The Challenge

1. Change the boundary condition heads to make this an unconfined model. You can pick whatever heads you would like but I recommend keeping both of them above zero (*Hint:these are the variables H_left and H_right in the starter code*). Run two simulations with the same head gradient across the model (i.e. H_lef-H_right being the same between your confined and unconfined cases) but where one is confined and the other is unconfined.

    - Plot the equipotentials and flow lines for both simulations

    - Plot the head difference between the two simulations

    - Describe how the two head profiles differ and explain why this is the case.

      The two head profiles differ because in the confined aquifer case, the head drops linearly along a constant gradient whereas the head drops along a nonlinear path for the unconfined gradient. That is because the area of flow is dependent on the head, that is to say it is dependent on the state of the system leading to a nonlinear relationship.

    - Would your answer be different if you changed the overall head gradient (H_left-H_right), still keeping it the same between confined and unconfined cases though?

      The answer explaining why the head profiles are different would not change, although the head gradients would be different.

2. For the two runs above (1) plot the flux across the left and right boundaries and (2) calculate the total flux.

    - Compare these calculations and plots and provide an explanation for why you see the behavior you do.

      In both boundary flux plots, we see that inflow and outflow are equivalent, that is because both systems are in steady state with no sources or sinks contained within the domain to introduce or remove water; all water must be accounted for and so we observe these plots.

    - The overall gradient is the same, as is the K of the medium. Is the flow the same for both boundary conditions? Why or why not?

      The reason for the difference in flow between each situation is due to the nature of unconfined aquifers. The calculated flow is affected by the smaller cross-sectional area of the unconfined aquifer.

3. Now add recharge at a constant rate of 1e-4 m/day over the entire land surface to an unconfined case with the left boundary set 7m and the right boundary set to a 2m.

    - Explain the head transect and boundary flows.

      The head transect illustrates higher head values near the centerline of the domain because the level of recharge exceeds the ability of the prior flux to persist. In fact, we can see that water is flowing out from both the inflow and outflow boundary, although the prior head difference continues to drive more water out across the outflow boundary.

- Is flow in this system 2D or 3D? Is it represented as 2D or 3D? Explain what you mean by your answers.

  Flow is still occurring in 2D. We have a single layer, 25x25 grid, which does not allow for vertical movement in the cells, thus all movement is restricted to 2-dimensional movements.

4. Update your model from #3 to model a system with zero recharge except for a farm located in [6:10, 6:10]. Recharge beneath the farm is 1e-4 m/day due to excess irrigation.

- Calculate the annual excess irrigation, in meters, that has been applied to the farm.

  The excess irrigation came out to 16.000198 m/day, so the annual excess irrigation is valued to be 5840 m^3/year.

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Left Flux = 12.3991  Right_flux= 28.3993  Difference = 16.000198
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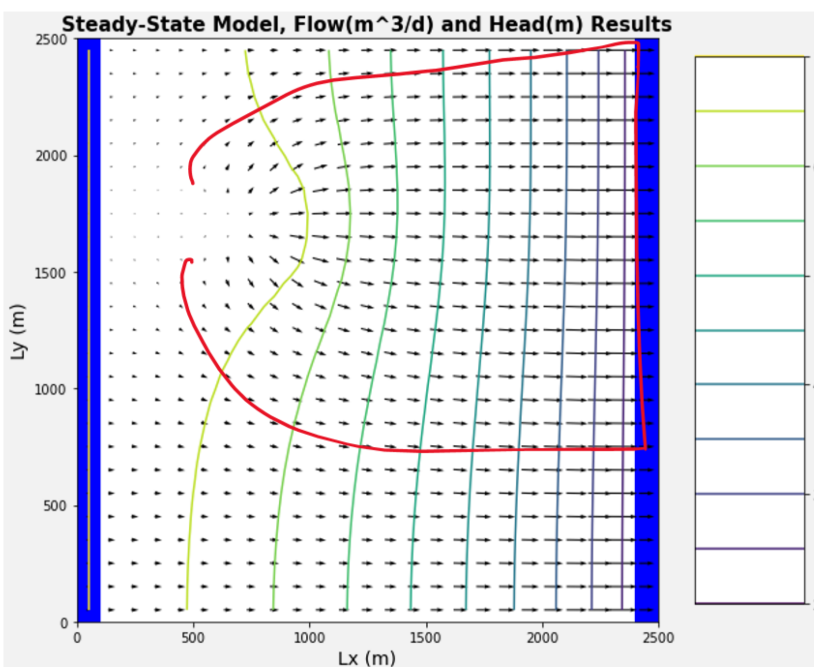
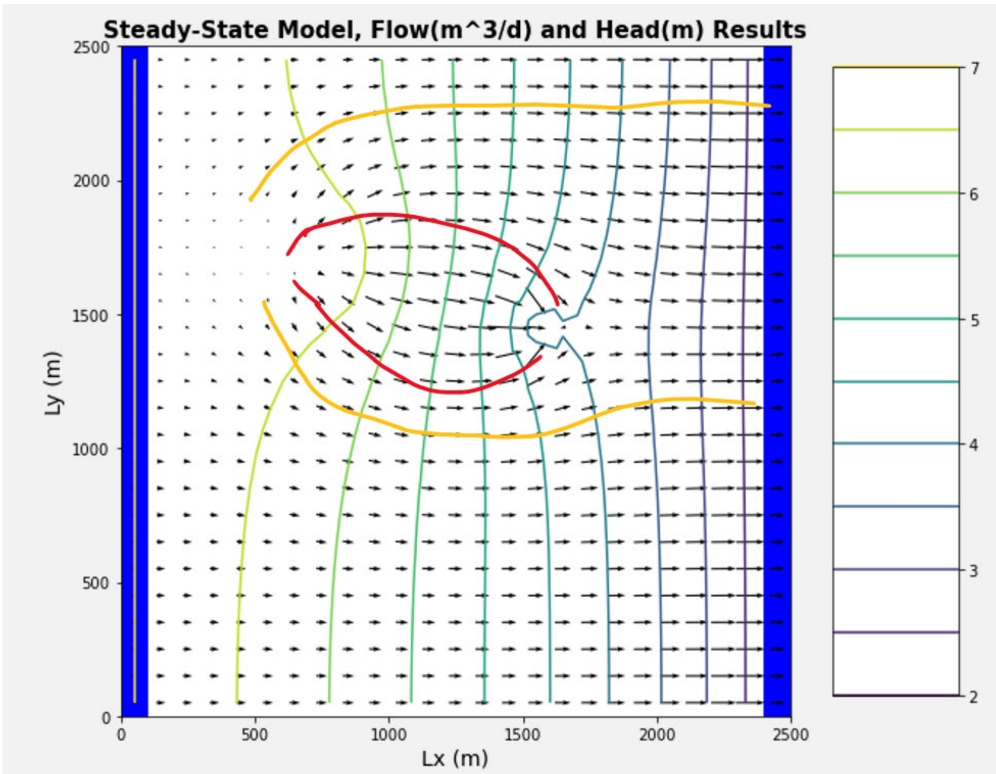
- Assuming that the crop is cotton, it is located in southern Arizona, and cotton is grown all year (for simplicity), calculate the total irrigation rate on the farm that would be associated with this amount of excess irrigation.

  Unsure how to answer this question. The total irrigation rate would be the same as the difference

- Finally, use the flux diagram to identify the area within the domain that might be subject to contamination if the recharge water was somehow tainted (you can do this by saving the plot to powerpoint and annotating it there).



5. Lastly, start the well located at [10,15] pumping at a rate of 8 m3/day. Using one color, identify the capture zone of the well. Using a second color, show the area that might be contaminated by the irrigated farm fields (see not above you can do your annotations in powerpoint if that is easier.).



- Comment on the impact of the well on the pattern of potential contamination.

  The well narrows the area of potential contamination, but it does not completely stop the movement of contaminants, nor does it significantly reduce it.

- How will the steady state capture zone of a model with recharge differ from that in the same model without recharge?

  I'm assuming this means recharge across the entire domain, and not just from the site representing an irrigated farm. In that case, the steady state capture zone would likely be broader because there would be a more equal head profile distribution around the well, making more water as likely to be captured compared to the above situation where there is an irrigated field introducing water into the domain at a much higher rate than its surroundings.

Glossary questions:

1. What does it mean for an aquifer to be unconfined? How does this impact how we calculate flow and how do we expect it to impact head gradients and fluxes?

   An unconfined aquifer is an aquifer that is not under pressure. Flow is calculated differently because the head gradient is not a constant value across the domain. This is due to the nonlinear nature of an unconfined aquifer system where the change in head is dependent on the cross-sectional area which is dependent on the height of water (the head). Unconfined systems introduce diminished flows compared to equivalent head gradients in confined systems and much higher fluxes which are necessary to drive flow through the rapidly diminishing cross-sectional area.

2. List each layer type available in the LPF and BCF packages. Provide a brief summary explanation for each. Explain how approaches differ.

   BCF6:

   0. Confined: The transmissivity remains constant for the entire domain since the there is no change in wetted area, storage coefficients are also held constant
   1. Unconfined: The transmissivity varies since the saturated thickness can change due to decreasing head. Storage coefficient, however, remains constant.
   2. Confined/unconfined (Transmissivity constant): Transmissivity is held constant although the storage coefficient may change between specific storage (confined) and specific yield (unconfined).
   3. Confined/unconfined (Transmissivity varies): Both the transmissivity and storage coefficients are variable. Transmissivity changes according to saturated thickness and the storage coefficient changes based on the (un)confined situation of the aquifer.

   LPF:

- 0—confined: The layer is set as a confined cell with a constant head gradient
- > 0—convertible: The layer can be calculated as either a confined or unconfined cell
- < 0—convertible: The layer will be convertible unless a THICKSTRT option is in effect, in which case the cell is considered a confined cell.

2. How can MODFLOW, which does not model unsaturated flow, represent an unconfined aquifer?

   MODFLOW only calculates flow through the saturated thickness of an aquifer. Thus, it depends on the cells being set as convertible/confined (LPF) or confined/unconfined/limited convertible/fully convertible (BCF).

3. Define recharge. How do we represent recharge in a MODFLOW model? What package do we use and what are the assumptions of this package? Where exactly is the top boundary of the model?

   Recharge is an inflow of water into a system that contributes positively to a water budget, usually in the form of infiltration across a surface (e.g., rain or irrigation) that reaches the water table. In MODFLOW, recharge is included in the RCH package and modeled by setting up values of specified flux (LT^{-1}) and multiplied with the area of the top layer to calculate a volumetric flux. The “top” boundary is selected using the NRCHOP option which allows the user to choose between three variables:

   1. Top layer: Recharge is at the top grid layer
   2. Specified layer: for time-varying recharge layers
   3. Top active cell: recharge location can move up or down depending on the wet or dry condition of the top cells.