

Henry Problem with Model Muse and MF6/Buoyancy package.

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FLOPY VERSIONs:

1. USGS:

https://modflow6-examples.readthedocs.io/en/latest/_notebooks/ex-gwt-henry.html#Define-parameters

2. This one is edited from USGs version, but shows the density slope/calculation:

<https://deltares.github.io/imod-python/examples/mf6/Henry.html>

New Project ☐

save, oftenly...

Draw a polygon to generate the grid: (make sure to check the “Use to set Grid cell size” box and give a value of 0.025.

Object Properties

Properties | Vertices | Time Series | Comments/Captions

Evaluated at: ☒ Cells ☐ Cell corners ☐ Position locked

Name: Grid

☒ Duplicate cells allowed Quadtree refinement

☒ Use to set grid cell size

Grid cell size:

☒ Color object line

☐ Color object interior

☐ Set values of enclosed cells

☐ Set values of intersected cells

☐ Set values of cells by interpolation

Minimum fraction of cell length:

Number of Z formulas: ☐ Zero ☐ One ☒ Two

Z-coordinate:

Higher Z-coordinate:

Lower Z-coordinate:

Object information (not editable):

Object length:

Object area:

Object order:

Object Properties

Properties | Vertices | Time Series | Comments/Captions

	Section Number	X	Y	New section
1	1	0	0	☒
2	1	2	0	☐
3	1	2	1	☐
4	1	0	1	☐
5	1	0	0	☐

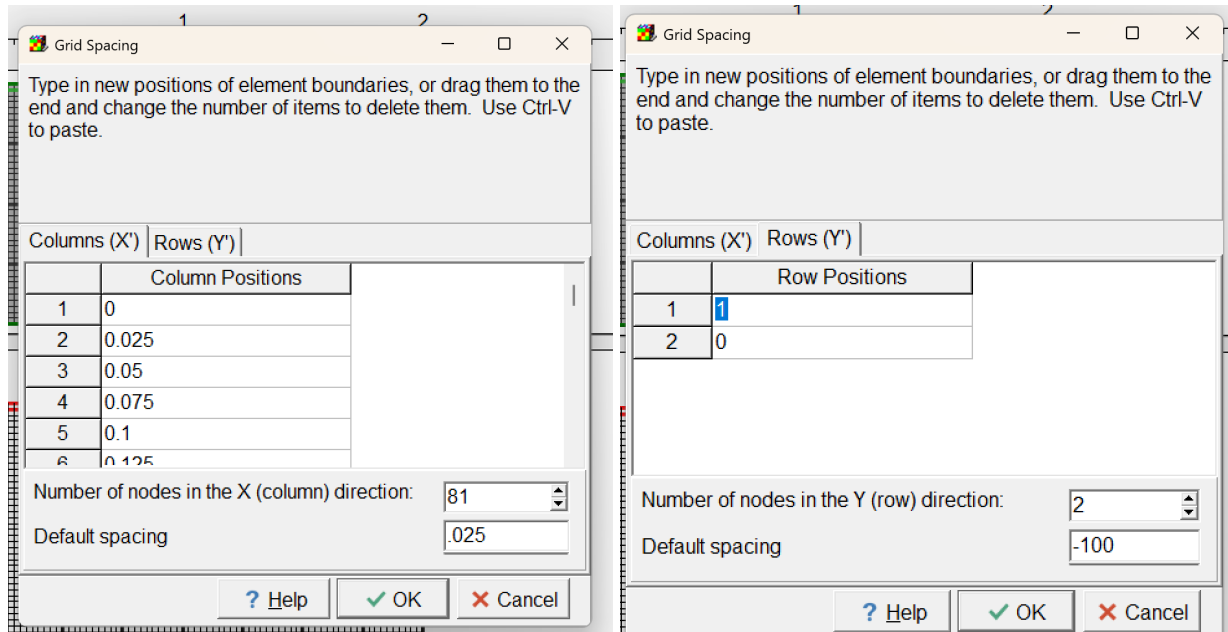
X	Y
0	0
2	0
2	1
0	1
0	0



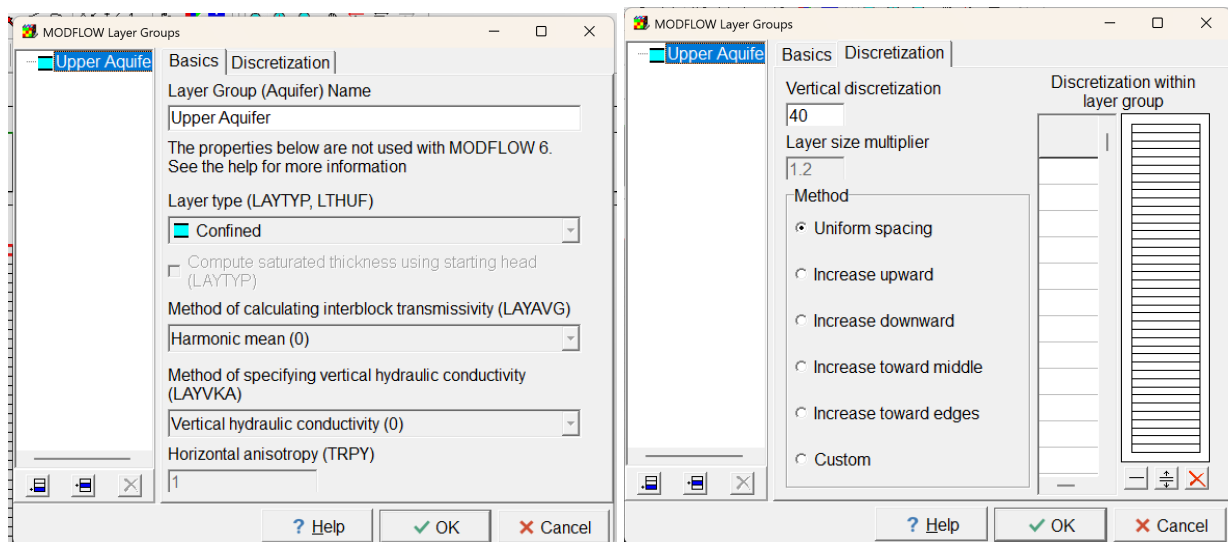
Generate the grid:

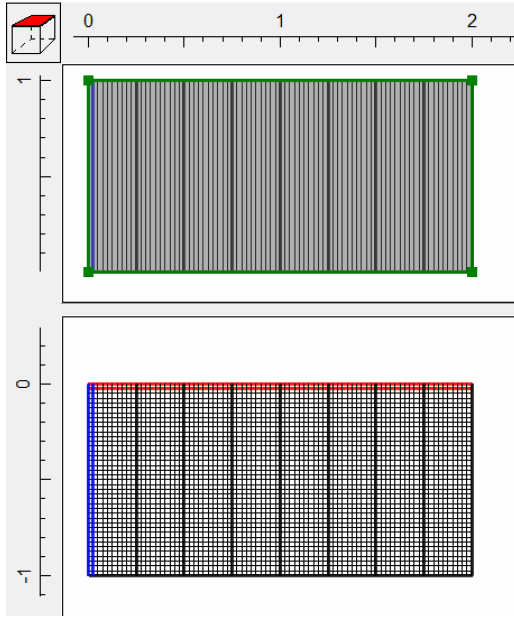
Adjust grid spacing to make only one row (two nodes), but 80 columns (81 nodes = $n+1$).

Also make sure you have only one row (Y) (2 nodes = $n+1$).



Model □ Model Layers: adjust to make 40 layers, equally spaced. You could alternatively set 40 layers, and manually set them as equally spaced, but because they're all same (no parameters vary between), easier to discretize a single "layer group" 40 times.





Looks like this:

Make sure the top pane only has 1 row (not 40!)

MODFLOW Time								
MODFLOW Adaptive Time Stepping								
			Length	Max first time step length	Multiplier	Steady State/ Transient		
			0	0	0			
Stress period	Starting time	Ending time	Length	Max first time step length	Multiplier	Steady State/ Transient	Drawdown reference	Number of steps (calculated)
1	0	0.5	0.5	0.001	1	Transient		500

Object Properties

Properties | Data Sets | MODFLOW Features | Vertices | Time Series | Comments/Captions

WEL: Well package

Formula				
Starting time	Ending time	Pumping rate	Well Multiplier	Chem
PEST Modifier		none	none	none
Modification Method		Multiply	Multiply	Multiply
0	0.5	0.071275	1	0

1 Number of times Insert Delete

Pumping rate interpretation Direct

Tabfile

Convert time units Help OK Cancel

1 Number of stress periods days (4) Time unit (ITMUNI)

meters (2) Length unit (LENUNI)

days (4) Time unit (ITMUNI)

Model: Modflow Options:

Model Packages and Programs

Turn on appropriate packages and adjust settings.

Flow Packages

- ☒ NPF: Node Point
- ☒ STO: Storage
- ☐ TVK: Time-Variability
- ☐ TVS: Time-Variability
- ☒ BUY: Buoyancy
- ☐ VSC: Viscosity
- ☐ HFB: Horizontal Flow

Boundary condition

- ☐ Specified head
 - ☐ CHD: Time
- ☐ Specified flux
 - ☐ RCH: Recharge
 - ☒ WEL: Well
- ☐ Head-dependent
 - ☐ DRN: Drainage
 - ☐ ETS: Evapotranspiration
 - ☒ GHB: General Head

Groundwater Transport

- Chem Species (
 - ☒ GWT: Groundwater
 - ☒ GWT: Grou
 - ☒ ADV: GWT
 - ☒ DSP: GWT
 - ☒ SSM: GWT
 - ☐ CNC: GWT
 - ☐ SRC: GWT
 - ☐ MST: Mobile
 - ☐ IST: Immobile
 - ☐ IMS: Iterative
 - ☒ Chem

DSP: GWT Dispersion Package

Comments

☒ Use XT3D (inverse of XT3D_OFF)

☐ Some XT3D terms on Right Hand Side (XT3D_RHS)

Longitudinal dispersivity treatment

- ☒ Single data set
- ☐ Separate data sets for horizontal and vertical flow

Transverse dispersivity for horizontal flow treatment

- ☒ Single data set
- ☐ Separate data sets for horizontal and vertical dispersivity

☐ Specify transverse dispersivity for vertical flow

☐ Use separate data sets for each species

STO: set as Ss

BUY:

slope = (max_density - min_density) / (max_concentration - min_concentration)

(1025-1000)/(35-0)=0.7142857

☐ TVK: Time-Varyi
☐ TVS: Time-Varyi
☒ BUY: Buoyancy
☐ VSC: Viscosity f
☐ HFB: Horizontal

Boundary conditions
☒ Specified head
☐ Specified flux

☐ RCH: Rechar
☒ WEL: Well pa

☒ Head-dependent fl

Solvers

Subsidence

Observations

slope = (maxden-minden)/(maxc-minc)

☐ Specify density
☐ Add off-diagonal terms to right-hand-side (f
☐ Write density

997.08

Reference density (der

Chem. Species	Reference Concentration (crhoref)	Slope (drhodc)
Chem	0	0.7142857

Solvers: Both 1) Solvers ☐ IMS and 2) GWTransp ☐ GWT ☐ IMS

Solver criteria need to be pretty tight for decent pct discrepancy, not sure how tight, but the following are likely overkill (what was set in the USGS FloPy tutorial). Solution did require “BICGSTAB” as linear acceleration (and a checked override box next to it) for solution to converge.

```
print_option="ALL",
outer_dvclose=hclos,
outer_maximum=nouter,
under_relaxation="NONE",
inner_maximum=ninner,
inner_dvclose=hclos,
rcloserecord=rclos,
linear_acceleration="BICGSTAB",
scaling_method="NONE",
reordering_method="NONE",
relaxation_factor=relax,
```

```
nouter, ninner = 100, 300
hclos, rclos, relax = 1e-10, 1e-6, 0.97
```

Basic | Nonlinear | Linear

Print option
All (2)

Complexity
Simple

Solution group max iteration:
1

☐ Continue even if no convergence
☒ Write outer solver convergence values to CSV file
☒ Write inner solver convergence values to CSV file
Use pseudo-transient continuation (PTC) (Inverse of NO_PTC a
Use PTC

Maximum number of allowed error messages (-1 for no limit) (MA
-1

☒ Check model input (Inverse of NOCHECK)
Print contents of memory (MEMORY_PRINT_OPTION)
None

☐ Use Newton formulation
☐ Use Under_Relaxation option
0.3333333333333333 max outer iterations fraction with ATS
(ATS_OUTER_MAXIMUM_FRACTION)

Option	Override	Value
Outer DVClose	☒	1e-10
Outer maximum iterations	☒	100
Under-relaxation scheme	☐	None
Under relaxation theta	☐	0.7
Under relaxation kappa	☐	0.1
Under relaxation gamma	☐	0.2
Under relaxation momentum	☐	0.001
Backtracking number	☐	10
Backtracking tolerance	☐	10000
Backtracking reduction factor	☐	0.2
Backtracking residual limit	☐	100

Option	Override	Value
Inner maximum iterations	☒	300
Inner DVClose	☒	1e-10
Inner RClose	☒	1e-6
Rclose option	☐	Absolute
Linear acceleration	☐	BICGSTAB
Preconditioner levels	☐	0
Preconditioner drop tolerance	☐	0
Relaxation factor	☒	0.97
Number of orthogonalizations	☐	7
Scaling method	☐	None
Reordering method	☐	None

Data □ “Edit data sets”: Sets these values globally instead of using a polygon.

Layer Definition:		
Model Top	1	m
Model Bottom	0	m
GWT:		
Longitudinal Dispersivity	0.57024	m ² /d
Horizontal transverse Dispersivity	0	m ² /d
Hydrology:		
Modflow Initial Head	1	m
Kx	864.0	m/d
Ky	=Kx	m/d
Kz	=Kx	m/d
Porosity	0.35	-
Specific Storage (default)	1E-5	/m
MT3DMS:		
Initial Concentration Chem	35	-
Longitudinal Dispersivity	0	m ² /d?

```
hydraulic_conductivity = 864.0 # Hydraulic conductivity ($m d^{-1}$)
```

Values from FloPy tutorial...

```
ghbcond = hydraulic_conductivity * delv * delc / (0.5 * delr)
ghbspd = [[(k, 0, ncol - 1), top, ghbcond, 35.0] for k in range(nlay)]
flopy.mf6.ModflowGwfghb(
    gwf,
    stress_period_data=ghbspd,
    pname="GHB-1",
    auxiliary="CONCENTRATION",
)

welspd = [[(k, 0, 0), inflow / nlay, 0.0] for k in range(nlay)]
flopy.mf6.ModflowGwfwel(
    gwf,
    stress_period_data=welspd,
    pname="WEL-1",
    auxiliary="CONCENTRATION",
)
```

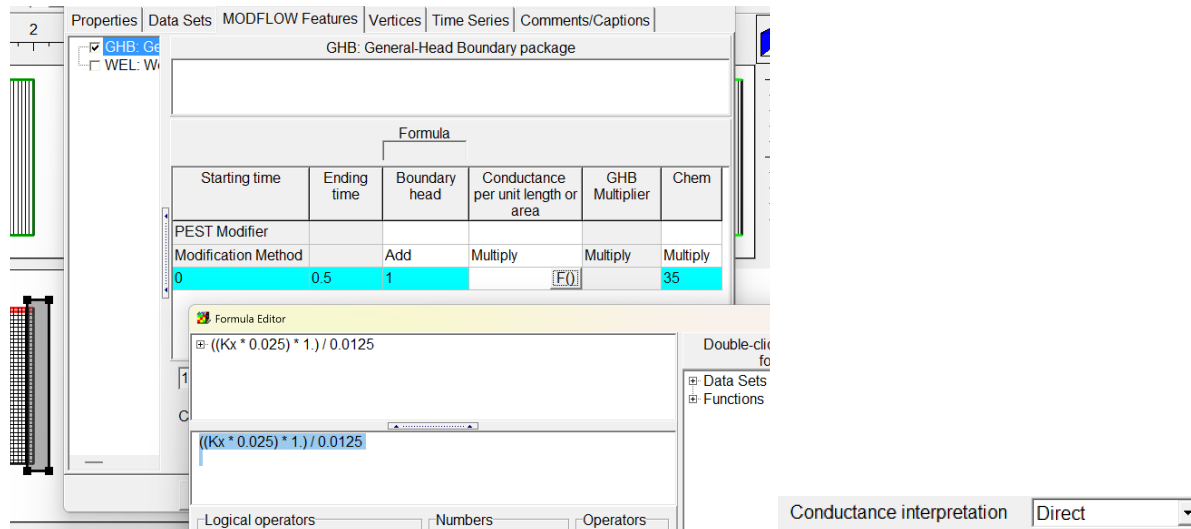
Well: inflow_a=5.7024, inflow_b=2.8512

```
delr = 0.025 # Column width ($m$)
delc = 1.0 # Row width ($m$)
delv = 0.025 # Layer thickness
```

WELL:

Double check your listing file at end to make sure well pumping rates are applied correctly—total rate should equal 5.7024. Above I take that value and divide by 40 to divide between the 40 layers.

GHB:

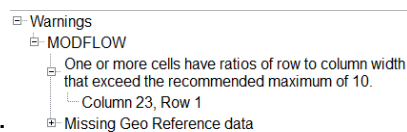


Don't forget to **save, oftenly...**



RUN it...

Some warnings and errors I encountered...



- Warnings:
 - Nothing to be concerned about
- Errors: innerDVclose >= OuterDVclose
 - Sol'n: not sure this matters, but could adjust
- Error: "cehm produces asymmetric coef matrix, but conj. Grad/ meth was selected,
 - Sol'n use "BICGSTAB" instead" turned "BICGSTAB" back on...

https://water.usgs.gov/nrp/gwsoftware/ModelMuse/Help/sms_sparse_matrix_solution_pac.htm

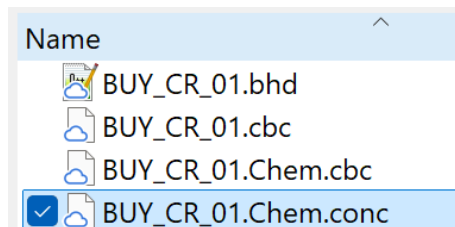
Linear acceleration: defines the linear acceleration method used by the default IMS linear solvers.

CG - preconditioned conjugate gradient method.

BICGSTAB - preconditioned bi-conjugate gradient stabilized method.

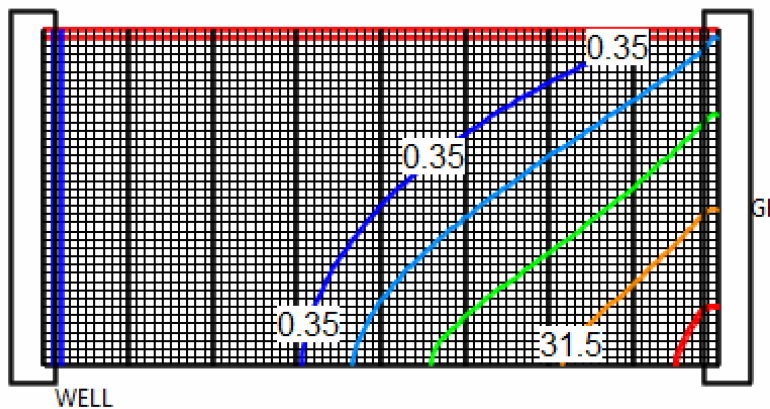
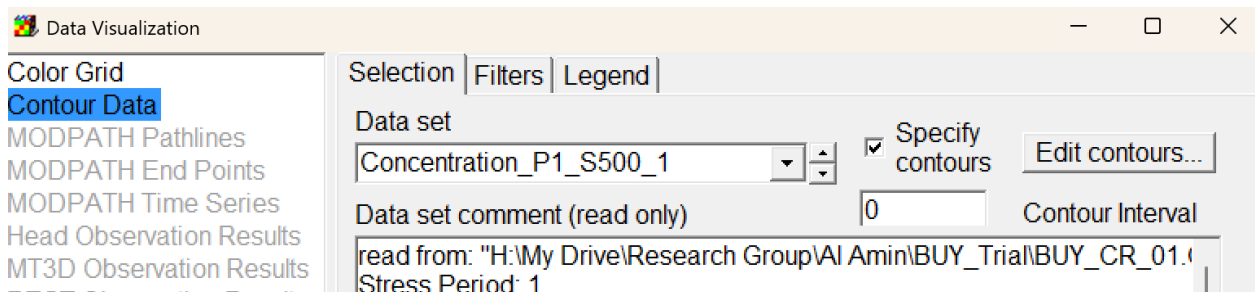


Plot data:



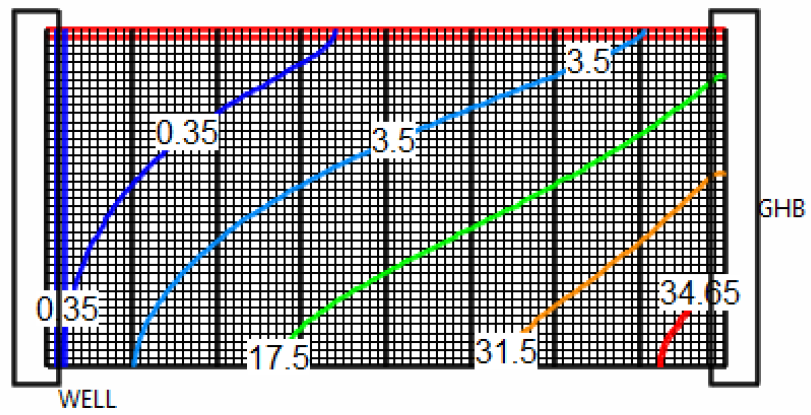
- bhd is heads, (binary heads)
- cbc is fluid fluxes, (cell-by-cell fluxes) – use for vectors...
- chem.cbc is chem fluxes, and (chem cell-by-cell)
- chem.conc is concentration (conc)

☐ Adjust contours to 1%, 10%, 50%, 90% and 99%



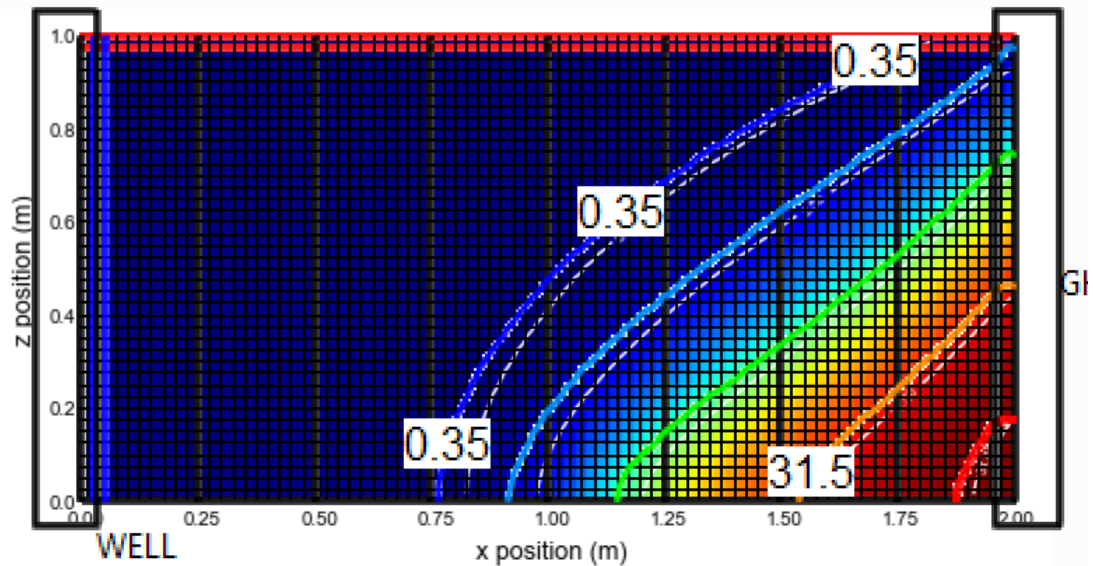
Inflow 1 :

Inflow 2 :



Overlay on top of benchmark to see a good match with the FLOPY Henry Mode

run_models took 6641.48 ms



Building model...ex-gwt-henry-b

run_models took 6788.65 ms

