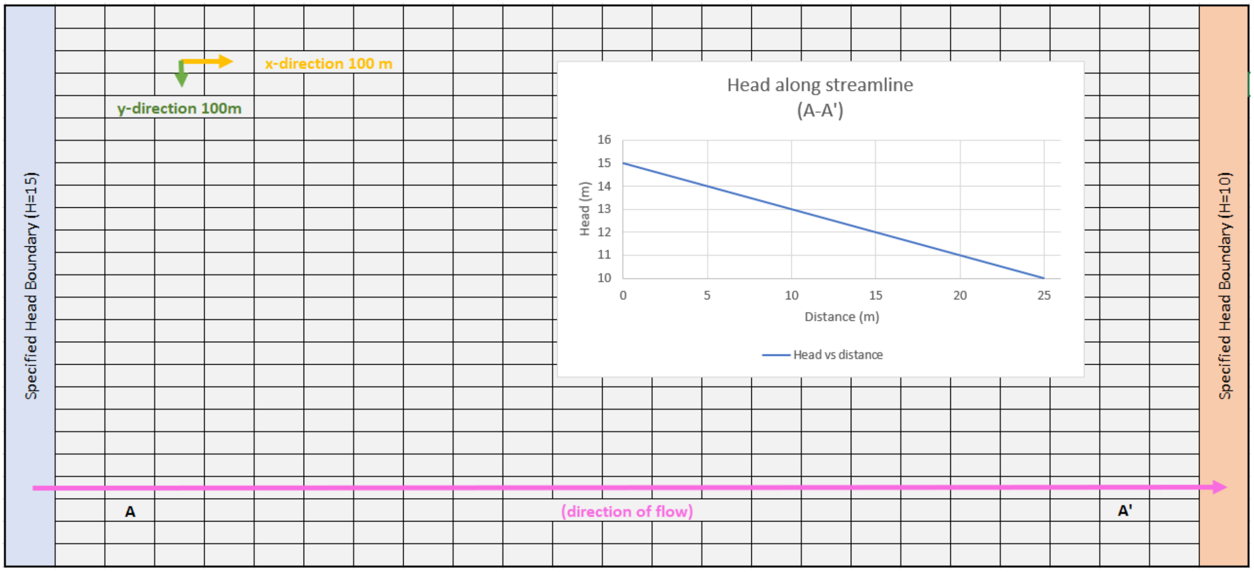
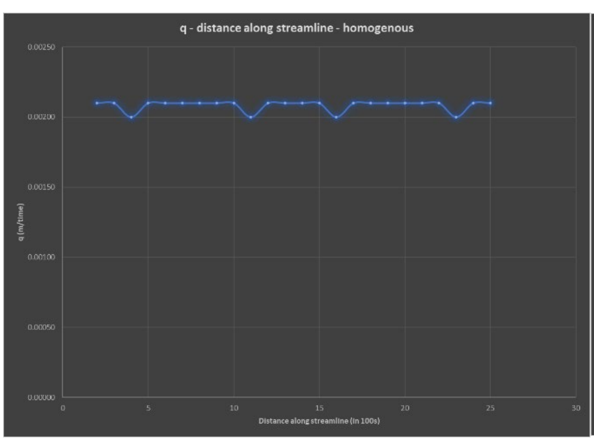
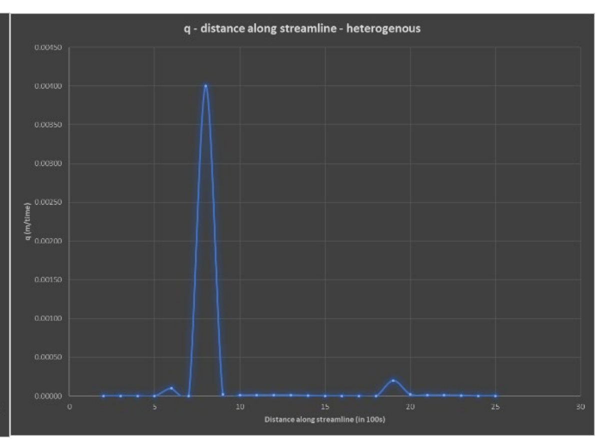
The Challenge

1. Create a conceptual model of the homogenous MODFLOW model: This should be an illustration that shows the locations and values of constant head boundaries, the number of grid cells and their spacing as well as any other model properties. You should also include in here a cross section with your predicted head gradient and direction of flow. You can draw this by hand if you would like.



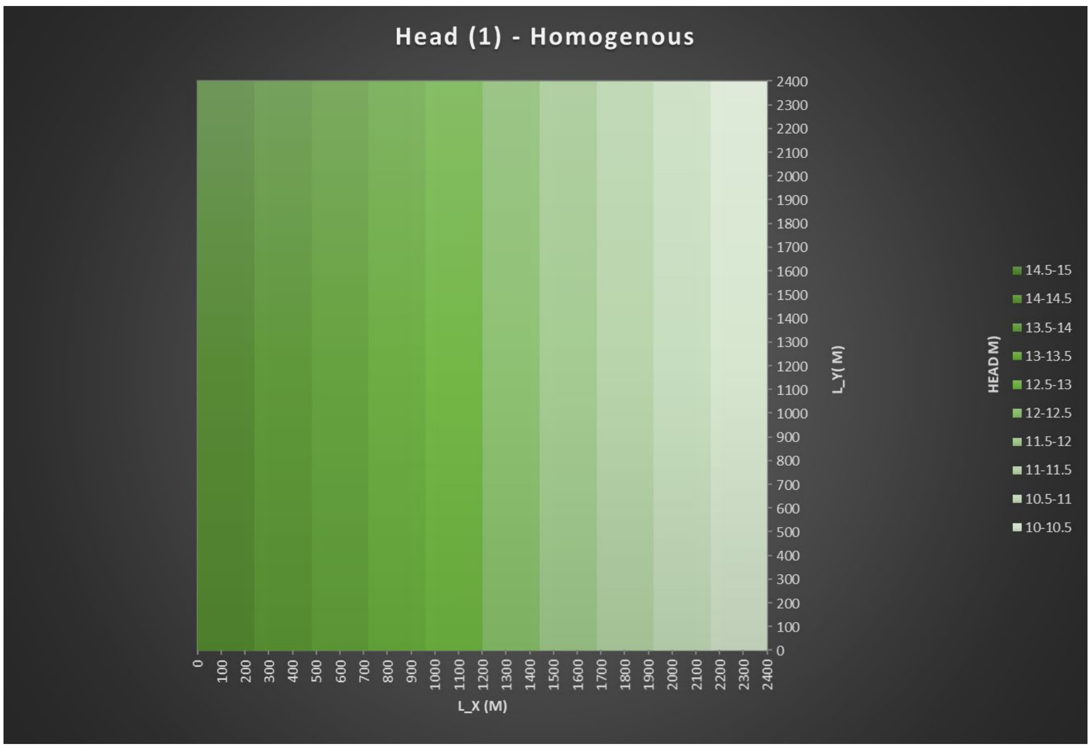
2. Show, based on the flux with horizontal distance from a constant head boundary, that the model is steady state. Repeat this for a homogenous and a heterogenous cases where you place different K values in series in the direction of flow (Note: to modify the K values you should change the .bcf file, just be careful because spacing matters! Note 2: see the excel sheet for an example calculating flux. Keep in mind that that heads are calculated at the center of a cell and the K values are defined across the entirety of a cell)





The above graphs show the flux along the length of a column of homogenous (left) and heterogenous (right) K-value soils. The graph on the left shows four variations (2.0E-3) from the predominant value of 2.1E-3 due to rounding errors in MODFLOW. The graph on the right, depicting a homogenous soil, is greatly flawed for reasons I could not understand despite troubleshooting the issue. In any case, we would know that the system is flowing at steady state because if there was no change in flux across the system. With that rule, we can see the homogenous system is steady state (despite the errors), however we cannot come to that conclusion for the heterogenous column because there is simply too great divergence of flow in the system.

3. Show the steady state head contour in plan view for the homogenenous and heterogeneous (zones in series) condition. Use this plot to defend a contention that flow is 1D. Then, drawing on your first assignment, use the results to explain WHY the equivalent hydraulic conductivity, Keq, is closer to the lower of the two K values.

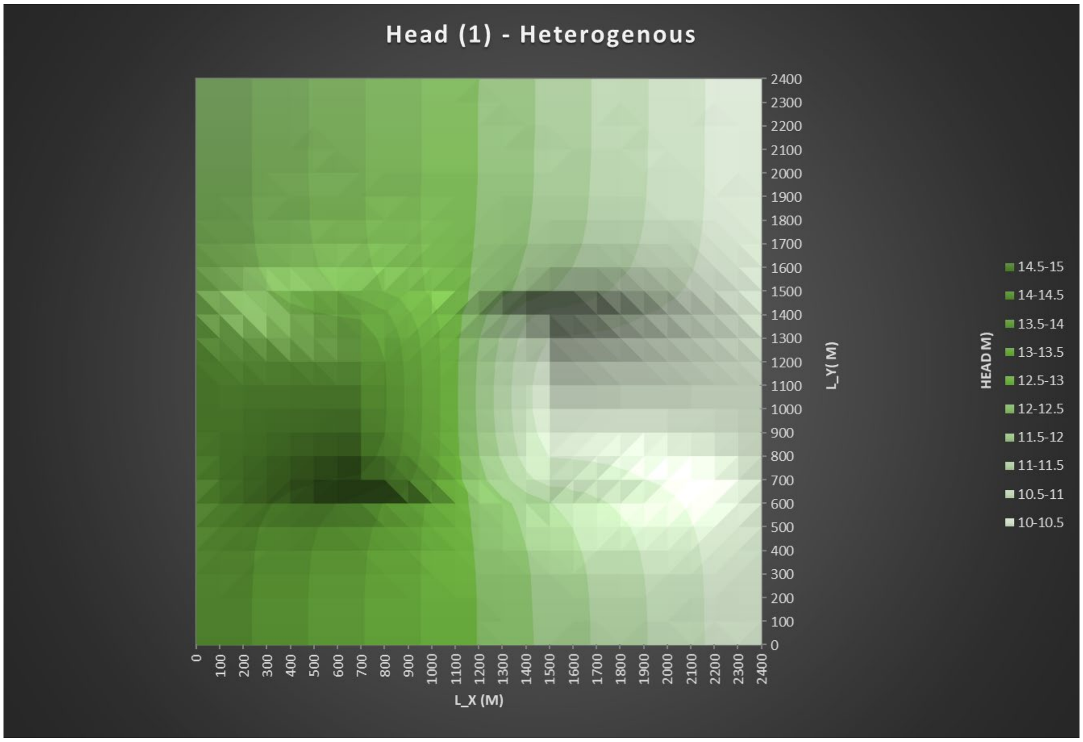


Because homogenous is the only scenario that I could get working for this assignment, I have omitted the heterogenous plot. In this situation, we can see that flow is 1D because flow moves in the down direction of the head gradient. At intervals along the length of the column, head values are equivalent in the y-direction which restricts flow from moving in any direction other than the x-direction.

When K_{eq} is calculated, the harmonic means must be used since the flow is traveling across multiple layers of varying K-values. The way the harmonic mean is calculated, with the K-values serving as the denominators of fractions that get added together in the denominator of a main fraction, the smallest k-values impart larger influence since their fractions have a bigger impact.

4. Build a model based on a homogeneous domain with a square region of lower K in the middle of the domain. What can you learn based on your explanation of what controls the effective K for a 1D flow system now that you are applying it to a 2D system? What do you think the Keq of this

entire system would be compared to the high and low K values? Explain why it is much more difficult to develop a direct solution for this 2D system than it was for a 1D system (including the zones placed in series).



The K_{eff} for this system is much more complicated because the flow is not moving in 1D due to the intrusive block of low K-value in the center of the domain. The way in which K_{eff} is measured is much more difficult because flow is no longer moving in a straight line except near the top and bottom boundaries. The K_{eq} is most likely closer to the higher K-values of the surrounding soils because those K-values offer the most preferential flow for the water as can be seen in the equipotential lines in the above plan view. It is difficult to try and understand the K_{eq} because the movement of flow through the soil is not 2D. This means it's no longer enough to find the harmonic mean of the K-values in order to identify a K_{eq}.

5. For steady state conditions, there are equivalent Type I and Type II boundary conditions. What would the Type II boundary condition be that would result in the same equipotentials for the first model? What is the value of the constant flux? What about the second model? What are the values of the constant flux on the left and right boundaries? What is fundamentally different about the equivalent Type II boundary for the third model compared to the first two?

   The Type II boundaries that would be useful for the first model would be to set the left and right boundaries with a specified flux value of q = 2.1E-3 m/day. I was not able to get the second model to work properly, however it would have been q = 1.22E-3 m/day which I was able to calculate by finding the E_{eq}, dH, and dL.

Glossary Questions:

What is MODFLOW? What is a MODFLOW package (provide at least 2 examples)? What are the inputs to a MODFLOW model?

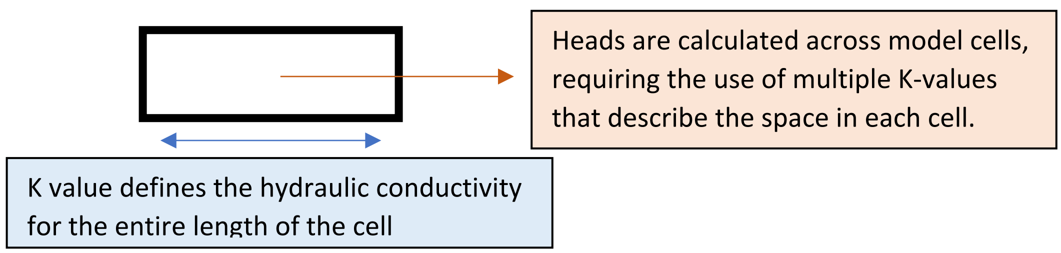
MODFLOW is a modelling software that utilizes multiple text files to include various inputs in order to generate a representative physical system. Some packages include BCF6 (Block-Centered Flow) and LPF (Layer Property Flow). The inputs to MODFLOW are any values that describe the parameters being used by the system.

What is the relationship between head gradients and hydraulic conductivity in steady state systems?

Head gradients and hydraulic conductivity are inversely proportional to each other. For steady states that experience equivalent flux, if one has a higher head gradient then it must have a lower K_{eff} to achieve an equal flux as the other steady state.

What is a model node? A model cell? Use a simple diagram to show the relationship between heads defined at nodes and properties defined in cells.

Model nodes are the spatial center of a cell where the head is calculated for the model cell. The model cell is a representative 2D or 3D space that is given properties as is required by the model in order to calculate the physical system.



What is the difference between TypeI and Type II boundary conditions and under what conditions might you use each? Provide at least 2 examples for locations where we might use Type I or Type II boundaries to represent a feature in the real world

Type I boundaries set a specified head value, Type II boundaries set a specified flux across the boundary. Two examples for a Type I boundary include representing a large body of water that remains relatively constant through time, such as a lake or river; another example includes an infinite sink of water such as water flowing into a gaining stream.

Examples for a Type II boundary include setting a no-flow boundary that could be used to contain flow in only one direction such as when an impermeable layer of bedrock is encountered. Another reason to use a specified flux includes representing an injection well that is constantly pumping at a set rate.