**The 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?
   * Graphical user interface, table

     Description automatically generated with medium confidence
   * The 3-layer flux has a lower input and output flux. This is because the low K center layer slows flow and would reduce the flux rate of water going into and out of our domain.
   * Chart, bar chart, histogram

     Description automatically generated
   * For the 3-layer model, the head values are not uniform. The top layer has higher head values while the bottom layer has a low head value. This is because pumping is occuring in the lower layer and the pumping is being confined by the low K center layer.
   * Chart

     Description automatically generated
   * The 3-layer value has a much more pronounced cone of depression from the pumping. This is because pumping is occuring over a smaller space (that lower layer). This leads me to a question though, which layer are we seeing when we pump in the head contours…?
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.

Chart

Description automatically generated

* + The scenario with the well in the middle layer results in an error in the output. This is likely caused by the pumping rate being unsustainable for low K layer it was placed into.
  + With the well located at the top layer we see that there is low head at the top layer and higher head at the bottom layer. This is because the low K center layer is impeding flux and therefore the pumping isn’t affecting that layer as much.

1. 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?
   * Chart, histogram

     Description automatically generated
   * I thought for sure that the single layer and multilayer scenario would yield the same outputs if all the parameters were the same. Yet, I see in our cross section this is not the case as the bottom layer has a lower head than the layers above it. With 3 identical layers, I would assume it would be the same as 1 layer.
   * I think this is because pumping is only occuring at the bottom of the well in our 3-layer simulation. If pumping was occuring in the center of the model, I think we would see a similar/exactly the same result as our 1-layer model.
2. 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 differecens you do or don't see.
   * Chart, bar chart

     Description automatically generated
   * In the above example the topography has been changed to slope right to left. This did not change our simulation head values compared to our base case. This is because the topography isn’t interacting with our groundwater. With BC of constant heads on either side, the GW will continue to move from left to right regardless of topography.
   * Chart, histogram

     Description automatically generated
   * In the above example, the topography has been lowered in such a way that the groundwater has peaked through the topography. This is an example of a lake!
   * Chart, histogram

     Description automatically generated
   * The head transect is very interesting as it shows how our water table does not respond to the pumping of the well in the 3-layer simulation as much as it does with the 1 layer model (where we can see that dip in the center).

**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 allow us to model heterogenous layers of varying topography. This would change the flux rates in and out of our system.
   * Ways to make vertical discretization: Uniform spacing, custom, and layer size multiplier. We can change the thickness of the layers within a group by changing the method (uniform spacing, increase upward/downward/toward middle/toward edges, custom).
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?
   * Adding more layers could potentially increase the accuracy of your model if it simulates the real world better.
   * Vertical discretization will be effected by any processes that have a vertical dimension to flux (ex., evapotransipration) and we would need to consider the effect changing the top layer would have on these vertical processes.
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.
   * “Surface Water is just exposed groundwater”, my new favorite hydro quote. Surface water infiltrates into the subsurface becoming groundwater. When the groundwater is exposed from low topography, it becomes surface water.
   * Diagram

     Description automatically generated([Hydrogeological Techniques](https://www.groundwater.com.au/media/W1siZiIsIjIwMTcvMDIvMjgvMDFfNTZfNDNfMTYxX0Nvbm5lY3RlZF9hbmRfZGlzY29ubmVjdGVkX3N0cmVhbXNfdXBkYXRlZF8yMDE3LnBkZiJdXQ/Connected%20and%20disconnected%20streams%20-%20updated%202017.pdf))
   * A disconnected stream occurs when the aquifer is disconnected from the stream. This can be caused by a low streambed hydraulic conductivity.
   * A coupled model is a model that combined different processes together and they interact together in a simulation. We can couple together our surface water and groundwater interactions.
   * To model a system with both surface water and groundwater interacting, additional boundary conditions will need to be taken into account. For example, for a disconnected stream we may want to have a constant rate of recharge, while in a connected stream we may want to have a BC of constant head.