Challenge 1: Compare the impact of pumping on the single-layer model vs the multi-layer model. What physical explanation do you have for the differences?

As can be seen in the head transect graph with three curves, the single-layer model (purple) depicts slight drawdown whereas the three-layer model's top (blue) and bottom (green) transect show a difference in head distribution response between themselves and with respect to the single-layer. In the three-layer model, the middle confining layer reduces the effect of pumping in the bottom layer on the top layer. Thus, in the three-layer model a significant portion of water must come from the bottom layer which is shown by steep drawdown. However, in the single-layer model, the water can be pulled from the entire thickness of the three layers as just one layer. This relates to the concept of diffusivity. Because the bottom layer in the three-layer model has the same storage and hydraulic conductivity as the entire thickness of the single-layer model, the single layer experiences less drawdown for the same pumping rate and stress period.

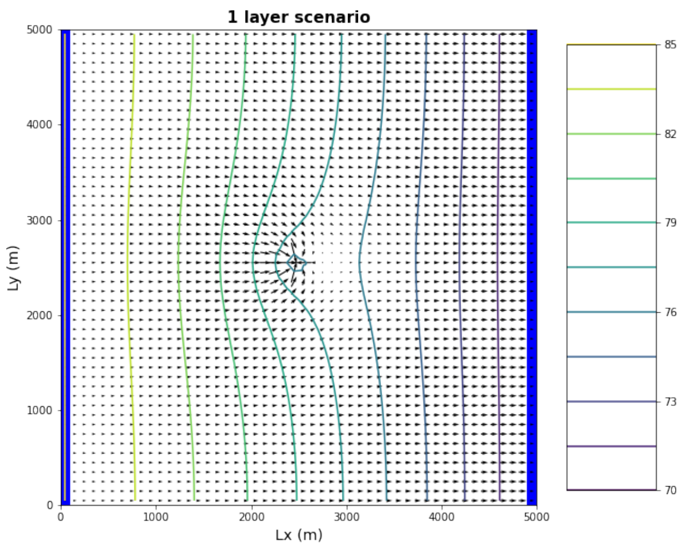


Figure 1 Head contour for single-layer pumping scenario

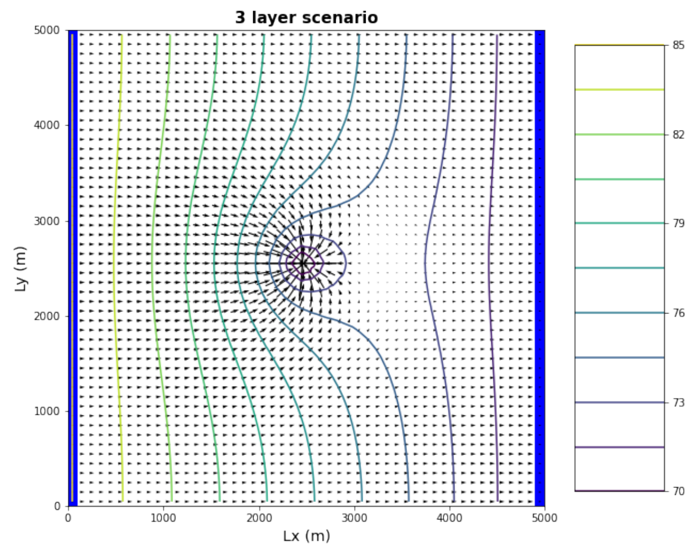


Figure 2 Head contour for three-layer pumping scenario with initial k-values

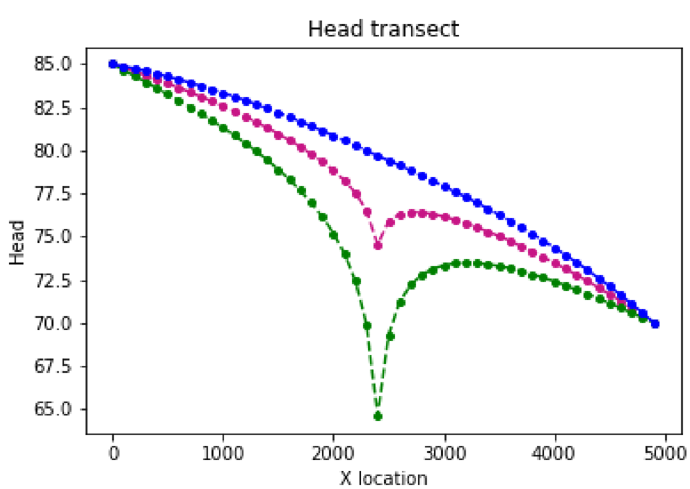
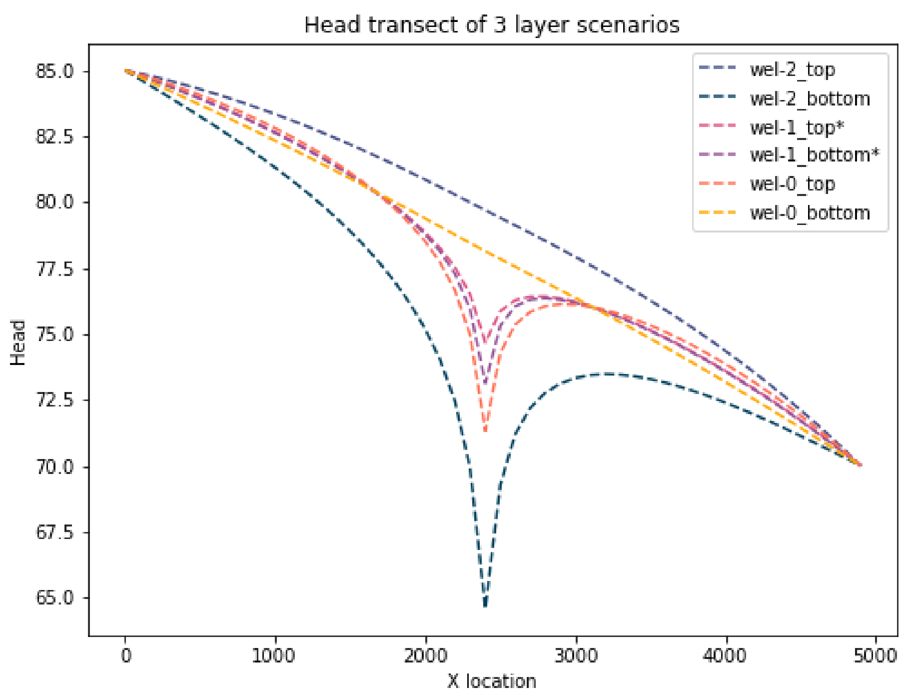


Figure 3 Head transect of row 24 for top and bottom layers of 3-layer model and the single-layer model.

Challenge 2: Repeat the three-layer simulations putting the well in each layer (i.e., once in the bottom once in the middle and once in the top) provide plots and discussions comparing and contrasting your simulations. Provide at least one plot where you have all of your runs in the same figure.

In this head transect of row 24 in three different 3-layer scenarios, we can loosely compare the effects of moving the well in different layers. Unfortunately, I was not able to use the prescribed hydraulic conductivity of 0.0001 m/day in the scenario that situated the well in the middle layer because the model would break due to the difficulty of flow. Instead, I had to increase the hydraulic conductivity in the middle layer to 0.01 m/day in order for the model to run well.

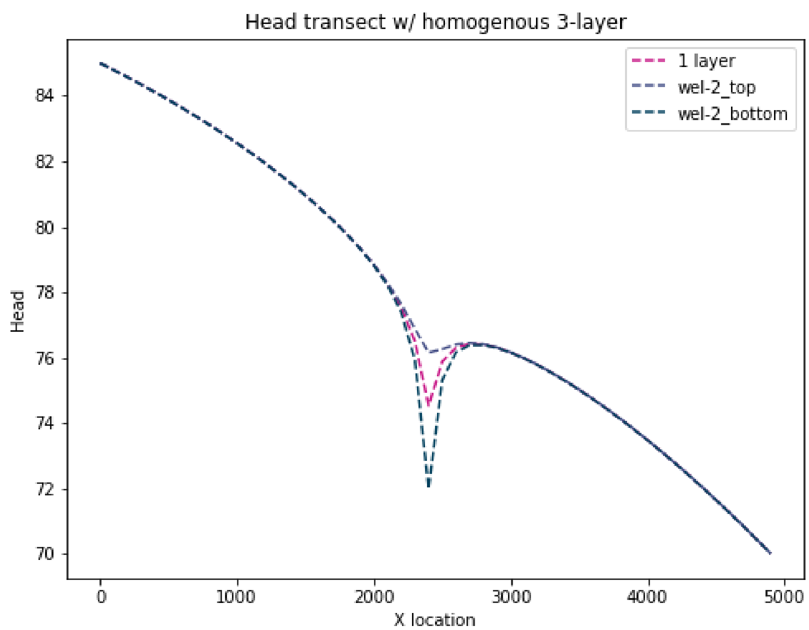
In any case, the *wel-2* code refers to a well placed in the bottom layer, *wel-1* denotes a middle layer placement, and *wel-0* a top layer placement. The top and bottom layer reflect similar curve characteristics, but the corresponding layers are flipped between the two cases due to the middle confining layer. For the well placed in the middle layer, both of the layers (top and bottom) experience drawdown.



*increased k-value (0.01 m/day)
color scheme from https://learnui.design/tools/data-color-picker.html

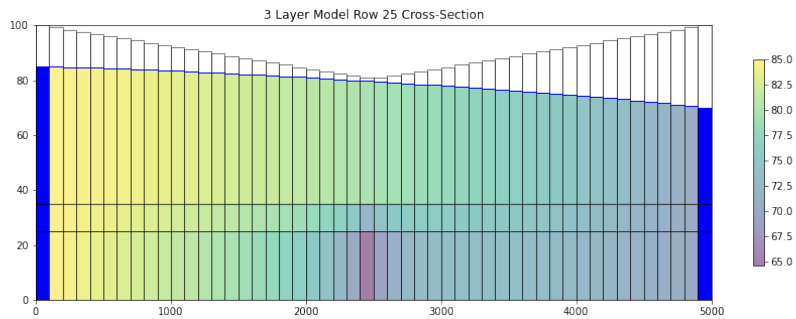
Challenge 3: Change the properties of your three-layer model so that it matches the 1-layer model (but still has 3 layers) put the pump in the bottom layer and compare and contrast with your one-layer solution. How does your answer to this challenge compare with your answer to the first?

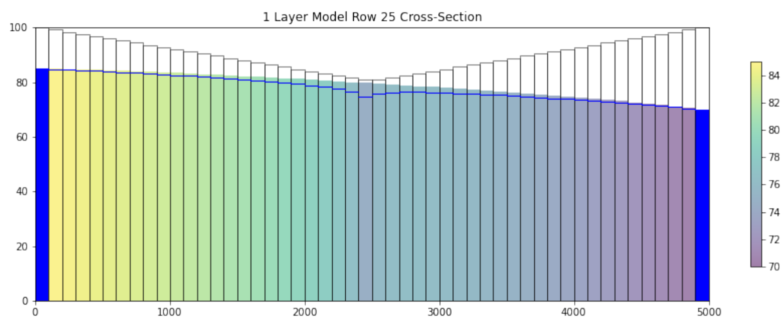
This question returns to the concept of transmissivity. Because the entire 3-layer model has equivalent hydraulic conductivity to that of the single-layer model, the transmissivity is the same. Interestingly, the single-layer (purple) fits between the other two 3-layer curves that show the top (light grey) and the bottom (dark blue). Away from the pumping stress, the head distribution is equivalent for the curves as they all align. This suggests that the effect of pumping is significant enough to be felt at the top layer.

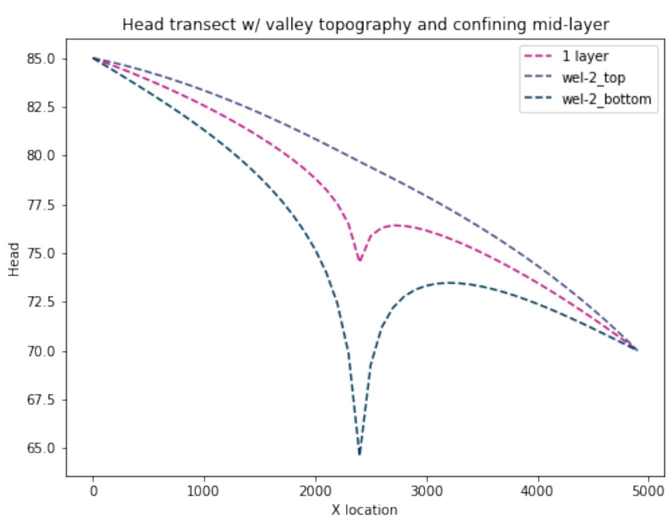


Challenge 4: Modify the topography of your domain so that it is no longer sloping left to right (you can make it a valley or have it sloping the other way, whatever you want). Re-run you 1 and 3 layer solutions and explain any differences you do or don't see.

I used a mountain valley experiment, but the resulting curves match very closely with the answers provided above. I don't think there is any discrepancy between the two graphs due to the topography as there is no parameter we have included that depends on their values.







Glossary Questions

1. *Layers: Why do we want multiple layers in our groundwater models? Compare and contrast the different approaches to vertical discretization (briefly describe different approaches and discuss their strengths and weaknesses).*

   Multiple layers are necessary to generate vertical flow in models and to include variations in hydrogeologic characteristics such as storage, hydraulic conductivity, etc. One vertical discretization approach is based on using evenly sized grid cells but off-setting them and their number in order to represent geologic units more accurately. Another option is to have grid cells of varying thicknesses and allow units to "pinch out" as they near extinction from the domain. The difficulty of this particular method is the trouble of how cells approaching "pinch out" are represented; often, the hydrologic inputs for these cells is inconsistent with the inputs for larger grid cells belonging to the same unit.

2. *Discretization: What are the pros and cons of adding more layers to a model? Are there considerations for vertical discretization that are different from horizontal discretization?*

   The pros of more layers to a model reflect an approach to achieving better resolution of real-world dynamics. Unfortunately, introducing more complexity will result in more difficulty solving the model. Some considerations for vertical discretization is understanding the bottom layer of each unit and ensuring it doesn't misrepresent the model. Another con of adding more layers into a model is the expanded assumptions that are introduced by the new layer and all of its required hydrologic inputs and parameters.

3. *Stream Aquifer Exchange: How is water exchanged between a stream and an underlying aquifer? Include the following concepts: (dis)connected streams; streambed hydraulic conductivity; boundary condition type; and coupled models.*

   Water is exchanged between a stream and an underlying aquifer through the vadose zone if there is a disconnected stream or through the water table directly for shallower baseflow. In these circumstances, flux occurs across the streambed which can introduce a need to develop and understand the parameters and necessary inputs. The issue with Type I boundary conditions is that they represent an unlimited source/sink within the model and this should be recognized.