×	-11	Borehole	es and Observat	ions			×
	Boreho	les.) Observal	ions)					£	Boreholes	Observations				
	No.	Borehole Name	Active	X (easting)	Y (north	ning) Layer	-		Borehole Name	Observation Time	Weight	Head	Drawdown	Concent
	1	W1		1320	1	080 1-	-11		W1	1	1	195,8	0	
	2	W2		1525		905 1			W2	1	1	196,15	0	
	3	3		0		0 1				0	1	0	0	
	4	4		0		0 1				0	1	0	0	
	5	5		0		0 1				0	1	0	0	
	6	6		0		0 1				0	1	0	0	
	7	7		0		0 1				0	1	0	0	
	8	8		0		0 1				0	1	0	0	
	9	9		0		0 1				0	1	0	0	
	10	10		0		0 1				0	1	0	0	
	11	11		0		0 1				0	1	0	0	
	12	12		0		0 1				0	1	0	0	
	13	13		0		0 1					•			
	14	14		0		0 1			Options					
	15	15		0		0 1			🖲 Use o	bserved heads for th	ne calibration			
	16	16		0		0 1,	-		🔘 Use o	bserved drawdowns	for the calibra	ation		
	47	47	-				<u> </u>		-	1				
	Sav	e Loa	±	Clear					Save	Load	Clear			
-												or		
				1	ок 🛛 Са	ancel Help							Lancel	Help

- Real-world coordinate system UTM (The Universal Transverse Mercator)
 557935.1, 1031526 272, 289, 1
- Relative coordinate system relative position of modeled
 grid in the status bar

tive	position of m	nodeled
91	7.7288, 2050.985	1,1,1
	0	

3197.448

Hydraulic parameters:

- Horizontal hydraulic conductivity one or more values
- Vertical hydraulic conductivity in the multi-layer model, the ratio of horizotnal to vertical conductivity is vertical conductivity ranging from 3:1 to 10:1
- Anisotropy factor the ratio of horizontal conductivity (or transmissivity) along the x and y direction
- Vertical leakance quasi-three dimensional models replace the modeled layer and represent semiconfining unit - resistance to the vertical flow



• Transmissivity – define in Layer Type \rightarrow User specified or Calculated

Storage parameters - transient simualation – water is released from or taken into storage within the porous material

• Specific storage (S_s) – volume of water released from storage within a unit volume of porous material per unit decline in head

 Storage coefficient (S) – in the 2-D areal simulations, vertically averaged parameter equal to the volume of water released per unit area of aquifer per unit decline in head

 $S = bS_s$ b = aquifer thickness

• Specific yield – storage parameter of the unconfined aquifer, volume of gravity drainaged water per volume of porous material

Effective porosity – advective modelling, from 1 % (fractured rocks) to 35 % (coarse grained sand or gravel)

PMWIN – Models

🚭 Processing Modflow - [MY VERY FIRST MODEL.PM5]							
File Grid Parameters	Models	Tools	Help				
	MODF MOCC MT3D MT3D PEST UCOE PMPA	FLOW 3D))MS (Inverse)DE (Inve	e Modeling rse Model	g) ling))))))		

MOC3D, MT3D, MT3DMS – transport modeling

MODFLOW – flow field







PMPATH – advective modeling



PEST, UCODE – automated parameter estimation

OPTIMISATION RESULTS

Parameters ---->

Parameter	Estimated	95% percent con	fidence limits
	value	lower limit	upper limit
rch_1	4.000760E-09	3.275596E-09	4.886464E-09

Note: confidence limits provide only an indication of parameter uncertainty. They rely on a linearity assumption which may not extend as far in parameter space as the confidence limits themselves - see PEST manual.

See file PESTCTL.SEN for parameter sensitivities.

PMWIN – Models

Flow packages - inflow and outflow to/from model and within the model

f

III. Type of boundary condition

Drain, GHB, Evapotranspiration, Reservoir, River, Streamflow-Routing

Sources and Sinks

Recharge, Well

Additional

Horizontal-Flow barriers

Density

Interbed Storage

Wetting Capability

Processing Modflow - [MY VERY FIRST MODEL.PM5]							
File Grid Parameters	Models Tools Help						
	MODFLOW MOC3D MT3D PEST (Inverse Modeling) UCODE (Inverse Modeling) PMPATH (Pathlines and Contours)	 Density Drain Evapotranspiration General Head Boundary Horizontal-Flow Barriers Interbed Storage Recharge Reservoir River Streamflow-Routing Time-Variant Specified-Head Well Wetting Capability Output Control Solvers Run 					

PMWIN – Models

III. Type of boundary condition: flux across is dependent on the difference between a user-supplied specified head on one side of the boundary and the model-calculated head on the other side

$$L = Q_L / A = K_z / b'(h_{source} - h)$$

L = leakage rate Q_L = volumetric flux A = area of the cell K_z' = vertical hydraulic conductivity of the interface b' = thickness of the interface h_{source} = head in the source reservoir h = head in the aquifer

- Drain water releases model
- **GHB** simulation of the distant constant head boundary condition
- Evapotranspiration water releases model in accordance with extinction depth
- River upper limit for water inflow
- Streamflow Routing allow hyraulic parameters of the stream channel flow
- Reservoir similar to River package, allow simulate more reservoirs

PMWIN – MODFLOW

General Head Boundary - III. Type of boundary condition

$$Q_b = C_b - (h_b - h) \qquad C_b = K \cdot A / L$$

High C_b represents equivalent of constant head



River - III. Type of boundary condition

$$C_{riv,str} = \frac{KLW}{W}$$
 $Q_{riv,str} = \frac{KLW}{M}(h_s - h_a)$

K is vertical hydraulic conductivity of riverbed sediments, L is lenght of the river in the cell, W is wide of the river and M is thickness of the rvierbed sediments

PMWIN – MODFLOW

Sources and Sinks:

- Recharge upper boundary condition
- Well injection well + injected rate
 - pumping well pumped rate

Well in multi-layer model:

• **Confined layer** - divide of pumped/injected rate in model in accordance with transmissivity of each layer T_{L}

$$Q_k = Q_{total} \frac{T_k}{\sum T}$$

Unconfined layer – to set a very large vertical hydraulic conductivity (e.g. 1 m/s) to all cells of the well

• **Exact extraction rate** from each penetrated layer – to set a minimal pumped rate to the each layer (e.g. 1.10⁻¹⁰) and than use the water budget calculator

🖬 Reset	Matrix 🗵					
	Recharge Flux [L/T]: 43E-09					
	Layer Indicator (IRCH): 0					
	Parameter Number [-]: D					
Recharge Options • Recharge is only applied to the top grid layer Vertical distribution of recharge is specified in IRCH C Recharge is applied to the highest active cell.						
Caution: All cell values in the current layer will be replaced by the values specified above.						
OK Cancel Help						
	🗞 Cell Value 🛛 🔀					
	Recharge Rate of the Well (L^3/T): -0.05					
	Parameter Number [-]					
Current Position (Column, Row) = (91, 99)						

PMWIN – MODFLOW

Next flow packages:

- Horizontal-Flow barrier thin impermeable geologic feature (fault, slurry wall), impede the horizontal flow
- **Density** approximation of density flow model without considering the salinity distribution
- Interbed Storage water volume released from storage by elastic adn inelastic compaction of compressible fine-grained beds in a aquifer due to groundwater extraction
- Wetting capability the simulation of a rising water table into dry model cells

PMWIN – PEST, UCODE

Automated parameter calibration:

- Assign parameter number to calibrated value
- Calibrated value : hydraulic parameters, storage parameters, recharge and boundary conditions III. type



Output file PESTCTL.REC includes
 optimized results
 Parameters ---->

OPTIMISATION RESULTS				
Parameters	->			
Parameter	Estimated Value	95% percent confid	dence limits unner limit	
rch_1	4.000760E-09	3.275596E-09	4.886464E-09	
Note: confidence limits provide only an indication of parameter uncertainty. They rely on a linearity assumption which may not extend as far in parameter space as the confidence limits themeelves - see PEST manual.				
See file PESTCTL	SEN for parameter	sensitivities.		

List of Calibration Parameters (PEST)					
Parameters Group Definitions Prior Information Control Data Options					
Number	Active	Description	PARVAL1	PARLBND	PARUBND 🔺
1	⊠	horizontal conductivity	5,6E-07	5E-08	0,00005
2		recharge	4E-09	4E-08	4E-10
3			0	0	0
4			0	0	0
5			0	0	0
6			0	0	0
7			0	0	0
8			0	0	0
9			0	0	0
10			0	0	0
11			0	0	0
12			0	0	0
13			0	0	0
14			0	0	0
15			0	0	0
16			0	0	0



PMWIN – PMPATH

Advective modeling - based on flow field from Modflow, 3-D demonstration of the flow

Appearance Cross Sections Velocity vectors Contours Cross Sections	Simulation Mode/Time Pathline Colors RCH/EVT Options Current Time Stress Period: 1 Time Step: 1 Time Step: 1 Time Mark Interval: 5 Visible Cross Sections Visible Visible	Velocity Vectors
Projection Column: 256 Minimum Elevation: 1000 Maximum Elevation: 3203.618	Size: 10 Size: 3 Simulation Mode Simulation Mode Simulation Mode Simulation Mode Stop Condition Particles stop, when they enter cells with internal sinks	
OK Cancel Ontrol panel ** PMPATH - [chacha2layer, pm5] File Run Options Help ** + × @ @ @ @ @ []]] []] []] []] []] []]] []	Particles stop, when the simulation time limit is reached OK Cancel	
	Position of the mouse pointer – real coordinates	On board
Streamline	Position of the mouse pointer – cell indices	270, 275, 1 3,0232E+03 1,1051E-06 4,5228E-03 1 1 1 1 Horizontal Vertical Stress Current at the cell velocity period time step

PMWIN – MOC3D, MT3D, MT3DMS

Transport models:

- based on the flow field from modflow
- solute transport advection, affected by disperzion, diffusion and retardation

MOC3D – define the subrid for solute-transport equations

MT3D, MT3DMS – similar, solute-transport within Modflow grid with own boundary conditions

Input parameters

- Initial Concentration and Source/Sink Concentration
- Advection (from Modflow)
- Disperzion:

Horizontal transverse dispersivity Vertical transverse dispersivity Longitudinal dispersivity

Chemical reaction

The effective molecular diffusion coefficient

Sorption - Linear and unlinear Freundlich and Langmuir equilibrium isotherm

Rdioactive decay or biodegradation - First order decay rate and First order sorbed rate



PMWIN – Tools

🚭 Processing Modflow - [ČERŤÁK.PM5]					
File Grid Parameters Models	Tools Help				
1	Digitizer Field Interpolator (PMDIS) Field Generator (PMFGN)				
	Presentation Results Extractor Water Budget Graphs ►				

• Digitizer – digitized points



Field Interpolator – interpolation of digitized points to the 3-D surface

Х

• Field Generator – stochastic modeling – generate field with heterogeneously-distributed hydraulic conducitivity values

PMWIN – Tools

204

197

Variance = .1487915

Observed Heads

Results Extractor: 😴 Processing Modflow - [ČERŤÁK.PM5] File Grid Parameters Models Tools Help Digitizer 2 Field Interpolator (PMDIS).. Field Generator (PMFGN)... Resultant data sets in the sheet Presentation Results Extractor... Water Budget.. Head-Time Graphs Drawdown-Time **Presentation**: Load resultant data sets Mead-Time Curves Head Comparison of Calculated and Observed Heads Name Plot Color 2.13E+2-204 P1 OP1 OP3 OI1 OI2 OI3 Graphs: lated Heads 11 Time dependent results ۲ Graph Style 1.87E+2-→ Time 8.64E+6 Linear C Semi-Log X-Axis (Time) Min. time: Y-Axis Data Types Save Plot As.. Min. value Scatter diagram Calculated \bullet 187.4237 ✓ Observation Data >> Max. time: Max. value Options Scatter Diagram >> 8640000 212.6811

Ticks:

Ticks:

10

Draw horizontal grid

Draw vertical grid

🔽 Auto Adjust Min/Max

Help

Close

PMWIN – Tools

Water Budget

- Check the quality of the simulation results
- Allow flow rates between all faces of model cell
- Zone flow rate exchange across the cell
- Whole model compare the discrepancy.

Water balance Discrepancy:

- Recommended discrepancy < 1%
- Discrepancy > 1% denotes coarse grid, high closure (convergence) criterium, too long time step
- Discrepancy > 10% denotes incorrect conceptual model

WATER BUDGET OF ZONES WITHIN EACH INDIVIDUAL LAYER ZONE 1 IN LAYER 1 FLOW TERM IN OUT IN-OUT STDRAGE 0.0000000E+00 0.0000000E+00 0.0000000E+00 CONSTANT HEAD 0.0000000E+00 0.0000000E+00 0.0000000E+00 HORIZ EXCHANGE (LOWER) 1.6763251E-02 1.197104E-03 1.544341E-02 EXCHANGE (LOWER) 1.6763251E-02 1.9197104E-00 0.000000E+00 0.000000E+00 PALNS 0.0000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 RECHANGE 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 RIVER LEAKAGE 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 SITREAM LEAKAGE 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 SUM OF THE LAYER 1.9135412E-02 1.9135518E-02 -1.0617077E-02 JISCREPANCY [%] 0.00 0.000000E+00 0.000000E+00 0.000000E+00 SUM OF THE LAYER 1.9135518E-02 -1.9617077E-02 <th></th> <th></th> <th></th> <th></th>				
ZONE 1 IN LAYER 1 FLOW TERM IN OUT IN-OUT IN-OUT STORAGE 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 CONSTANT HEAD 0.0000000E+00 0.000000E+00 0.0000000E+00 0.000	WATER BUDGET OF	ZONES WITHIN EA	CH INDIVIDUAL L	AYER
FLOW TERM IN OUT IN-OUT STORAGE 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 CONSTANT HEAD 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 HORIZ. EXCHANGE 1.6763251E-02 1.3197104E-03 1.5443541E-02 EXCHANGE (UPPER) 0.000000E+00 0.000000E+00 0.000000E+00 WELLS 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 RECHARGE 1.5850021E-03 0.000000E+00 0.000000E+00 0.000000E+00 RIVER LEAKAGE 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 STREAM LEAKAGE 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 SUM OF THE LAYER 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 SUM OF THE LAYER 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 SUM OF THE LAYER 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 STORAGE 0.000000E+00 0.0000000E+00	ZONE 1 IN LAY	ER 1		
WATER BUDGET OF ZONES OVER THE ENTIRE MODEL ZONE: 1 IN OUT STORAGE 0.0000000E+00 0.0000000E+00 CONSTANT HEAD 0.0000000E+00 0.0000000E+00 0.0000000E+00 CONSTANT HEAD 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 HORIZ. EXCHANGE 7.8715780E-04 3.26532382=05 7.54504446E-00 EXCHANGE (LOPER) 0.0000000E+00 0.0000000E+00 0.0000000E+00 EXCHANGE (LOWER) 1.6763251E-02 1.3197104E-03 1.5443541E-02 MELLS 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 RCHARGE 1.5850021E-03 0.0000000E+00 0.0000000E+00 0.0000000E+00 RIVER LEAKAGE 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 INTERBED STDRAGE 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 STORAGE 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 STORAGE 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.00000	FLOW TERM STDRAGE CONSTANT HEAD HORIZ. EXCHANGE EXCHANGE (LOWER) WELLS DRAINS RECHARGE HEAD DEP BOUNDS STREAM LEAKAGE INTERBED STDRAGE MULTI-AQIFR WELL SUM OF THE LAYER DISCREPANCY [%] ZONE 1 DOES N	IN 0.0000000E+00 0.000000E+00 7.8715780E-04 0.0000000E+00 1.6763251E-02 0.0000000E+00 0.00000000E+00 0.00000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.00000000E+00 0.00000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.000000E+0000000E+00 0.0000000E+00 0.0000000E+00 0.0000	OUT 0.0000000E+00 3.2653283E-05 0.000000E+00 1.3197104E-03 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.0000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.00000E+00 0.000000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.000000E+00 0.000000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.00000E+00 0.000000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000	IN-OU 0.000000E+0 0.000000E+0 0.000000E+0 0.000000E+0 0.544341E-0 0.000000E+0 1.5443541E-0 0.000000E+0 -1.7783154E-0 0.0000000E+0 0.0000000E+0 0.0000000E+0 -1.0617077E-0
WATER BUDGET OF ZONES OVER THE ENTIRE MODEL ZONE: 1			ER 2	
ZONE: 1 STORAGE 0.0000000E+00 0.0000000E+00 0.0000000E+00 CONSTANT HEAD 0.0000000E+00 0.0000000E+00 0.0000000E+00 HORIZ. EXCHANGE 7.8715780E-04 3.2653283E-05 7.5450446E-0 EXCHANGE (UPPER) 0.0000000E+00 0.0000000E+00 0.0000000E+00 WELLS 0.000000E+00 0.0000000E+00 0.0000000E+00 RECHANGE 1.5850021E-03 0.000000E+00 0.0000000E+00 RECHARGE 1.5850021E-03 0.000000E+00 1.5843541E-02 HEAD DEP BOUNDS 0.000000E+00 1.7783154E-02 -1.7783154E-02 HEAD DEP BOUNDS 0.000000E+00 0.000000E+00 0.000000E+00 STREAM LEAKAGE 0.000000E+00 0.000000E+00 0.000000E+00 INTERBED STDRAGE 0.000000E+00 0.000000E+00 0.000000E+00 SUM OF ZONE(1) 1.9135412E-02 1.9135518E-02 -1.0617077E-03 DISCREPANCY [%] 0.00 WATER BUDGET OF THE WHOLE MODEL DOMAIN: FLOW TERM IN 0.000000E+00 0.0000000E+00 CONSTANT HEAD 7.1051237E-03 2.0705394E-02 -1.3600271E-03 WATER BUDGET OF THE WHOLE MODEL DOMAIN: FLOW TERM 0.000000E+00 0.0000000E+00 0.000000E+00 RECHARGE 5.6796219E-02 0.000000E+00 0.000000E+00 RELLS 0.000000E+00 0.0000000E+00 0.000000E+00 RELLS 0.000000E+00 0.0000000E+00 0.0000000E+00 RECHARGE 5.6796219E-02 0.000000E+00 0.000000E+00 REVER LEAKAGE 0.000000E+00 0.000000E+00 0.000000E+00 REVER LEAKAGE 0.000000E+00 0.0000000E+00 0.000000E+00 REVER LEAKAGE 0.000000E+00 0.0000000E+00 0.000000E+00 REVER LEAKAGE 0.000000E+00 0.000000E+00 0.000000E+00 REVER LEAKAGE 0.000000E+00 0.0000000E+00 0.000000E+00 REVER LEAKAGE 0.000000E+00 0.000000E+00 0.000000E+00 0.000	WATER BUDGET OF Z	ONES OVER THE E	NTIRE MODEL	
IN OUT IN-OUT STDRAGE 0.000000E+00 0.000000E+00 0.000000E+00 CONSTANT HEAD 0.000000E+00 0.000000E+00 0.000000E+00 HORIZ. EXCHANGE 7.8715780E-04 3.2653283E-05 7.5450446E-0 EXCHANGE (UPPER) 0.000000E+00 0.000000E+00 0.000000E+00 EXCHANGE 1.6763251E-02 1.3197104E-03 1.5443541E-0 MELLS 0.000000E+00 0.000000E+00 0.000000E+00 DRAINS 0.000000E+00 0.000000E+00 0.000000E+00 RIVER LEAKAGE 0.000000E+00 0.000000E+00 0.000000E+00 RIVER LEAKAGE 0.000000E+00 0.000000E+00 0.000000E+00 ITTERED STDRAGE 0.000000E+00 0.000000E+00 0.000000E+00 INTERED STDRAGE 0.000000E+00 0.000000E+00 0.000000E+00 STDRAGE 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 INTERED STDRAGE 0.000000E+00 0.000000E+00 0.0000000E+00 <tr< th=""><th>ZONE: 1</th><th></th><th></th><th></th></tr<>	ZONE: 1			
WATER BUDGET OF THE WHOLE MODEL DOMAIN: FLOW TERM IN OUT IN-OU' STORAGE 0.0000000E+00 0.0000000E+00 0.0000000E+00 CONSTANT HEAD 7.1051237E-03 2.0705394E-02 -1.3600271E-00 WELLS 0.0000000E+00 0.0000000E+00 0.0000000E+00 DRAINS 0.0000000E+00 0.0000000E+00 0.0000000E+00 RECHARGE 5.6796219E-02 0.0000000E+00 0.0000000E+00 RIVER LEAKAGE 0.0000000E+00 0.0000000E+00 0.0000000E+00 STREAM LEAKAGE 0.0000000E+00 0.0000000E+00 0.0000000E+00 STREAM LEAKAGE 0.0000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 INTERBED STORAGE 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 INTERBED STORAGE 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00	STDRAGE CONSTANT HEAD HORIZ. EXCHANGE EXCHANGE (LOWER) EXCHANGE (LOWER) WELLS DRAINS RECHARGE ET RIVER LEAKAGE HEAD DEP BOUNDS STREAM LEAKAGE INTERBED STDRAGE MULTI-AQIFR WELL SUM OF ZONE(1) DISCREPANCY [%]	IN 0.000000E+00 0.000000E+00 0.871578E-04 0.000000E+00 0.0000000E+00 0.000000E+00 0.0000000E+00 0.0000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.00000E+00 0.00000E+0000E+00 0.0000000E+00 0.000000E+00 0.0000000E+00 0.000000E+	0UT 0.000000E+00 3.2653283E-05 0.0000000E+00 1.3197104E-03 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 0.0000000E+00 1.9135518E-02	IN-OU 0.000000E+0 7.5450446E-0 0.000000E+0 1.5443541E-0 0.000000E+0 0.0000000E+0 0.0000000E+0 0.0000000E+0 0.0000000E+0 0.0000000E+0 0.0000000E+0 0.0000000E+0 0.0000000E+0 0.0000000E+0
FLOW TERM IN OUT IN-OU' STORAGE 0.000000E+00 0.000000E+00 0.000000E+00 CONSTANT HEAD 7.1051237E-03 2.0705394E-02 -1.3600271E-00 WELLS 0.000000E+00 0.000000E+00 0.000000E+00 DRAINS 0.000000E+00 0.000000E+00 0.000000E+00 RECHARGE 5.6796219E-02 0.000000E+00 0.000000E+00 RIVER LEAKAGE 0.000000E+00 0.000000E+00 0.000000E+00 HEAD DEP BOUNDS 0.000000E+00 0.000000E+00 0.000000E+00 STREAM LEAKAGE 0.000000E+00 0.000000E+00 0.000000E+00 INTERBED STORAGE 0.000000E+00 0.000000E+00 0.000000E+00 MULTI-AQIFR WELL 0.000000E+00 0.000000E+00 0.000000E+00	WATER BUDGET OF T	HE WHOLE MODEL	DOMAIN:	
	FLOW TERM STDRAGE CONSTANT HEAD WELLS DRAINS RECHARGE ET RIVER LEAKAGE HEAD DEP BOUNDS STREAM LEAKAGE INTERBED STDRAGE MULTI-AQIFR WELL	IN 0.00000000000000000000000000000000000	OUT 0.0000000E+00 2.0705394E-02 0.0000000E+00 0.0000000E+00 0.0000000E+00 4.3201953E-02 0.0000000E+00 0.0000000E+00 0.0000000E+00	IN-OU 0.000000E+0 -1.3600271E-0 0.0000000E+0 0.000000E+0 0.000000E+0 0.000000E+0 0.000000E+0 0.0000000E+0

References

Anderson, M. P., Woessner, W. W. (1992): Applied Groundwater Modeling, Simulation of Flow and Advective ransport.- Academic Press Inc., San Diego, California.

Andersen, P. F. (1998): A manual of instructional problems for the U.S.G.S. Modflow model.- Robert S. Kerr environmental research laboratory office of research and development U.S. environmental protection agency, Oklahoma.

Hsing Chiang, W., Kinzelbach, W. (2000): 3D-Groundwater Modeling with PMWIN.- Springer.

www.Wikipedia.com