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Model Description

The model you are provided this week is similar to the previous homework. It is a homogeneous box domain with one layer.

In the starter code the model is confined. There is a well located at [0,10,15], but it is not being pumped. The recharge rate is zero. The left and right boundaries have constant heads of 20 and 10, respectively.

For the challenge you are going to be exploring two things (1) what happens if this swaps from confined to unconfined conditions, (2) how recharge impacts your solution.

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., $H_{left}-H_{right}$ 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.
 1. Both profiles have a head gradient of 4 meters from the left boundary to the right boundary, and the confined aquifer has head contours at equal intervals, because the gradient is linear. In the unconfined aquifer, the gradient is not linear, and the head contours become more closely spaced toward the right side of the domain. This is because head is not linear in an unconfined aquifer. This is because according to Darcy's law, for the same Q , as the cross-sectional A gets smaller, dh/dL must increase.
 - 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?
 1. Although area [L^2] does not scale linearly, specific flux, q [L^3/L^2] or [L] does. So a head gradient of (9m-5m) will produce the same head profile as a gradient of (7m-3m).
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.
 1. With no recharge or pumping, and the system being steady-state, $Q_{left} = Q_{right}$ for both the confined and unconfined simulations.
 - 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?
 1. The flow of the unconfined aquifer is less than the confined aquifer, because as water table decreases towards the right, the cross-sectional area that the water can flow through decreases. This creates a bottleneck, like an 8-lane highway turning into a 4-lane highway. For the confined aquifer, even though the head gradient is the same as the unconfined aquifer, the flow path is an 8-lane highway the whole way across.

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 is greatest at approximately column 11. The head at this point is almost 14m, which makes it greater than the left boundary, which is normally the highest column of head. As water flows from high head to low head, this makes the flow direction left of column 11 go toward the left. So water is actually exiting the domain from both the left and right boundaries.
 - Is flow in this system 2D or 3D? Is it represented as 2D or 3D? Explain what you mean by your answers.
 - The model still only has one z-layer, but the recharge has to come from the top. 0.1mm of recharge is applied per unit area, so for each 100m x 100m cell, there is 1 m of a downward head gradient. Why this 1-meter downward gradient causes the maximum head to increase to 14 and be centered at column 11, I do not understand.
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.
 - .1mm per day x 365 days = 36.5 mm excess per year.
 - 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.
 - I don't know where the 80% efficiency assumption came from, but if 20% is excess, and that excess is 36.5mm/year, then the total irrigation is $36.5\text{mm}/0.2 = 182.5\text{mm/year}$ irrigation.
 - 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).
 - Around and downgradient from the recharge area.
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 zone of potential contamination is still the same, according to the supplied correct figure.
 - How will the steady state capture zone of a model with recharge differ from that in the same model without recharge?
 - Apparently, it doesn't differ.

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?
 1. An unconfined aquifer does not have a constant elevation head. The cross-sectional area of a point with lower head will be smaller than one with a larger head, due to the lower water table. This means the change in head with respect to space is not linear, like in a confined aquifer. In a confined aquifer, Storativity is a function of the specific storage of the matrix, and the thickness of the matrix. In an unconfined aquifer, Storativity is made up of the aforementioned specific storage and also specific yield, which is when the pores of the aquifer actually do drain and become unsaturated.
2. List each layer type available in the LPF and BCF packages. Provide a brief summary explanation for each. Explain how approaches differ.
 1. BCF Package (From user guide):
 1. 0—confined—Transmissivity and storage coefficient of the layer are constant for the entire simulation.
 2. 1—unconfined—Transmissivity of the layer varies. It is calculated from the saturated thickness and hydraulic conductivity. The storage coefficient is constant. This type code is valid only for layer 1.
 3. 2—confined/unconfined—Transmissivity of the layer is constant. The storage coefficient may alternate between confined and unconfined values. Vertical flow from above is limited if the layer desaturates – **Transmissivity being constant means the saturated thickness stays constant, which isn't actually representative of an unconfined aquifer.**
 4. 3—confined/unconfined—Transmissivity of the layer varies. It is calculated from the saturated thickness and hydraulic conductivity. The storage coefficient may alternate between confined and unconfined values. Vertical flow from above is limited if the aquifer desaturates. – **This is more representative of an unsaturated aquifer, and the limited vertical flow from above for unsaturated sections would have effects on recharge.**
 5. LPF Package (From user guide):
 1. 0—confined
 2. >0 – convertible – **This means that if the head is less than the cell thickness, it will be treated as unconfined.**
 3. <0 – convertible unless the THICKSTRT option is in effect. When THICKSTRT is in effect, a negative value of LAYTYP indicates that the layer is confined, and its saturated thickness will be computed as STRT-BOT.
3. How can MODFLOW, which does not model unsaturated flow, represent an unconfined aquifer?
 1. By treating cells with head lower than thickness as if they were only as thick as the calculated head.

4. 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?
 1. Recharge is water that is added to the aquifer from above. It is done with the floppy mfrch module. It is flux that is distributed to the top of the model, and is multiplied by horizontal area to calculate the volumetric flux.