Evolution of a freshwater lens in a coastal area

Variable-density groundwater flow modelling with SEAWAT



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Introduction

Analysis of a homogeneous aquifer with the following geometry: horizontal *L*=10 km by vertical *D*=150 m. The profile is two-dimensional. Discretisation: 100*15 rectangular cells, so Δx =100 m and Δz =10 m. Hydrostatic pressure at the left and right boundary: viz. freshwater head only increases with depth due to density differences. In the central part of the aquifer, over a length of 40 cells (4 km) a natural groundwater recharge is taking place at t=0 year, with a rate of 360 mm/year. Initially the salt concentration is equal to 19000 mg Cl⁻/l. In the beginning, no hydrodynamic dispersion is taken into account: $D_{mor}=0$ m²/s, $\alpha_L=\alpha_{TH}=\alpha_{TV}=0$ m, as well as $R_d=1$ (no retardation). Other soil parameters are: hydraulic conductivity k=20 m/d; porosity n_e =0.35 and anisotropy=k_{vert}/k_{hor}=0.1. From a solute solver point of view: we use the Finite Difference solver with a Courant number of 0.75. Convergence criterion is 10⁻⁸ m and numerical time step Δt =1.0 year.

Parameters			
Layers	15	K _{hor}	20 m/d
Rows	1	T (=K _{hor} *thickness cell)	200 m²/d
Columns	100	Anisotropy K _{hor} /K _{ver}	10
Δx	100 m	ne	0.35
Δу	1 m	αL	0 m
Δz	10 m	αΤ	0 m
Stress periods	3	recharge	360 mm/y
Initial concentration	19000 mg Cl ⁻ /l	Recharge concentration	0 mg Cl ⁻ /l
bouyancy	0.025		

Exercise 000: making of the model

- 1. Go to: File, New Model Name the new model: e.g. 'fwlens000'
- 2. Go to: Grid, Mesh Size

_ayer (K Dimension) —	15			_	
Number of Layers:					
vlodel Thickness:	150	Model Top Ele∨ation	0		
Row (I Dimension)				_	
Number of Rows:	1				
Vodel Extent:	1				
Column (J Dimension) —					
Number of Columns:	100				
Model Extent:	10000]			
Cross-Sectional Display	/				
√ertical Exaggeration:	30]			
	Load	Help Ca	incel	эк 🛛	

- 3. Go to: Grid, Layer Property
 - Make all 15 model layers '0: Confined'

🚾 Laye	er Property						
Flow Pac	kage: Block Centered Flow (B	CF)					
Layer	Туре	Horizontal Anisotropy	Vertical Anisotropy	Transmissivity	Leakance	Storage Coefficient	Interbe 🔨 Storage
1	0: Confined	1	VK	Calculated	Calculated	Calculated	

Make sure that Transmissivity and Leakance are 'Calculated' for all model layers

4. Place a fixed head in the model at the sea Go to: Grid, Cell Status, IBOUND (MODFLOW)

Make IBOUNDs in modellayer=1, Row=1, Columns=1-30 and 71-100: -1 (now this cell has a fixed head)

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-													_		 			 	_	 	-		_	_	 _	 			*

Leave Editor, save (so now the value is saved).

 Go to: Parameter, Time Make 15 stress periods Make the Simulation Time Unit: days SP1: period length 1E-09 sec, No. of Time Steps 1 SP9-10 period length 9131.25 (this is 25 years), No. of Time Steps 25

👌 Time	Paramete	rs				— 🗆	×			
Period	Active	Period Length	No. of Time Steps	Multiplier (Flow)	Transport Stepsize	Max. No. of Transport Steps	 (T⊡			
1	V	1E-09	1	1	0	50000				
2		9131,25	25	1	0	50000				
3	•	9131,25	25	1	0	50000				
4	•	9131,25	25	1	0	50000				
5	•	9131,25	25	1	0	50000				
6	V	9131,25	25	1	0	50000				
7		9131,25	25	1	0	50000				
8	V	9131,25	25	1	0	50000				
9	V	9131,25	25	1	0	50000				
10	\checkmark	9131,25	25	1	0	50000				
11		9131,25	25	1	0	50000				
•		1 157407E-05	1	1	Π	50000	•			
Simulat	ion Time	Unit		Simula	ation Type —— eadv-State Flov	w Simulation				
Auto	Update F	^D eriod Length			ansient Flow Si	mulation				
Total Per Total Tim Total Sim	Total Period Number = 11 Total Time Steps = 251 Total Simulation Time = 9,13125E+4 days									
	Load Save As OK Cancel Help									

Ok

6. Go to: Parameter, Initial & Prescribed Hydraulic Heads [L]

activate this parameter by adding 0m to the cells in the first row where the head is fixed (IBOUND=-1). Note the values are already 0m; it you do not save and activate this package, it will not be active

Leave Editor, save (so now the value is saved).

7. Go to: Parameter, Horizontal Hydraulic Conductivity Go to: Value, Reset Matrix

Set to 25 (in 2D, 'Apply to the entire model' or 'Apply to the current cross section is the same')

😪 Reset Matrix	×								
Horizontal Hydr. Conductivity [L/T]:									
Parameter Number [-]: 0									
Select "Apply to the entire model" to se Select "Apply to the current layer" to se	t the values to all cells of the model. t the values to all cells of the current layer.								
C Apply to the entire model Apply to the current cross section	OK Cancel Help								

Leave Editor, save

8. Go to: Parameter, Vertical Hydraulic Conductivity Go to: Value, Reset Matrix

Set to 2.5 (anisotropy	y k_h/k_v is a factor 10) ×
Vertical Hydr. Cond	uctivity [L/T]: 2.5
Paramete	er Number [-]: 0
Select "Apply to the entire model" to se Select "Apply to the current layer" to se	t the values to all cells of the model. t the values to all cells of the current layer.
C Apply to the entire model Apply to the current cross section	OK Cancel Help

Leave Editor, save

9. Go to: Parameter, Effective Porosity Go to: Value, Reset Matrix Set to 0.35

Na Reset Matrix	×
Effective Porosity [-]: 0.35	
Select "Apply to the entire model" to set the value to all cells of the model. Select "Apply to the current layer" to set the value to all cells of the current layer.	
C Apply to the entire model Apply to the current cross section OK Cancel Hel	p

- Leave Editor, save
- 10. Go to Model, MODFLOW (Flow Simulation), Flow Packages, Recharge

Go to Colum 31:	
Right mouse, set to 0.001m/d (is 1 mm/day)	
🚟 Recharge Package	×
Recharge Flux [L/T]: 001	
Layer Indicator (IRCH): 0	
Parameter Number [-]: 0	
Recharge Options (applied to entire model)	_
Recharge is only applied to the top grid layer	
C Vertical distribution of recharge is specified in IRCH	
○ Recharge is applied to the highest active cell.	
Current Position (Layer, Row, Column) = (1,1, 31) The recharge option is applied to the entire matrix. IRCH is only required, i the second recharge option is selected.	if
OK Cancel Help	

		0000
Copy this value of 0	.001 to the cells 32-70) of model layer 1 with
	Layer: • Rov	w: • • Column: • •
check value here:	-1517.205, 388.9737, -5	0

11. Go to Model, MODFLOW (Flow Simulation), Solvers, PCG2 Just use the default values

🗺 Preconditioned Conjugate	Gradient Pac	:kage 2	×								
Preconditioning Method Modified Incomplete Chole Neuman Series Polynomia	esky al										
Calculate the upper bound on the maximum eigenvalue Relaxation Parameter:											
Allowed Iteration Numbers:		Convergence Criteria Head Change [L]: .001 Residual [L^3/T]: .001									
Printout From the Solver All available information The number of iterations on None Printout Interval:	Damping Damping Parameter:										
,,	ОК	Cancel	Help								

12. Go to Model, MT3DMS/SEAWAT, Simulation setting

Simulation Settings (MT3DMS/SEAWAT)										
Simulation Mode: Variable Density Flow and Transport with SEAWAT										
Type of Reaction: No kinectic reaction is simulated										
Species Staichiometry (MT3D99) SEAWAT										
Number A	ctive	Description	Density On	DRHODC	CRHOREF	^				
▶ 1	🔽 new Species 🔽 🔽 25 0									

Set Simulation Mode: Variable Density Flow and Transport with SEAWAT Set Species, Number 1, Active, 'Chloride concentration mg Cl-/L', Density 'On' Set DRHODC=0.001316 (this is the DRHODC term, Equation of State: $\partial p/\partial C$) as of seawater with a Chloride concentration of 19000 mg Cl-/L: DRHODC=25/19000=, as 1025=1000+0.001316*19000

- 13. Go to Model, MT3DMS/SEAWAT, Initial Concentration Go to Value, Reset Matrix: Initial concentration=19000 Leave Editor, save, close
- 14. Go to Model, MT3DMS/SEAWAT, Advection Set Finite Difference (FD)

Hold Advection Package (MT3DM	IS)		×
Solution Scheme:	Finite Differenc	e Method	•
Weighting Scheme:	Upstream weig	Inting	•
Particle Tracking Algorithm:	Hybrid 1st orde	er Euler and 4th ord	er Runge-Kutta 💌
Simulation Parameters			
Courant number (PERCEL)		0,75	
	OK	Canaal	Hole
	011	Cancer	neip

- 15. Go to Model, MT3DMS/SEAWAT, Dispersion, Edit, Ok Go to Value, Reset Matrix Longitudinal Dispersivity=0 (m), Ok Leave Editor, save
- 16. Go to Model, MT3DMS/SEAWAT, Sink/Source Concentration Go to: Constant Head Cells, Edit Go to: Value, Reset Matrix
 - Set to 19000 (seawater at the constant head cells)
- 17. Go to Model, MT3DMS/SEAWAT, Sink/Source Concentration Go to: Recharge, Edit Go to: Value, Reset Matrix

 - Set to 0 (fresh water at the recharge cells)
- 18. Go to: Model, MT3DMS/SEAWAT, Output Control, Output Times Set Output frequency=11

Output Control (MT3D/MT3DMS)			×
Output Terms Output Times Misc.			
Output Frequency: 0	Numb	er Out	put Time
Method 1: > Type in Output Frequency then Press TAB > Specify the Output Time(s)			
Method 2: > Click on the column header Output Time > Specify Min, Max output times and interval			
	OK	Cancel	Help



🚫 Output Time		×
	Minimum= 🛛	0
	Maximum=	82181.25
	Interval=	8218.125
	ОК	Cancel

CHANGE Number=1, Output Time 0 to 0.001!

Output Frequency 11	Number	Output Time.
Culput requency.	1	0,001
	2	8218,125
	3	16436,25
Method 1:	4	24654,38
-> Type in Output Frequency then Press TAB	5	32872,5
-> Specify the Output Time(s)	6	41090,63
· opeony the output rane(o)	7	49308,75
Method 2	8	57526,88
-> Click on the column header Output Time	9	65745
Click of the column fielder output rime	10	73963,13
-> Specily Min, Max output times and interval	11	82181,25

Ok

19. Run the model Go to: Model, MT3DMS/SEAWAT, Run

onerete	Description	Destination File
enerate	Description	Destination File
<u> </u>	Basic Package	C:\goe\ine\zuzu\practicais_zuzu\tresnwater_iens\uuu\pasi a.t.a.a.tit.a.t.0000laaaatiaa.t
<u>N</u>	Block-Centered Flow (BCF6)	C:\goe\ine\zuzu\practicals_zuzu\treshwater_iens\uuu\pct6
	Output Control	C:\goe\ine\2020\practicals_2020\freshwater_iens\000\cd c\approx bit = \2020\freshwater_iens\000\cd c\approx bit = \2020\freshwater_iens\000
	Recharge	C:\goe\ine\zuzu\practicals_zuzu\tresnwater_iens\uuu\rchb
<u>N</u>	Solver-PCG2	C:\goe\ine\zuzu\practicais_zuzu\tresnwater_iens\uuu\pcg.
	Basic I ransport Package	c:\goe\ine\2020\practicals_2020\treshwater_lens\000\mtm
	Advection Package	c:\goe\ine\zuzu\practicals_zuzu\treshwater_iens\uuu\mtm
<u> </u>	Dispersion Package	c:\goe\ine\zuzu\practicals_zuzu\tresnwater_iens\uuu\mtm
<u> </u>	Generalized Conjugate Gradient Solve	C:\goe\ine\zuzu\practicals_zuzu\tresnwater_iens\uuu\mtm
	Sink and Source Mixing Package	c:\goe\ine\2020\practicals_2020\treshwater_lens\000\mtm
	Variable Density Flow Package	c:/goe/ine/zuzu/practicals_zuzu/treshwater_tens/uuu/swzt
otions — Regene	rate all input files	
		OK Cancel Help
		OK Cancel Help
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WINDOWS\; r Iter.	ystem32)cmd.exe 1 Inner Iter, 2: Max, DC = 0.3241E	OK Cancel Help
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20. Go to: Tools, 2D-Visualization, MT3dMS/SEAWAT, Solute Concentration

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22. Period 10, Step 25: Time=82181.25



Exercise 001: geometry of the problem and observation points: fwlens001

Check PMWIN input files: heads, time-characteristics, IBOUND, MODFLOW; SEAWAT parameters.

- Run SEAWAT.
- Check the concentration results.
- Place some observation wells at interesting points, to see the change in concentration can be seen as a function of time.
- Create an EXCEL-figure with the output of the observation wells. How fast has the lens 95% of its final volume?

Exercise 002: analytical versus numerical solution for steady-state situation: fwlens002 The steady-state analytical solution of the position of the fresh-saline interface is known:

$$H = \sqrt{\frac{f(0.25B^2 - x^2)}{k(1 + \alpha)\alpha}}$$

See the lecture notes. Analyse whether or not the analytical and numerical solutions for the steady-state situation are in comparison with each other.

Exercise 003: effect of dispersion: fwlens003

- Simulate dispersion by changing the dispersion from 0.0m to α_L=1.0 m ('<u>M</u>odels'->'MT3DMS / SEAWAT'->'Dispersion'); use default α_{TH}=α_{TV}=0.1 m.
- Run SEAWAT.
- Analyse the effect due to the differences; compare visually with the reference case.

Exercise 004: determine the maximum extraction rate without serious upconing of saline groundwater: fwlens004

- Place in PMWIN/Models/MODFLOW/Flow Packages/Well extraction wells with reasonable rates. Place three observation points in the extraction wells. Note that the concentration under the dunes at t=0 years is initially still 19000 mg Cl⁻/l.
- Run SEAWAT.
- How much groundwater (approximately, in m3/day/m') can be extracted without serious upconing of saline and brackish groundwater (serious means a TDS-concentration>300 mg/l. Make only a coarse and quick calculation. Try to supply 100.000 people with drinking water on an island with a length L of 10 km?
- What to do to reduce the upconing (no calculations, just give suggestions)?