COURSE: GROUNDWATER MODELLING USING MODFLOW

Session 7: Three-dimensional steady-state simulation with recharge, constant-head, a river and wells.

Objective:

The objective of this session is learning how to define the aquifer type, establish hydraulic parameters, select and unselect objects, define time values, assign boundary conditions, run the model, analyze the global water balance, and import the hydraulic heads.

Setting up model parameters

Open ModelMuse.exe and choose the option Create New MODFLOW Model. In the "Geo Reference and model Description" window change the length units to "meters" and time units to "seconds", after that click on "Next".

🐉 ModelMuse	-		×
Geo Reference and Model Description Model description			
Simulation starting date Projection type Length unit	Time unit		
1/ 1/2000 ▼ © epsg ○ proj4 Meters ▼	Seconds	-	
Simulation starting time Projection			
00:00:00			
	0 11-1-1	Next	
	? <u>H</u> elp	Next-	2

Defining model grid properties

The configuration of the "**Specify initial grid**" options is as follow:

- The number of rows is equal to 11 and the number of columns is equal to 8.
- The **number of layers** is equal to **3**.
- The column width is equal to 150 and row width is 200.
- The model top is set as 0

- The **layer group name** is set as **AqX**, where "X" is the layer number.
- The bottom elevations are -20, -25 and -35 meters.

After making these configurations click on "Finish".



Defining time properties

To define the time properties, go to "Model / MODFLOW Time..."



The time units are left as default, a steady-state simulation of 1 stress-period of 1 day.

🐉 MODFL	OW Time							_		\times
			Length	Max first time step length	Multiplier	Steady State/ Transient				_
Stress period	Starting time	Ending time	Length	Max first time step length	Multiplier	Steady State/ Transient	Drawdown reference	ste	ber of eps ilated)	T
1	-1	0	1	1	1	Steady state		1		
										-
1 Vumber of stress periods seconds (1) Time unit (ITMUNI)										

Discretization model

Then go to **Model / Modflow Layer Group**. Then will appear a dialog box and the layers in the model and change the Layer type:

- Unconfined aquifer Convertible
- Confined Confined Layer
- Confined Confined Layer

🔀 MODFLOW Layer Gr	oups	- 🗆 × 🛛	📆 MODFLOW Layer Gr	oups — 🗆 >	<
AqAlluvia	Basics Discretization Layer Group (Aquifer) Name AqAlluvial Layer type (LAYTYP, LTHUF) Convertible Compute saturated thickness using start (LAYTYP) Method of calculating interblock transmissive Harmonic mean (0) Method of specifying vertical hydraulic conductivity (0)	vity (LAYAVG)	AqAlluvial AqConi AqBedRock	Basics Discretization Layer Group (Aquifer) Name AqConf Layer type (LAYTYP, LTHUF) Confined Compute saturated trickness using starting head (LAYTYP) Method of calculating interblock transmissivity (LAYAVG) Harmonic mean (0) Method of specifying vertical hydraulic conductivity (LAYVKA)	•
	Horizontal anisotropy (TRPY)			1	-
				Horizontal anisotropy (TRPY)	
	? <u>H</u> elp ✓ OK	X Cancel		? Help ✓ OK X Cancel	1
	MODFLOW Layer G AQAIIvrial AQAIIvrial AQAConf AgBedRock	Basics Discretizati Layer Group (Aquife AqBedRock Layer type (LAYTYP, Confined Confined Confined Confined Confined Confined Method of calculating Harmonic mean (0)	r) Name LTHUF) g interblock transmissivity (g vertical hydraulic conducti inductivity (0)	LAYAVG)	
		?	Help VK	× Cancel	

Defining hydraulic conductivities

According to the characteristics of the aquifer, the hydraulic conductivities for each layer have been defined, introducing the following values in m²/seconds.

Layer	Kh(m/d)	Kh(m/s)	Kv (m/s)
AqAlluvial	5	5.78704E-05	1.15741E-05
AqConf	0.1	1.15741E-06	5.78704E-07
AqBedRock	10	0.000115741	1.15741E-05

Then create a rectangle object with **Create rectangle object** as the imagen. In the properties of this object change the following:

🔀 Object Properties		_	\Box \times		
Properties Data Sets MC	DFLOW Features Vertices Comme	ents/Captions			
Evaluated at Cells CC	ell corners	Object information (not ec Object length	litable)		
Name K Aq Alluvial	0 Quadtree refinement 100 Set object line color Set object fill color	Object enight 7121.31519274376 Object area 2911283.10734725 Object order 6			
Color object interior Set values of enclosed of Set values of intersected Set values of cells by intersected	ells Minimum fraction d cells of cell length				
Number of Z formulas	⊙ Two				
Z-coordinate	(Model_Top + AqAlluvial_Bottom) / 2		Edit F()		
Higher Z-coordinate	Model_Top		Edit F()		
Lower Z-coordinate	AqAlluvial_Bottom		Edit F()		
		<u>? Н</u> еlp	X Cancel		

Select **Data Sets** and go **Required/ Hydrology / Kx**, here we can define the hydraulic conductivities mentioned (Kx and Ky). Click on **OK**.

🔀 Object Properties		- 🗆	×	3 Object Properties		- 🗆 ×
Properties Data Sets MODFLOW Fea	tures Vertices Comments/Captio	ins		Properties Data Sets MODFLOW Fea	tures Vertices Comments/Caption	ons
	Formula for "Kx" data set 5.78703703703704E-5	Edit F().		⊕ ⊤ Optional	Formula for "Ky" data set Kx / 5.	Edit F()
	Data set comment	Associated model data		Modflow_Initial_Head	Data set comment	Associated model data PHAST: MEDIA-Ky
Layer elevations can only be specified using objects with Zero Z formulas.		PHAST: MEDIA-Kx MODFLOW LPF, UPW: HK MODFLOW BCF: TRAN,HY MODFLOW 6 NPF: K	*	Layer elevations can only be specified using objects with Zero Z formulas. PHAST-style interpolation		MODFLOW LPF, UPW: HANI MODFLOW HUF and BCF:
PHAST-style interpolation				· · · · · · · · · · · · · · · · · · ·		
Use PHAST-style interpolation	⊂Interpolation direct	CZ CMix				
Distance 1 0 Value 1	0 Mixture formula					
Distance 2 1 Value 2	1	Edit F()			
	?	Help VOK X Can	ncel			

Then generate a new object to define the hydraulic conductivities for AqConf:

🐉 Object Properties	- 🗆 ×	😕 Object Properties	- 🗆 ×
Properties Data Sets MODFLOW Features Vertices Comme	nts/Captions	Properties Data Sets MODFLOW Features Vertices Comments/Captions	
Evaluated at C Cell corners C Position locked Name K.A.q. Conf P Duplicate cells allowed Quadtree refinement C Use to set grid cell size	Object information (not editable) Object length [7058.95691609977 Object area [2871619.84975396	Proptional Promula for "Kx" data set I.15740740740741E-6 Properties Ky Collect Properties	
Grid cell size 100	Object order	Comment	
Color object line Set object line color	_ /	Laver elevations can ol Br Required Kx/2	
Color object interior Set object fill color		using objects with Zero	_
Image: Set values of enclosed cells Minimum fraction of cell ength Image: Set values of cells by interpolation 0		PHAST-style interpola	Associated model data
Number of Z formulas		Data set comment	Associated model data
Z-coordinate (Model_Top + AqAlluvial_Bottom) / 2.	Edit F()	Distance 1 0 Value 1 0 Mixture formula Distance 2 1 Value 2 1 1	Edit F()
Higher Z-coordinate AqAlluvial_Bottom	Edit F()		
	? Help ✔OK ★ Cancel	? Нер	✓ OK X Cancel

Then generate a new object to define the hydraulic conductivities for AqBedRock:

3 Object Properties	– 🗆 ×	Object Properties	– 🗆 ×
Properties Data Sets MODFLOW Features Vertices Comments/Captions		Properties Data Sets MODFLOW Features Vertices Comments/Captions	
Name K_Aq_BedRock V - Duplicate cells allowed 0 Quadtree refinement 0 Use to set grid cell size 2881224	022675737 ea	⊕ □ Optional	Edit F()
Grid cell size 100 Object on □ Color object line Set object line color 0 □ Color object interior Set object fil color ■ □ Set values of enclosed cells Minimum fraction of cell length ■	der	Properties Data Sets MODFLOW Features Vertices Comments/ □ Modflow Im □ C ptional Layer elevations can on □ P Required □ PHAST.style interpolat □ PLAST.style interpolat	CaptionsEdit F()
Set values of cells by interpolation Set values of cells by interpolation Caro Conc Conconc Conc Conconc Conc Conconc Conc Conc	Edit F()	Use PHAST-style in FK2 Modflow_Initial_Head Distance 1 Use PHAST-style in Value 1 Use PHAST-style in Value 2 Use PHAST-style in	Associated model data
? Help	✓ OK X Cancel	? Help	✓ OK X Cancel

Defining initial condition

Let's define the initial condition to do this go to **Edit/Edit data sets...** and choose the **Required/Hydrology** options, here we can define the **Modflow_Initial_Head** mentioned.

🐉 Data Sets	- 🗆 ×
 ⇒ Optional ⇒ Required ⇒ Hydrology → Active → Horizontal_Anisotropy → Kx → Ky → Kz → Modflow_Initial_Head → Modflow_Specified_Head ⇒ Layer Definition → Model_Top → AqAlluvial_Bottom → AqBedRock_Bottom 	Basic Comment Name Modflow_initial_Head Type Orientation Real J 3D J Evaluated At Units Cells J Interpolation Anisotropy Inone J Default formula Edit formula Model_Top + 2.
Add Delete	? Help ✓ Apply I Close

Defining boundary conditions

In this exercise, we add 4 boundary conditions, Recharge (RCH), the Constant head (CHD), well (WEL) and River (RIV). To activate the packages go to **Model/MODFLOW Packages and Programs...**

MODFLOW Packages and Programs		-		×
UZF: Unsaturated-Zone Flow packag SWI2: Seawater Intrusion package	RCH: Recharge package Comments			
Boundary conditions Specified head	Recharge location option Top active ce Recharge assignment method ^c Objects overwrite values of previous of ^c Sum values of all objects Name Value		□ Tim	e va
Solvers Subsidence	0 👤 Number of parameters	×	<u>D</u> elete	
	? <u>H</u> elp ✓ OK	1	X Canc	el

Once you have checked the three boundary conditions click on **Ok.**

First, to define the **CHD** Object, create a polyline with **Create polyline object** as the imagen. In the properties of this object change the following:

3 Object Properties	- 🗆 X
Properties Data Sets MODFLOW Features Vertices Comment	s/Captions
Evaluated at	Object information (not editable)
Name CHD_22m	Object length 1085.03401360544
Duplicate cells allowed O Quadtree refinement Use to set grid cell size	Object area
Grid cell size 100	Object order
Color object line Set object line color -	3
Color object interior Set object fill color	
☐ Set values of enclosed cells ✓ Set values of intersected cells Minimum fraction of cell length	
Set values of cells by interpolation	
Number of Z formulas	
Z-coordinate (Model_Top + AqAlluvial_Bottom) / 2.	Edit F()
Higher Z-coordinate Model_Top	Edit F()
	? Help ✔OK ★ Cancel

Now go to the "**MODFLOW Features**" tab and check the "**CHD**" option, the "Starting and ending times" are set from "-1 to 0" and the Starting and ending head is set equal to ModelTop+2. Click on **OK** to proceed with the next boundary condition.

🐉 Object Properties					_		\times	
Properties Data Sets M	roperties Data Sets MODFLOW Features Vertices Comments/Captions							
CHD: Time-Variant S	Specified-Head p	ackage						
CH: Recharge pacl								
	Formula							
	Starting time	Ending time	Starting head	Ending head				
	-1	0	Model_Top + 2.	Model_Top + 2.				
	1 🛔 I	Number o	ftimes		+⊟ Insert	X Dele	ete	
	Time-se	ries interp	oolation LINEAR-	END 🔽				
Conve	rt time units	;		? <u>H</u> elp	🗸 ОК	🗙 Ca	ncel	

Then create another CHD Object with the following properties:

Object Properties		- 0	×	
Properties Data Sets MO	DFLOW Features Vertices Comments	s/Captions		
Evaluated at © Cells C Ce	Il corners	Object information (not editable)		
Name CHD 18m		Object length 1072.58080730943		
Duplicate cells allowed	0 Quadtree refinement	Object area		
□ Use to set grid cell size		0		
Grid cell size	100	Object order		
Color object line	Set object line color -	_ 4		
Color object interior	Set object fill color	1		
 Set values of enclosed c Set values of intersected 	cells of cell length			
Number of Z formulas				
CZero One				
Z-coordinate	(Model_Top + AqAlluvial_Bottom) / 2.	Edit F())	
Higher Z-coordinate	Model_Top	Edit F())	
Convert	time units	? <u>H</u> elp ✔ OK ★ Cand	cel	

Now go to the "**MODFLOW Features**" tab and check the "**CHD**" option, the "Starting and ending times" are set from "-1 to 0" and the Starting and ending head is set equal to ModelTop-2. Click on **OK** to proceed with the next boundary condition.

🔀 Object Properties					-		\times				
Properties Data Sets MC	Properties Data Sets MODFLOW Features Vertices Comments/Captions										
CHD: Time-Variant CHD: Time-Variant RCH: Recharge pacl RIV: River package WEL: Well package		ackage									
	Formula										
	Starting Ending Starting head Ending head										
	-1	0									
	1 € N Time-ser	lumber o ies interp		-END	• ⊟ <u>I</u> nsert	× <u>D</u> ele	te				
Conver	t time units			? <u>H</u> elp	🗸 ОК	🗙 Ca	ncel				

The "WEL" package is located in a grid cell, use the **Create point object** tool. Draw a point located in the layer 3, row 5 and column 6

The properties of the point are as follows:

- Name it **WEL**
- Give it a **Color line** to differentiate the well.
- Set the **number of Z formulas** to **Two** with the following characteristics:

Higher Z-coordinate = **Upper_Bottom**

Lower Z-coordinate = **Middle_Bottom**

🛃 Object Properties		- 🗆 ×
Properties Data Sets M	DDFLOW Features Vertices Comments/Captions	
Evaluated at ଜ Cells ଜ C	Position locked Object informat Object length	tion (not editable)
Name Well		
 Duplicate cells allowed Use to set grid cell size 	0 Quadtree refinement Object area	
Grid cell size	100 Object order	
Color object line	Set object line color 2	
Color object interior	Set object fill color	
Set values of enclosed Set values of intersecte Set values of cells by in	d cells of cell length	
Number of Z formulas	ି Two	
Z-coordinate	(Model_Top + Upper_Aquifer_Bottom / 2.	Edit F()
Higher Z-coordinate	Upper_Aquifer_Bottom	Edit F().
Lower Z-coordinate	Middle_Aquifer_Bottom	Edit F()
	7 Help	✓ OK X Cance

In the **"MODFLOW Features"** tab, **check** the WEL package and do the following settings:

- Set the Pumping rate to -0.00138 m3/s.
- Be sure to select Direct in the Pumping rate interpretation options.

Click on **OK** to continue with the next boundary condition.

😕 Object Properties	- • ×
Properties Data Sets MODFLC	W Features Vertices Comments/Captions
CHD: Time-Variant Specif	WEL: Well package
WEL: Well package	
	Formula
	Starting Ending time Pumping rate
•	
	-1 0 -0.0138888888888
•	-1 0 -0.0138888888888
	1 ≑ Number of times ·目 Insert × Delete
	Pumping rate interpretation Direct
	Time-series interpolation STEPWISE -
< >	Tabfil
Convert time	units ? Help 🗸 OK X Cancel

The "RIV" package is located in a grid cell, use the **Create point polyline** tool and draw the polyline as the image:

3 Object Properties		– 🗆 🗙	•	
Properties Data Sets MODFLOW Features V	ertices Comments/Captions			
Cells Cell corners	Position locked Object information (no	ot editable)		
Name River	Object length 2107.71897514384	ī		
Duplicate cells allowed O Quadtree	e refinement Object area			
Use to set grid cell size	0	-		
Grid cell size 100	Object order			
Color object line Set object	line color 5			
Color object interior Set object	fill color			
Set values of enclosed cells Of the set values of intersected cells Of cells Of cells Of cells	im fraction ength			
Number of Z formulas C Zero C One C Two				
Z-coordinate (Model_Top + AqAlle	.vial_Bottom) / 2.	Edit F()		
Higher Z-coordinate Model_Top		Edit F()		
Lower Z-coordinate AqAlluvial_Bottom		Edit F()		
	? <u>H</u> elp ✓ 0	K X Cancel		

In the "MODFLOW Features" tab, check the RIV package. the "Starting and ending times" are set from "-1 to 0" and the characters of the river are:

River stage: Interpolate(FractionOfObjectLength, (Model_Top + 2.), 0.0125, (Model_Top - 2.), 1.)

River bottom: Interpolate(FractionOfObjectLength, Model_Top, 0.0125, (Model_Top - 4.), 1.)

🔀 Object Properties					-		\times
Properties Data Sets MODFL	OW Featu	res Verti	ces Comments/	Captions			
CHD: Time-Variant Specif			RIV: R	iver package			
			Formula				
	Starting time	Ending time	River stage	Conductance	River bo	ottom	T
	•						
	-1	0	Interpolate(Frac	0.0015	Interpolate(F	ractionOf	C
	1 🌲	Number o	ftimes		• ⊟ Insert	X <u>D</u> ele	te
	Conduct	ance inter	pretation Dire	ct 🗸]		
	Time-sei	ries interp	olation STE	PWISE]		
Convert time	e units			<u>? H</u> elp	🗸 ОК	🗙 Can	cel

Click on **OK**.

Running the model

First, save the model **File/Save As**, save the simulation with the name **Model1.gpt.** Now we can run our model by clicking in the green arrow located in the upper left corner called "**Run**"



Save the model files in the same folder as the ".gpt", this folder appears as default, and click on **Save.** The model starts to run and when it finishes it shows a yellow square in the center of the window with green faces, which means the model has run successfully.



At the end of the water budget file, you can see the water balance and the importance of choosing the **"interpretation"** as **"Direct"** to have the exact value for the pumping and conductance in the boundary conditions.

		END OF TIME STEP 1,	
CUMULATIVE VOLUMES	L**3	RATES FOR THIS TIME ST	'EP L**3/T
IN:		IN:	
		STORAGE	
CONSTANT HEAD =			
	0.0000		= 0.0000
RIVER LEAKAGE =	1.0098E-03		
RECHARGE =	1.3699E-02	RECHARGE	= 1.3699E-02
TOTAL IN =	2.6531E-02	TOTAL IN	= 2.6531E-02
OUT:		OUT:	
		STORAGE	
		CONSTANT HEAD	
WELLS =	1.3889E-02	WELLS	
RIVER LEAKAGE =		RIVER LEAKAGE	= 3.3228E-03
RECHARGE =	0.0000	RECHARGE	= 0.0000
TOTAL OUT =	2.6531E-02	TOTAL OUT	= 2.6531E-02
IN - OUT =	-1.8626E-09	IN - OUT	= -1.8626E-09
PERCENT DISCREPANCY =	-0.00	PERCENT DISCREPANCY	-0.00

Close the water budget files and then we can continue to visualize the outputs.

Importing results

We can import the simulated heads going to "Import and display model results"

<u>F</u> ile	<u>E</u> dit	<u>G</u>	rid	<u>D</u> ata	<u>O</u> bject	<u>N</u> aviga	tion	View	<u>C</u> us	tomize
	8	Ŗ		• 🔽	Î.	5	Ж	Þa 🛍	шш	
×	÷∥≯		—	Ħ.	-+ _s ∖≓ Import ar	nd display	i y mo	odel resu	v r Its (Ct	rl+M)

Select the **Model1.fhd** file and click in **Open**

A new window appears indicating the period to be imported and the "**Display choices**", import only period we have as "**contour grid**"

📕 Select Mode	Results to Import			_		\times
Head: Peri	od: 1; Step: 1;	Total Time: 1				
Model Result	ts	 Classification 		Prefix		
Display cho				N1 10		
 Color grid 		Contour grid	C	Neither		
	color or conto					
Head: Perio	d: 1; Step: 1; T	otal Time: 1				•
Select all data sets	Deselect all data sets		? <u>H</u> elp	✓ ОК	🗙 Ca	ncel

And you get the distribution of the model, in which you can see the distribution of the water table.

