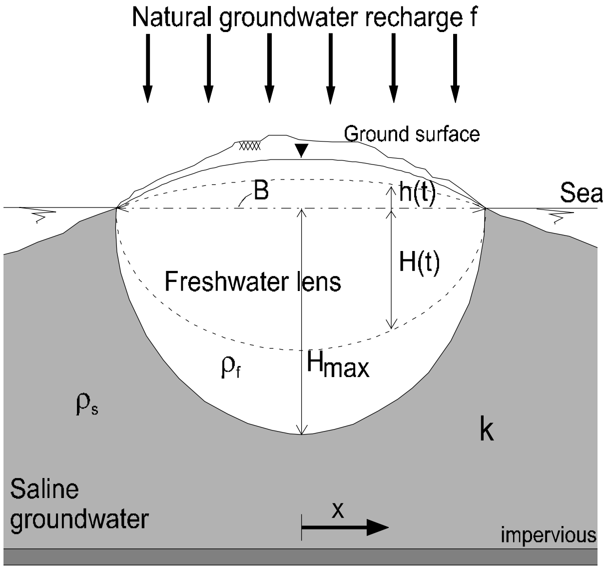
Evolution of a freshwater lens in a coastal area

Variable-density groundwater flow modelling with SEAWAT



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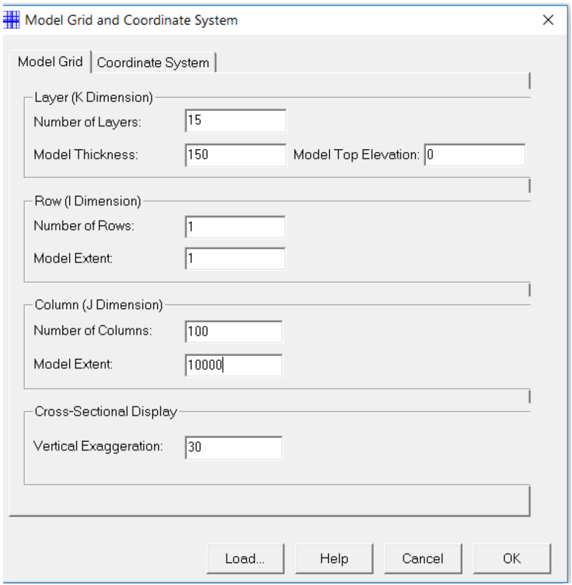
Introduction

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_{mol}=0 m^2/s, α_L=α_{TH}=α_{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.

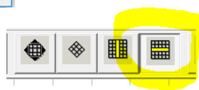
Parameters			
Layers	15	K_{hor}	20 m/d
Rows	1	T (=K_{hor}*thickness cell)	200 m^2/d
Columns	100	Anisotropy K_{hor}/K_{ver}	10
Δx	100 m	ne	0.35
Δy	1 m	αL	0 m
Δz	10 m	αT	0 m
Stress periods	3	recharge	360 mm/y
Initial concentration	19000 mg Cl^-/l	Recharge concentration	0 mg Cl^-/l
bouyancy	0.025		

Exercise 000: making of the model

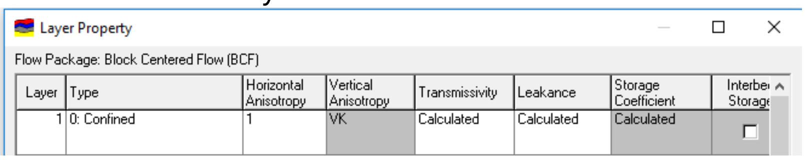
1. Go to: File, New Model
   Name the new model: e.g. ‘fwlens000’
2. Go to: Grid, Mesh Size



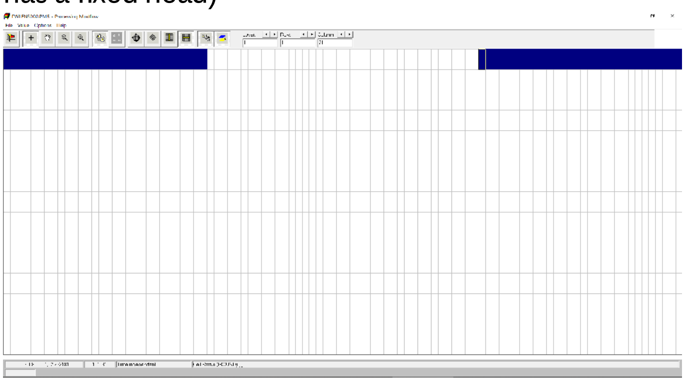
   use this view (as we are now in 2D vertical):



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

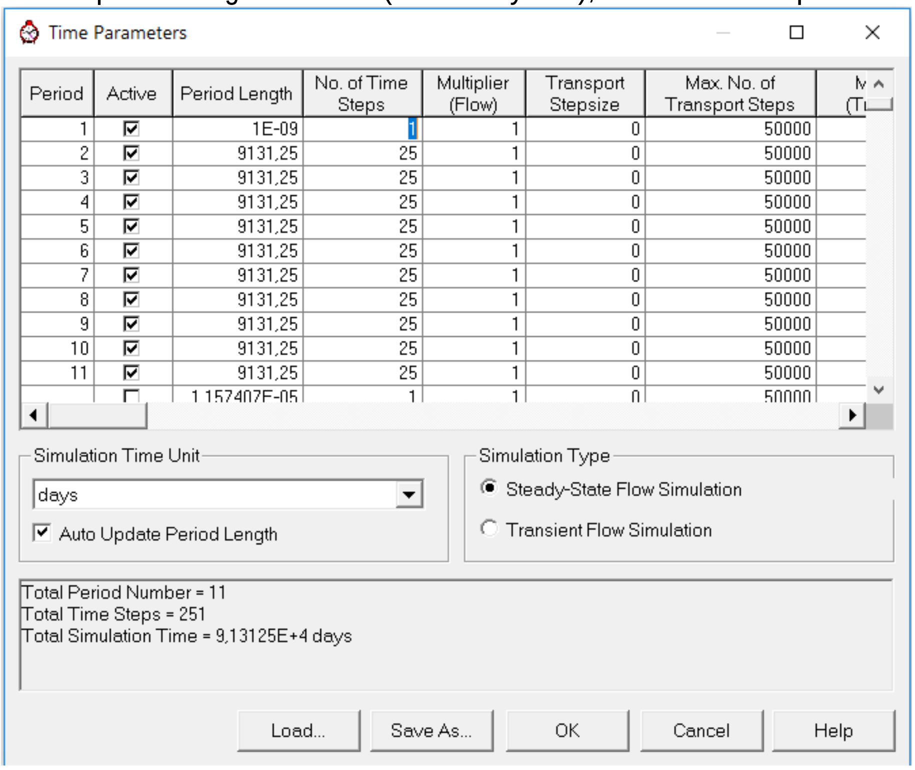


   Make sure that Transmissivity and Leakance are ‘Calculated’ for all model layers
4. Place a fixed head in the model at the sea
   Go to: Grid, Cell Status, IBOUND (MODFLOW)
   Make IBOUNDs in modellayer=1, Row=1, Columns=1-30 and 71-100: -1 (now this cell has a fixed head)



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

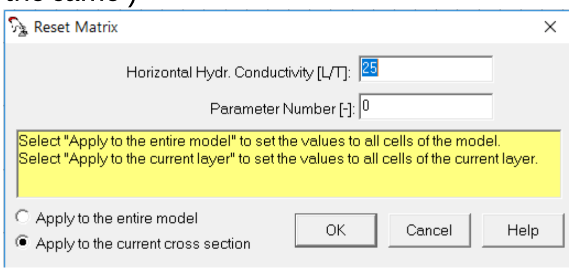
5. Go to: Parameter, Time
   Make 15 stress periods
   Make the Simulation Time Unit: days
   SP1: period length 1E-09 sec, No. of Time Steps 1
   SP9-10 period length 9131.25 (this is 25 years), No. of Time Steps 25



   Ok

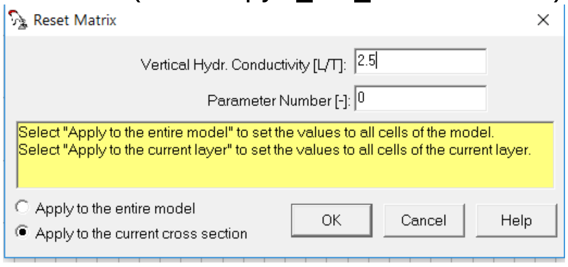
6. Go to: Parameter, Initial & Prescribed Hydraulic Heads [L]
   activate this parameter by adding 0m to the cells in the first row where the head is fixed (IBOUND=-1). Note the values are already 0m; it you do not save and activate this package, it will not be active
   Leave Editor, save (so now the 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')

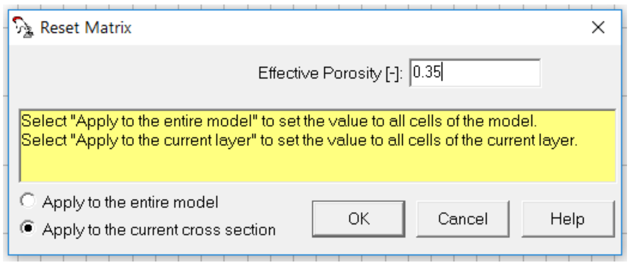


   Leave Editor, save

8. Go to: Parameter, Vertical Hydraulic Conductivity
   Go to: Value, Reset Matrix
   Set to 2.5 (anisotropy k_h/k_v is a factor 10)

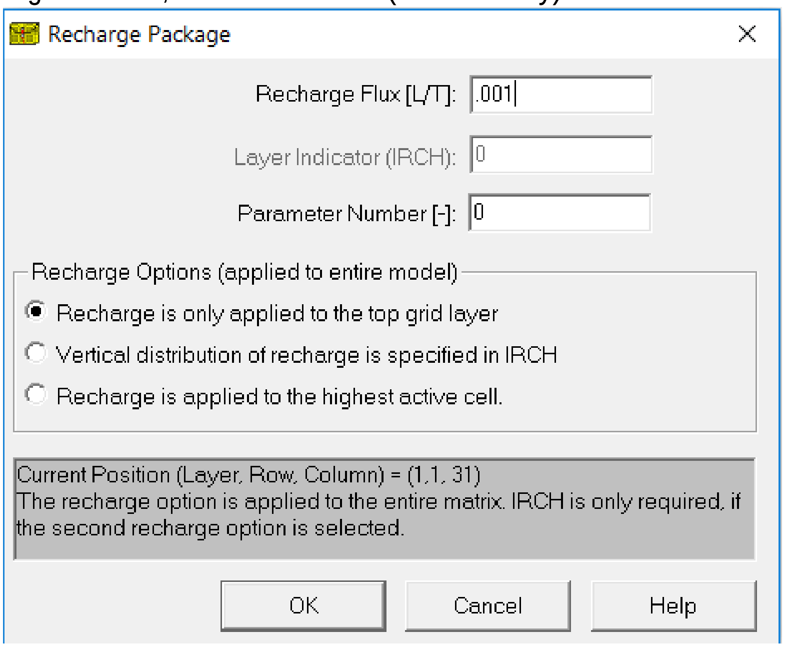


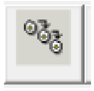
   Leave Editor, save
9. Go to: Parameter, Effective Porosity
   Go to: Value, Reset Matrix
   Set to 0.35



   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)



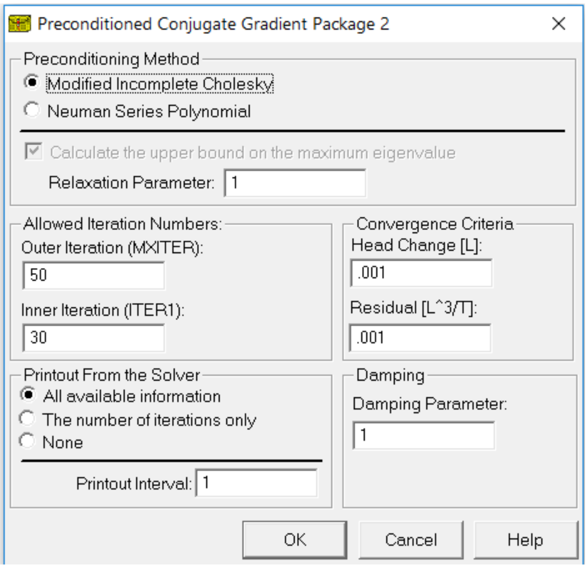
Copy this value of 0.001 to the cells 32-70 of model layer 1 with 

check value here: 

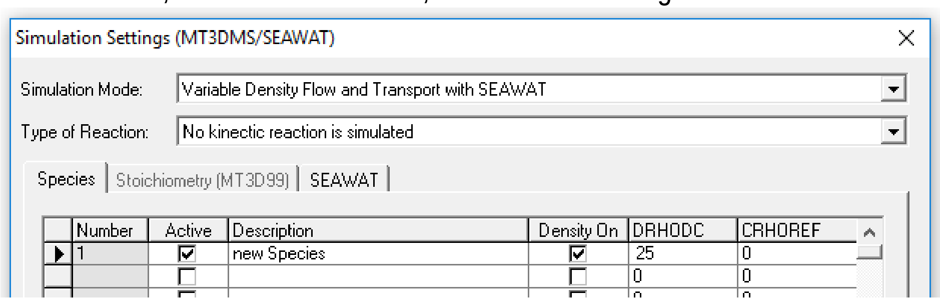
Ok

11. Go to Model, MODFLOW (Flow Simulation), Solvers, PCG2

Just use the default values



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



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: $\partial \rho / \partial C$)

as of seawater with a Chloride concentration of 19000 mg Cl-/L:

DRHODC=25/19000= , as 1025=1000+0.001316*19000

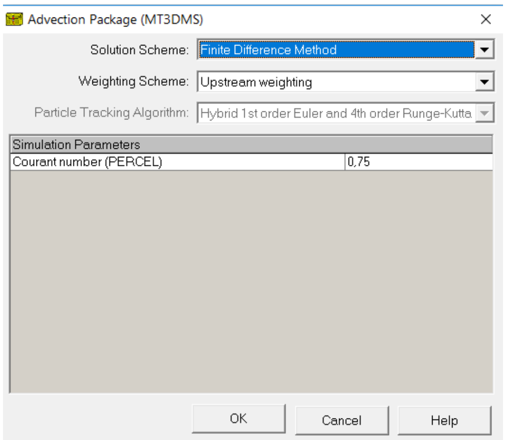
13. Go to Model, MT3DMS/SEAWAT, Initial Concentration

Go to Value, Reset Matrix: Initial concentration=19000

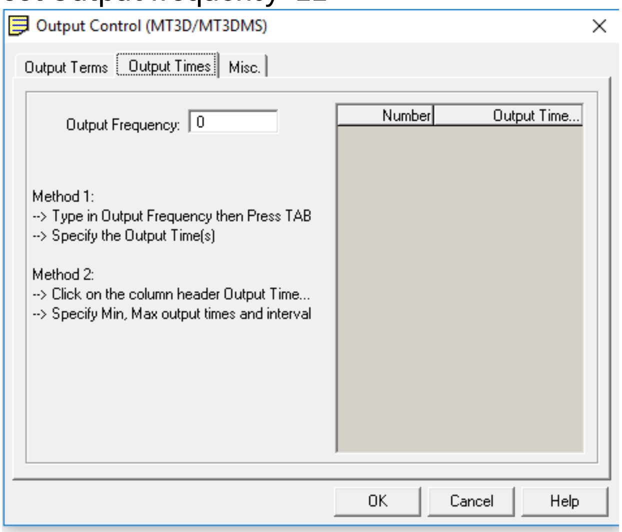
Leave Editor, save, close

14. Go to Model, MT3DMS/SEAWAT, Advection

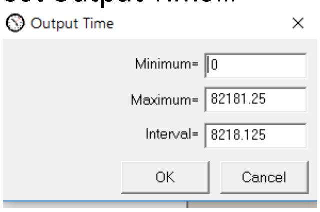
Set Finite Difference (FD)



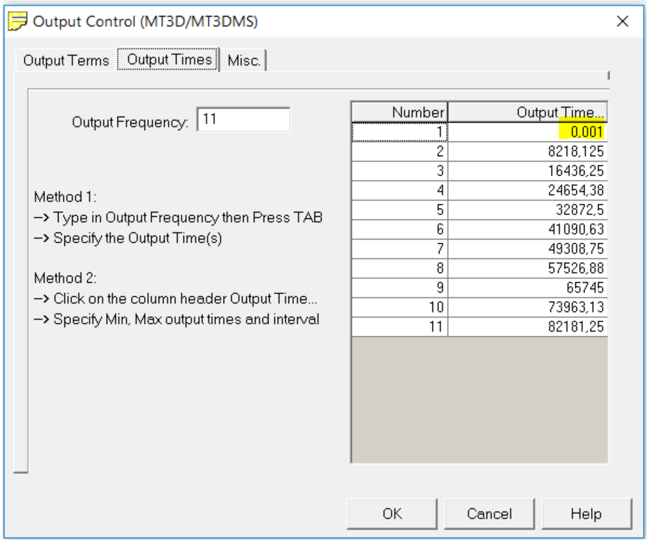
15. Go to Model, MT3DMS/SEAWAT, Dispersion, Edit, Ok
    Go to Value, Reset Matrix Longitudinal Dispersivity=0 (m), Ok
    Leave Editor, save
16. Go to Model, MT3DMS/SEAWAT, Sink/Source Concentration
    Go to: Constant Head Cells, Edit
    Go to: Value, Reset Matrix
    Set to 19000 (seawater at the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



Set Output Time...



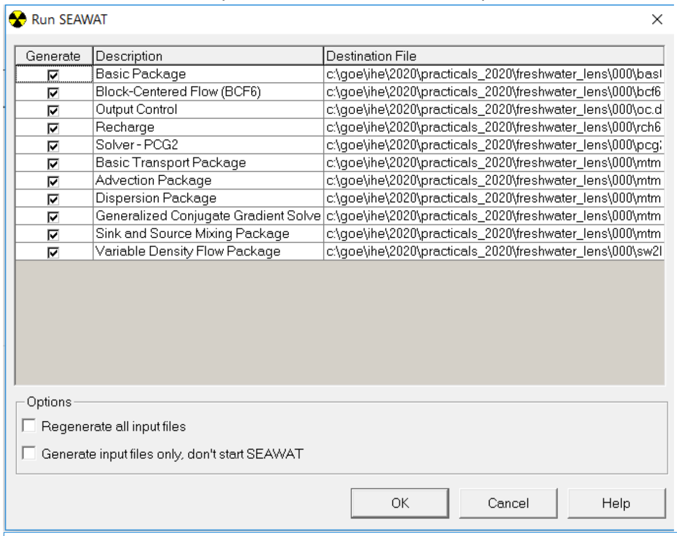
CHANGE Number=1, Output Time 0 to 0.001!

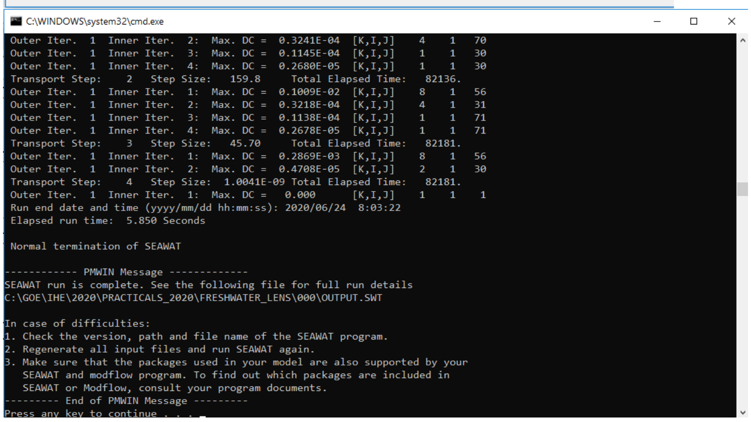


Ok

19. Run the model

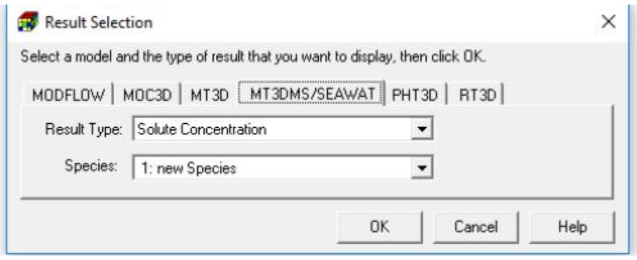
Go to: Model, MT3DMS/SEAWAT, Run



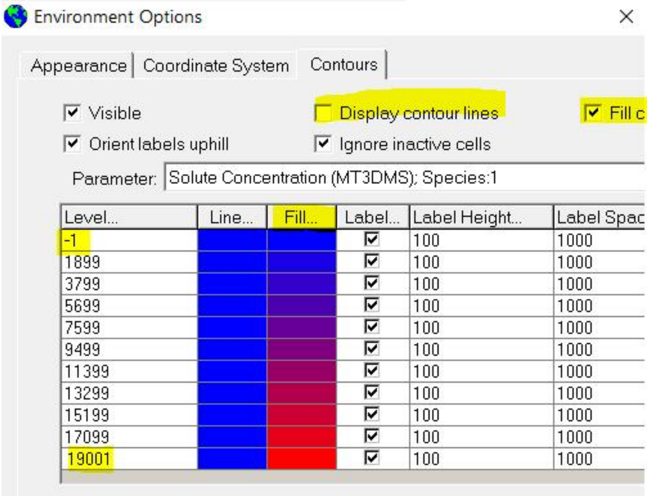


Output:

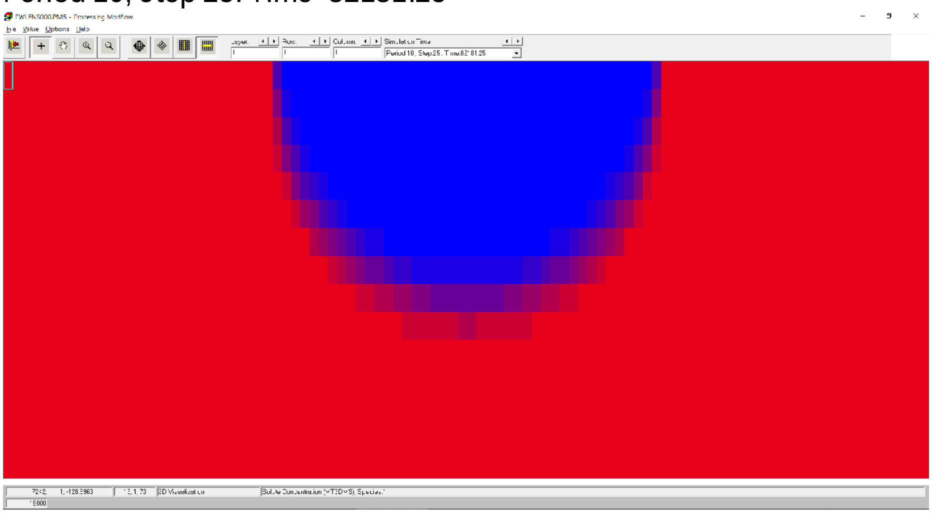
20. Go to: Tools, 2D-Visualization, MT3dMS/SEAWAT, Solute Concentration



21. Go to: Options, Environment
    Set Visible, Fill Contours
    Make for instance red and blue



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 ('Models'->'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)?