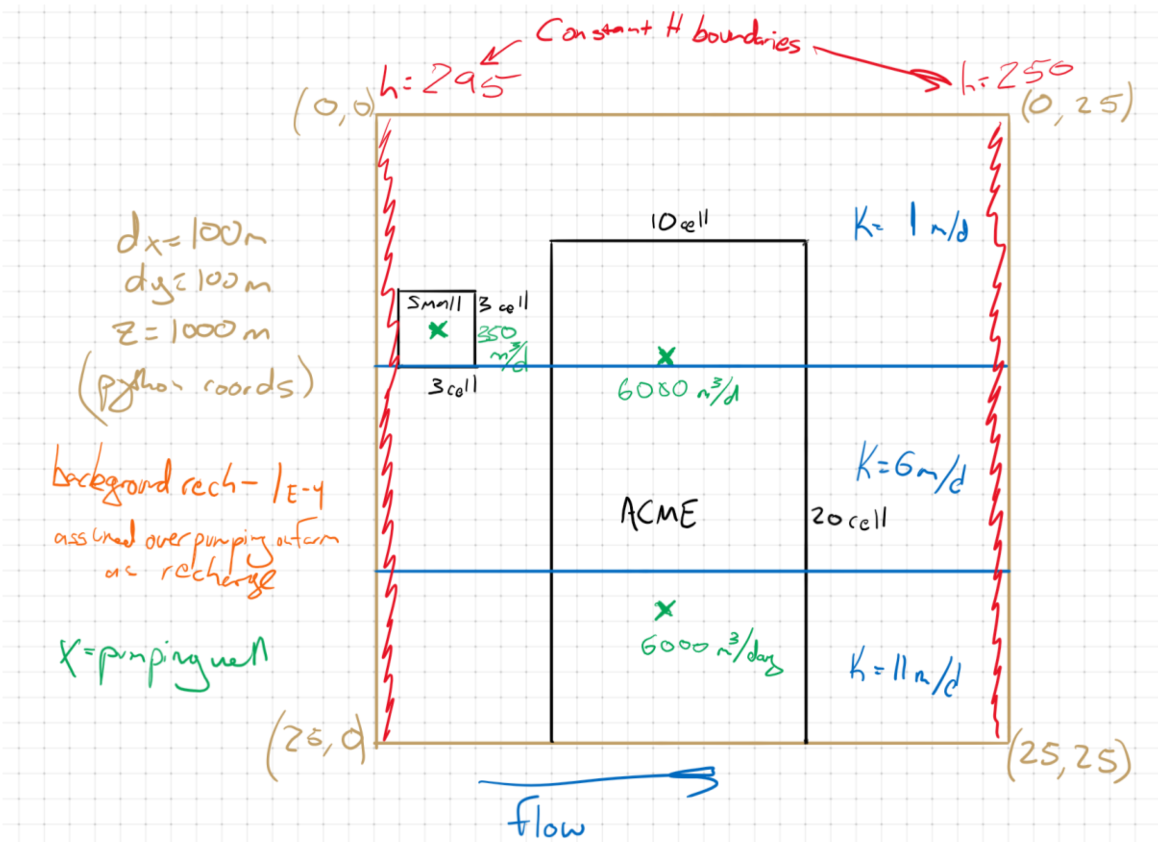
Jake Smith
Report
HW7

Model Design

Conceptual Model Diagram



Above figure gives an example case for pumping amounts and well locations

Description:

I chose a dx and dy (grid resolution) of 100m for my models. I chose this resolution because it felt like a simple number to work with in this case. It also was quite appropriate for the size of the farms. For example, the small farm was 30 acres, which converts to 348 sq. meters. A 100m resolution gives us 300 sq meters, which is sufficient for the purposes for our model space. This allowed a simple 3x3 cell square for the farm, and made centering the well a trivial matter. The lost area can simply be re-introduced when calculating the pumping and recharge by using the exact 348 area. For the large ACME farm the area worked out almost perfectly, as 500 acres is just over 2,000,000 sq meters, which works out to exactly a 10x20 cell rectangle as the image map dictates for us. 100m resolution also speeds up model iteration, as a smaller resolution like 10m would exponentially increase computing demands. My thickness (dz) was set to 300m. I chose this thickness because of the screening depth of the ACME wells being 200m below the surface. 300m dz ensures that we can see what is happening below the well, and also ensures there is adequate water to support our pumping within the model space.

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The first parameter I set were the type of head boundaries. I chose constant head boundaries because I felt this was the most appropriate option given our information in the scenario. We only know water table depths at observations wells. I simply selected a left head boundary at the left-most portion of the model space of (ztop – water table depth = H) so (300 – 5 = **295m**). I thought this was appropriate as the two wells with a WTD of 5m were both on the left edge of our model domain. The same logic was applied to the right constant head boundary, which was set to **250m**. I simplified WTD to 5 and 50 for the wells for simplicity's sake, as a decimal meter on the scale of this domain was negligible.

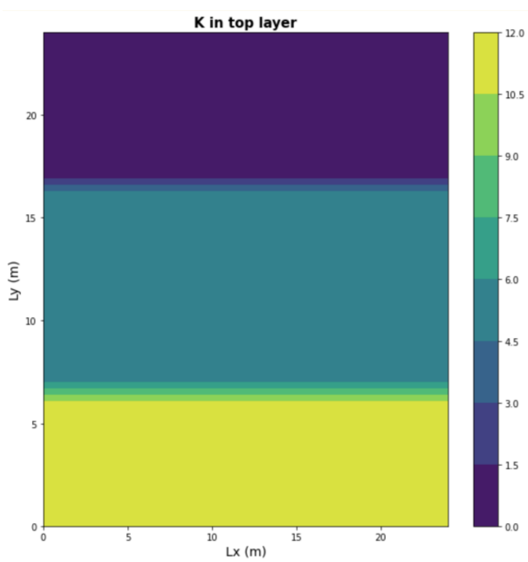
The parameters for the BCF/LPF packages were set as follows…

```
K_vals = np.zeros((nlay, nrow, ncol))
K_vals[:, :, :] = 11    # horizontal K values based on southern obs. wells
K_vals[:,8:18,:] = 6   # middle K value to create more of a gradient in the K field
K_vals[:,0:8,:] = 1   # low K inclusion based on northern obs. wells

K_vert = 1     #Either the value of hvertical K or the ratio of horizontal to vertical

n = 0.35        #assign porosity
Ss = 0.001      #assign storage coefficient
Sy = 0.3        #assign specific yield
laytype = 1       #0=confined, >0 = convertible (for the LPF file)
#print (K_vals)
```

I chose these K values based off of the information given at the observation wells. Again, values were simplified and averaged. I assumed a K of 1 m/day for the northern observation wells, and 11 m/day for the southern observation wells. I decided to add a 3rd K section in between the two well-based K sections in order to make a slight gradient in the K field of the model (demonstrated below).



The middle K section was removed for cases 4 & 5 in order to see what would happen to the drawdown.

The remaining properties (porosity, Ss, Sy, laytype) were set to the default values we had been using in our other projects, as we had no information on these characteristics in our scenario.

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Below are my calculations for recharge and pumping…

	small farm	large farm				
acres	30	500				
m^2	121410	2023500				
in/yr	41.2	74.3			Recharge m/day	
in/day	0.112877	0.203562			0.000573414	small farm
m/day	**0.002867**	**0.00517**	51.70466	10.34093	0.001034093	ACME
m^3/day min req.	348.0908	10462.44				
total pumping +20%	417.7089	12554.92				
		6277.462				

Recharge was set as follows in my FloPy code…

```
#Recharge
rech_zone = np.zeros((nrow,ncol))             #define an array of zeros
recharge = 1e-4                       #m/day
rech_zone[:,:] = recharge
rech_zone[8:11,1:4] = 1e-3 # Wildcat Farms
rech_zone[5:, 7:17] = 1e-2 #ACME

rch = flopy.modflow.mfrch.ModflowRch(model=m, rech=rech_zone, ipakcb=53)
```

I applied a net recharge of 1e-4 m/day to the entire model space, as this was given to us as an assumption in the HW description. I then decided to apply an additional recharge to the cells that made up each of the farms. My logic was that the farms wouldn't in reality pump exactly what they need, or less than what they need. They would have to over-pump by some extent. I chose an over-pumping factor of 20%. So I took the total amount required by each farm, based off of the given consumptive use for each crop, and multiplied it by 1.2 to get the new total pumping amounts for each farm. This worked out to be an additional recharge of roughly 1e-3 m/day for the small farm considering the area, and a recharge of roughly 1e-2 m/day for the area of the larger farm. This remained the same for every model iteration and case.

Pumping was set as follows for the base case (case 1) in FloPy…

```
Q_in = -400   #amount calculated based on given consumptive use of cotton
fluxes1 = [0,8,2, Q_in]  #small farm well
Q_in2 = -6000  #amount calculated based on given consumptive use of alfalfa, divided between the 2 wells
fluxes2 = [0, 9, 11, Q_in2]  #northern ACME well, central location
Q_in3 = -6000  #amount calculated based on given consumptive use of alfalfa, divided between the 2 wells
fluxes3 = [0, 19, 11, Q_in3]  #southern ACME well, central location
```

To determine my pumping rates, I took the consumptive use and first converted it to meters/day, then multiplied this by the sq. meters area of each respective farm to get cubic meters per day. These numbers were simplified for the purposes of the model to the above numbers, 400 for the small farm and 6000 for each of the two wells for the ACME farm. I made the assumption that both wells will likely be supplying roughly half of the farm, which also is why I placed the wells where I did in the conceptual diagram above.

Evapotranspiration was set to our default value of 5e-5 m/day as we had used in the other models. This ET was applied to the entire domain for each of the model cases. Every model had an extinction depth of 20m, as I wanted to capture at least the screening depth of the small farms well.

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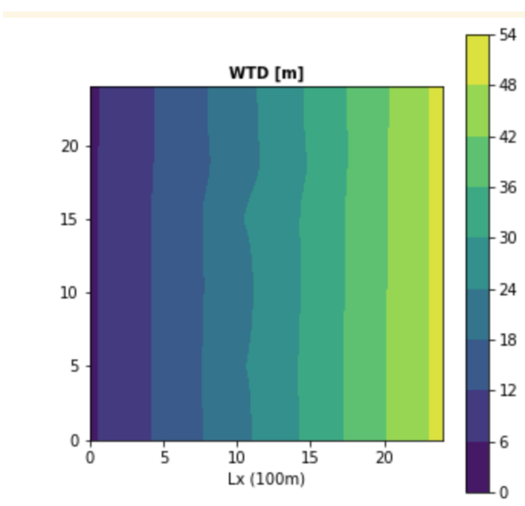
Assumptions:

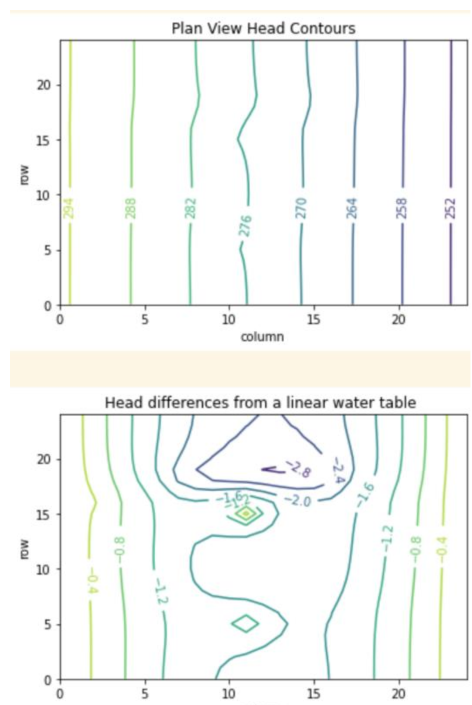
- Three distinct K sections, running parallel to flow in cases 1,2 & 3
- Two distinct K sections running parallel to flow in cases 4,5
- Rounding/simplification of parameters to whole numbers, or to one significant figure
- Over-pumping of each well by 20% of consumptive use need on the farms
- Homogeneity of parameters like ET and porosity and Ss & S
- Constant head boundaries to set water table depth
- Extinction depth of 20m for ET
- Observation wells set boundary conditions
- Flow is steady state
- The consumptive water use for Cotton in Arizona is 41.2 inches/year
- The consumptive water use for Alfalfa in Arizona is 74.3 inches/year
- The net recharge in non-irrigated areas within this area is 1e-4 m/day

Case Presentations & Discussion

Case 1:

In the first case, I wanted to represent the conceptual model I listed at the start of this report. This was what I considered to be the most realistic or likely scenario. I envisioned that ACME would be distributing its wells with no real consideration of impact to Wildcat farms, and have them placed to provide even coverage of one half of the farm each. They are also pumping the exact same amount, 6000 cubic meters per day. This scenario also factors in conductivity as a rough gradient of three sections, as illustrated in the description figure.





Water table depth and head contours and differences for Case 1

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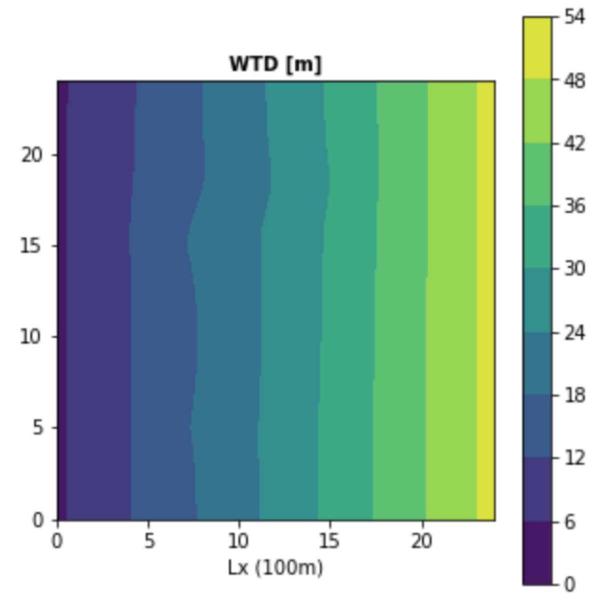
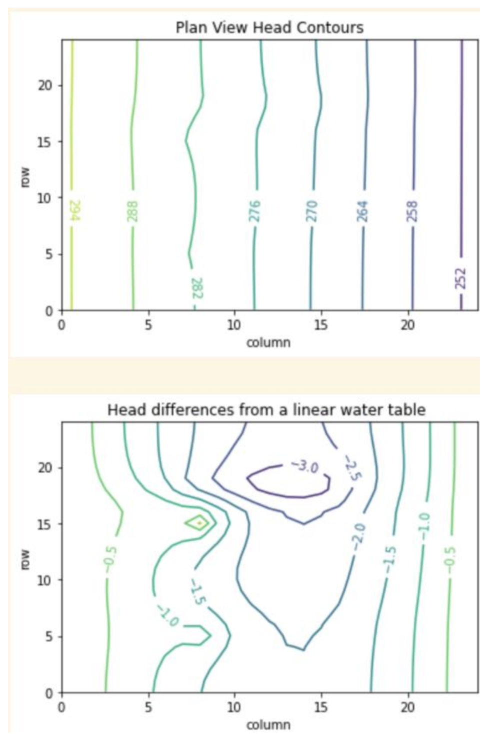
We can see in this case that the Wildcat farms will be unaffected by the pumping done by ACME, as the drawdown isn't enough for the water table to drop below the 20m screen depth of Wildcat's well.

Case 2:

This case is the same as case #1, but the wells are shifted 3 cells to the left closer to Wildcat farm. I ran this case to see if the location of the wells in the y-direction changed the impact to Wildcat farm. Now with the wells as close as possible to the farm in the y-axis, we may see a change to the water table depth. In both cases, the wells are located on the same x-coordinates, and are pumping 6000 m^3.





WTD and head contours/differences for case 2

There isn't a significant difference in WTD between case 2 and case 1, though we can see a difference on the head difference plot. The cone of depression is definitely influencing the western part of our domain more, but it's still not causing any risk of Wildcat farm's well running dry at our steady state solution. In both cases we see greater drawdown in the northern well due to the lower hydraulic conductivity this well is located in.

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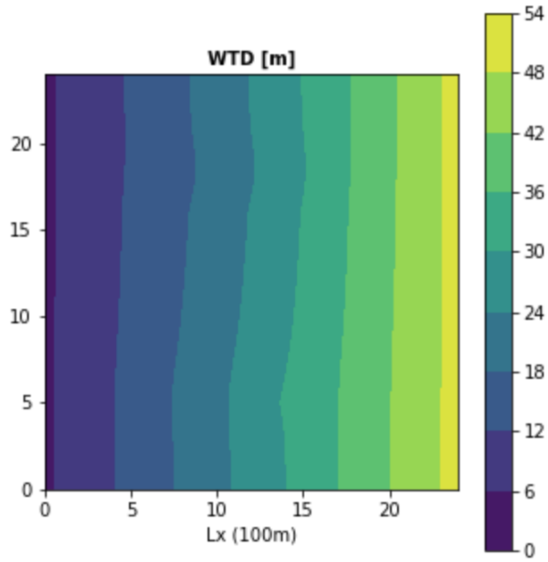
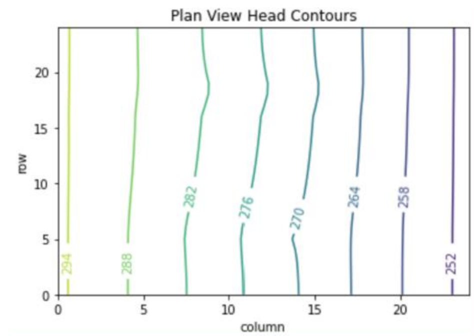
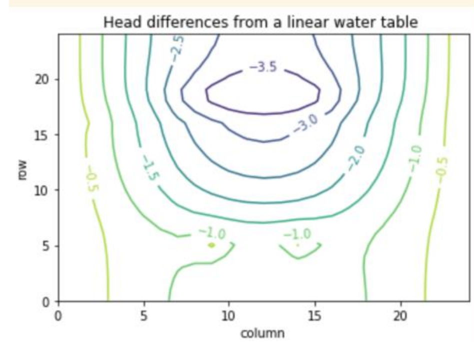
Case 3:

This was the proposed best-case scenario with the gradient K field. It has the same pumping rates for all wells, though the ACME farms wells are both moved to the southern portion of the domain. This would likely be the way ACME would pump water if they had access to the observation well data. They would know that pumping the volume that they need would be more appropriate for this higher conductivity region of our model space. This would have the beneficial effect of moving their pumping as far away from Wildcat Farms as possible.





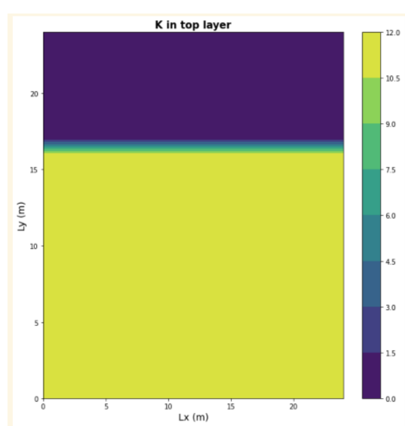


WTD and head contours/differences for case 3

We can see that in this case, there is minimum risk to the farm, as there is little to no distortion in WTD in the area around Wildcat. There is also noticeably less drawdown around each of the larger pumping wells.

Case 4:

Case 4 is identical to case 2, with the exception of the distribution of hydraulic conductivity.



Case 4 hydraulic conductivity plot

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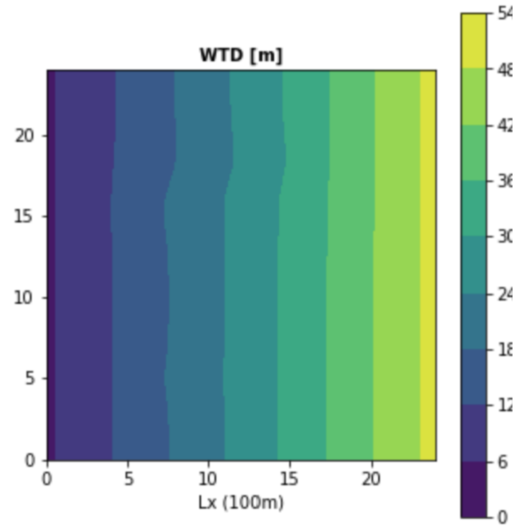
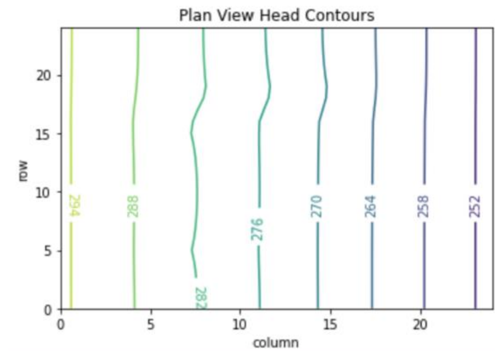
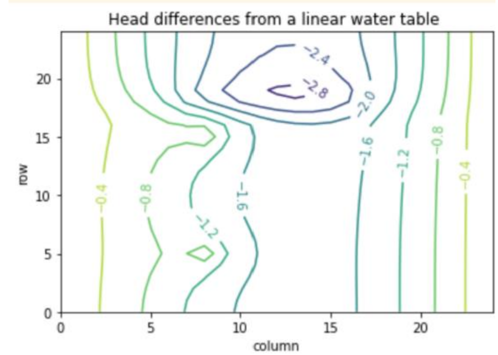
Will the removal of the gradient region in the center of the domain change the results?







WTD and head contours/differences for case 4

We can see that Wildcat Farms is even better off in this scenario than they were in case 2. This model run demonstrates that the higher the K region of the larger farm, the less impact on WTD the pumping will have. Reversing the K distribution would likely have the opposite effect, though I couldn’t get the model to converge when I did this. I don’t know whether this is due to over-pumping or some other issue in MODFLOW.

Case 5:

Our last case is the same K distribution and pumping as case 4, but the ACME wells are both moved to the northern portion of the farm. This would be the likely worst-case scenario for Wildcat Farms.

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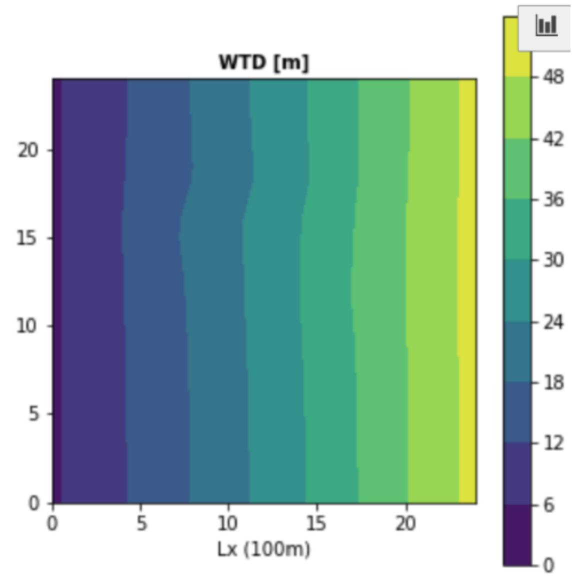

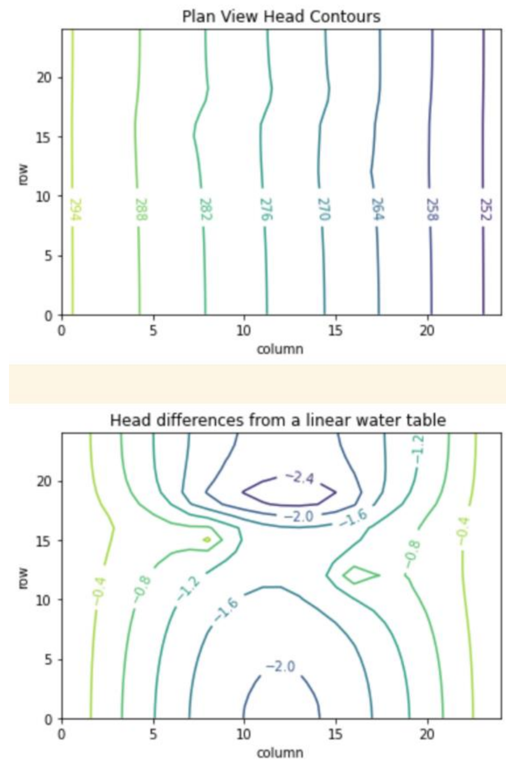

WTD and head contours/differences for case 5

Even in this worst-case scenario, we still don't negatively impact Wildcat farms. This bodes well for Wildcat farms, but only if the higher K region encompasses the ACME farm.

In my other iterations where most of the domain had a K of 1 m/day, the wells could no longer pump this much water without running cells dry. Though, I don't know if this is a MODFLOW quirk, or if this would actually be unsustainable pumping in our modelspace.

My ultimate conclusion is that in order for Wildcat farm to remain in a healthy position, ACME farm would have to distribute their pumping more in the southern portion of their farm, or that the hydraulic conductivity in the ACME region would have to be higher than one, at least 6 m/day, for there to be enough water to sustain ACME's needs while preserving the Wildcat Farm.

This is of course assuming that the dry cells meant that the pumping was unsustainable. There was a very fine line between seeing what I saw in the other models, and suddenly completely drying out a cell. I found this quite confusing and would like to discuss the solutions on Thursday.

I think that the most likely outcome would still be case 1, that ACME would just place their wells to evenly cover their crop, and simply pump evenly from each. This is the simplest and most effective way to meet their needs, and won't effect Wildcat hydraulic conductivity permitting.

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Glossary

1. What does it mean to be simulating saturated flow vs variably saturated flow? What are the advantages and disadvantages of each? Why is it much harder to solve for unsaturated flow? Integrate the concept of a linear versus a nonlinear model into your answer.

   Simulated saturated flow can be represented by Darcy's Law, and is linear in nature. This means that the soil medium is holding as much water as it can, and there is no non-wetting phase present in the model. There is only saturated hydraulic conductivity that needs to be taken into account. This is much simpler to compute and can usually be solved algebraically. However, this often isn't the reality underground… Darcy's Law cannot be used to accurately determine flow in the vadose zone, only beneath the groundwater table.

   Variably-saturated systems introduce a new aspect, a non-wetting phase in addition to the wetting phase (water). This makes things very complicated mathematically, as not you have to account for a non-linear relationship between the wetting and non-wetting phases hydraulic conductivity (intrinsic permeability). Richard's equation must be used in this case, which is a non-linear differential equation. This is much more computationally intensive, and often requires and iterative solution process. This iterative nature can often introduce error in final results, and sometimes solutions don't converge at all. It does allow you to model flow in the vadose zone and account for things like contaminant transport in soils.

2. What is meant by an internal source/sink for ground water flow and how is it different than a boundary condition? Give an example.

   An internal sink is something like a pumping well, its wherever water is being removed or from or injected into your model in a place other than your boundaries. A boundary condition might be set to constant head, but the well doesn't really see that, it will pump the same amount of water regardless. In fact, the boundary conditions usually cause the model to change in response to a sink or source incorporated into the model.

3. What is meant by 'forecast uncertainty' in the context of a groundwater model? What are the sources of this uncertainty? What is required for a prediction to be as robust as possible?

   It's a measure of inaccuracy within the model itself, and consequently the results you get as an output of your model. A potential source of this uncertainty could be model resolution, inaccurate model input parameters like K, simplifications made to numbers like rounding or significant figures, and generally incorrect assumptions about your model that don't represent reality. For a prediction to be as robust as possible, it is crucial that reasonable assumptions are made that are truly representative of your modeling area. Of course you'll never have all the knowledge you want, but an educated guess must be made.