Dear Wildcat Farms,

We here at BSBS consulting firm have completed our assessment in regard to whether your well will go dry from ACME farms pumping. Using Modflow, we chose a grid resolution of 100m x 100m x 1000m. We believe that this represented a system of reasonable resolution, and we are also aware that your farm sit ontop of a 1000 m thick aquifer.

Our assumptions we made for this model are as follows:

- We assumed that the hydraulic head gradient in the y direction was small so that the major direction of flow was in the x direction. This appeared reasonable based on the water table depths presented in the four observation wells.
- We assumed that the efficiency of cotton was 80% and that the efficiency of alfalfa was 85% based on online sources. Therefore, we assumed that the runoff from each crop resulted in additional recharge over their irrigated land.
    - Total Water Needed = Consumptive Use/Efficiency Rate
        - X(80%) = 0.0028
        - X = 0.0035 m/d
    - Excess Irrigation = Total Water Needed – Consumptive use
        - 0.0007 m/d = 0.0035 m/d - 0.0028 m/d
    - Therefore, based on your 30 acre of land we calculated an excess irrigation rate of 0.0007 m/d
    - For ACME farms we calculated an excess irrigation rate of 0.0008 m/d.
        - X(85%) = 0.0052m/d
        - X = 0.006 m/d
        - EI = 0.0052m/d – 0.006m/d = 0.0008 m/d
- We assumed a background evapotransiration rate over the entire domain of 0.00005 m/d. This represents an arid area.
- Alfalfa roots can penetrate 20 feet deep, therefore we assumed an extinction depth of 6m across the domain, which is a conservative estimate.
- The consumptive water use for Cotton in Arizona is 41.2 inches/year which converts to 0.0028 m/d. Therefore, your pumping rate for a 30-acre piece of property is 0.0028 m/d *300m * 300m = 252 m3/d.
- The consumptive water use for Alfalfa in Arizona is 74.3 inches/year which converts to 0.0052 m/d. Therefore, ACME farms pumping rate for a 500-acre piece of property is 0.0052 m/d *1000m * 2000m = 10400 m3/d.
- The net recharge in non-irrigated areas within this area is 1e-4 m/day

We assumed a constant head for our left and right boundary conditions. This was based on the 4 observation wells located around your property.

We have provided 3 scenarios for you, a representative case, better case, and worse case for your review. Here is a table depicting their differences.

Scenario	Case	Differences
1	Representative	• Four separate K values split into 4 quadrants • ACME farms pumping in the lower half of the domain
2	Better	• Two K values split horizontally down the middle • ACME farms pumping in the lower half of the domain
3	Worse	• Homogenous high K (12 m/d) for entire domain • ACME farms places one of their wells as close as possible to Wildcat Farms and pumps at near maximum rate. • The second well pumps minimally

Best/Worse Scenarios

Neither of the other outcomes were very different from the representative outcome. We don't believe that either of these scenarios are any more likely to happen or not happen than the representative scenario.

Most likely Outcome

From our three scenarios that we present to you, none would cause the water table to drop below 20 m for your farm. We believe that the most likely outcome is that your farm will have no problem, ever.

In conclusion, you seem to have picked your farm location perfectly! You appear to neighbor an unlimited aquifer immediately west of your property that can feed your crops and ACME crops nearly indefinitely. Please refer to the following pages to review our outputs from out modeling.

Sincerely,

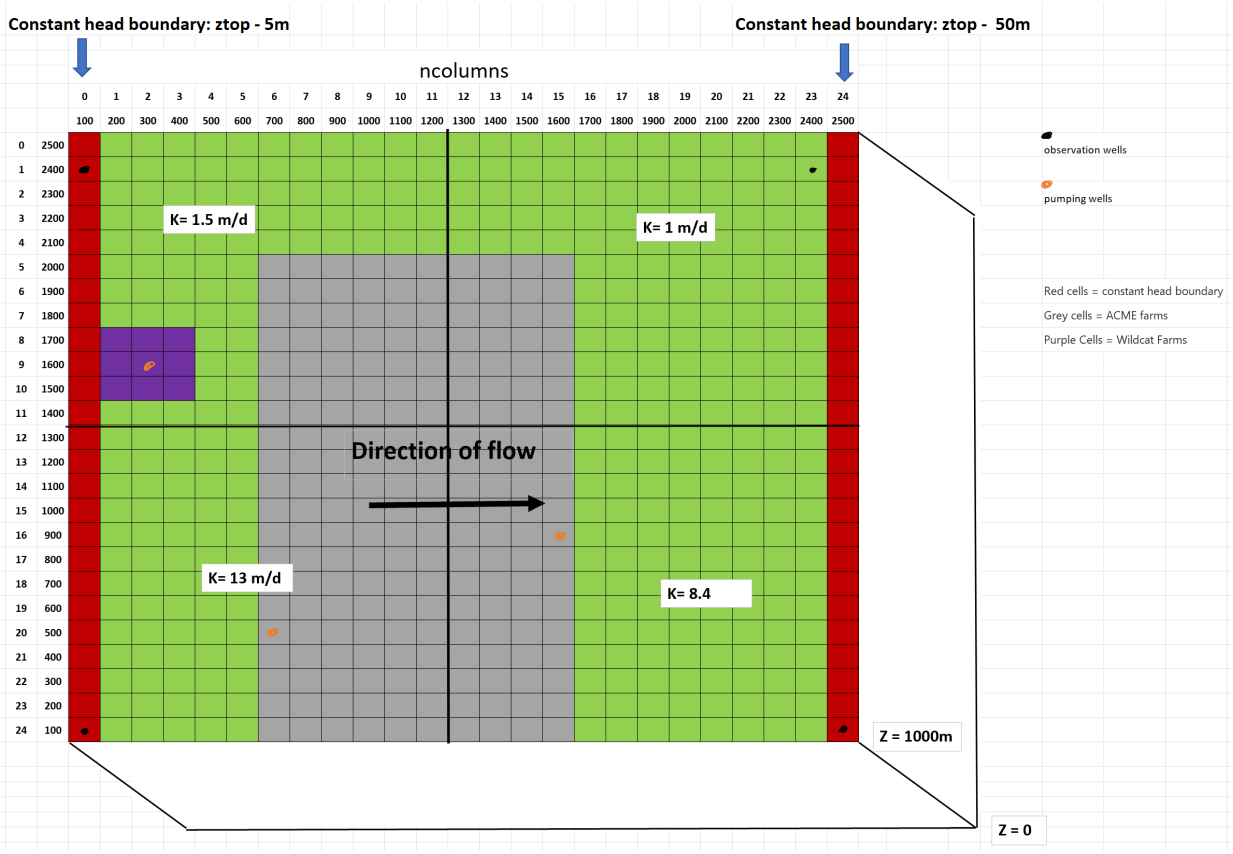
BSBS Consulting

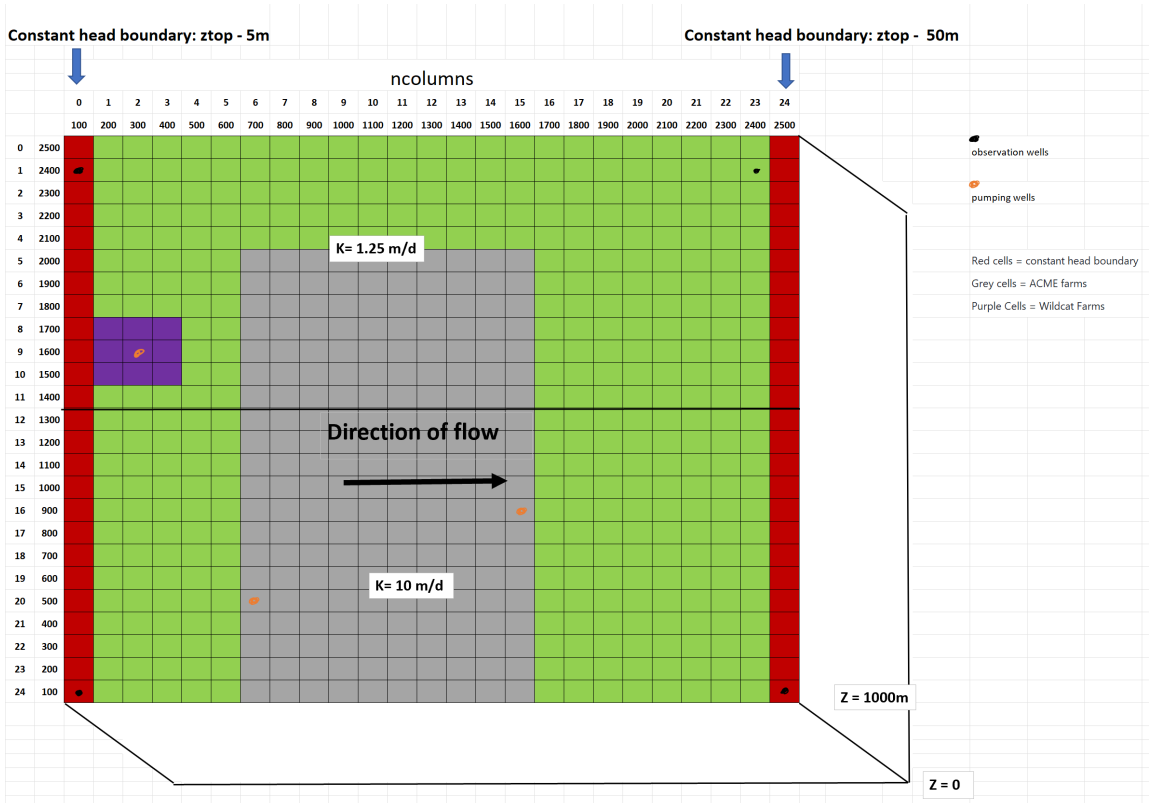
P.S.

Please note, if the aquifer that your farms sit ontop of is 600 feet or less, ACME farms will create a cone of depression large enough to deplete the entire domain. Further, if ACME farms drills any wells in areas of low K, they will drain the entire domain (dependent on their pumping rate). We assumed that ACME farms would like to draw water from areas of high K, and therefore did not create scenarios where the model would fail.

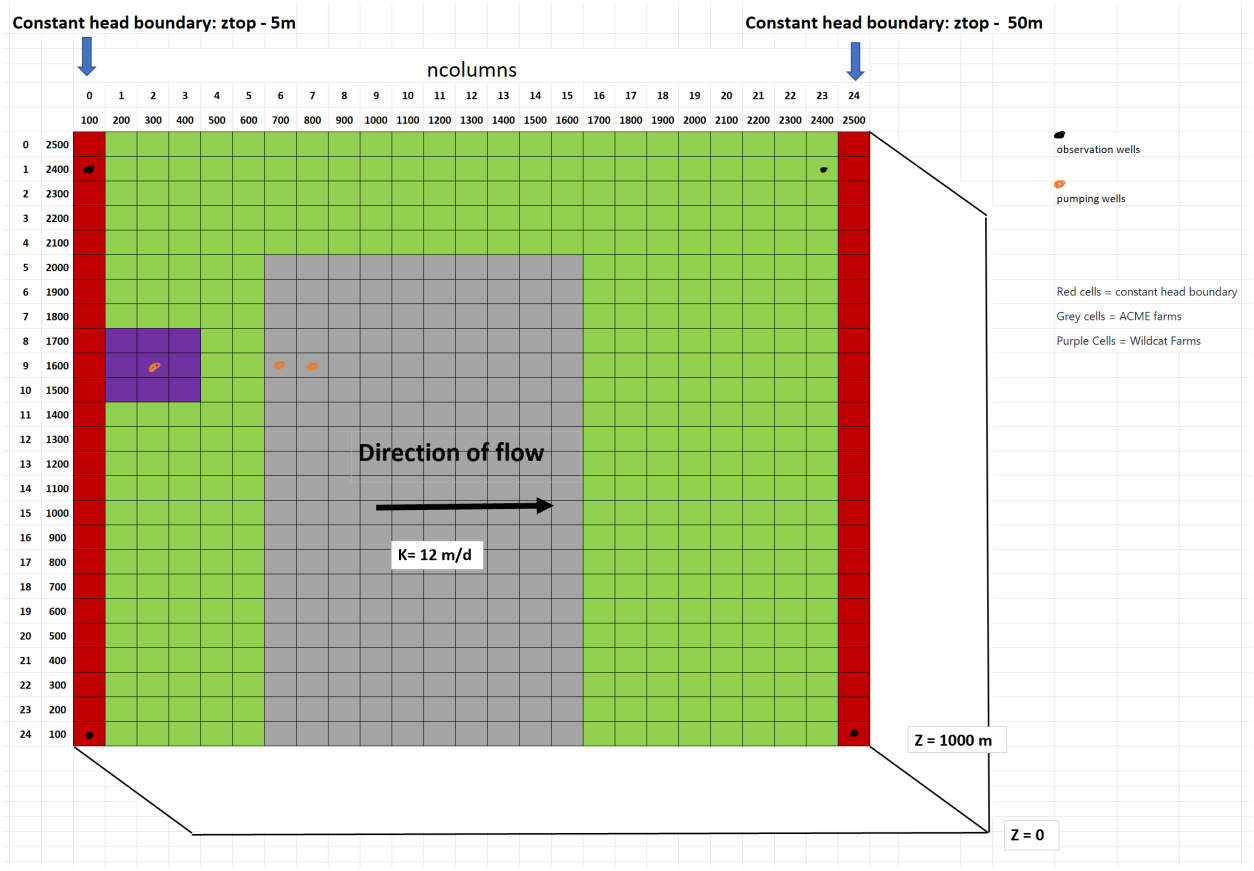
Conceptual Diagrams

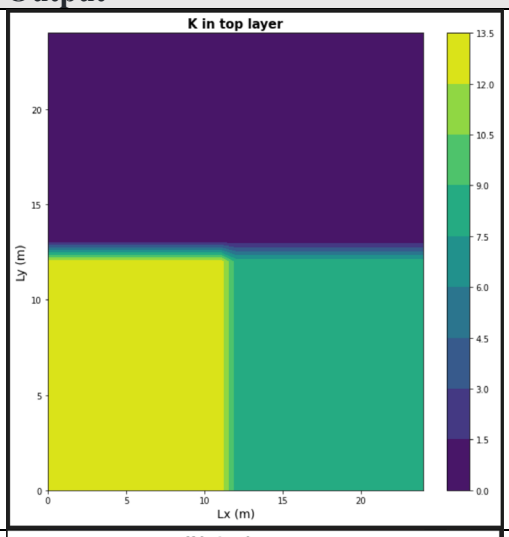
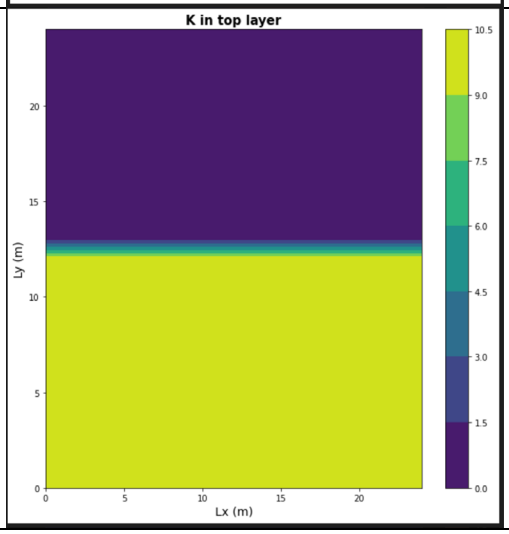
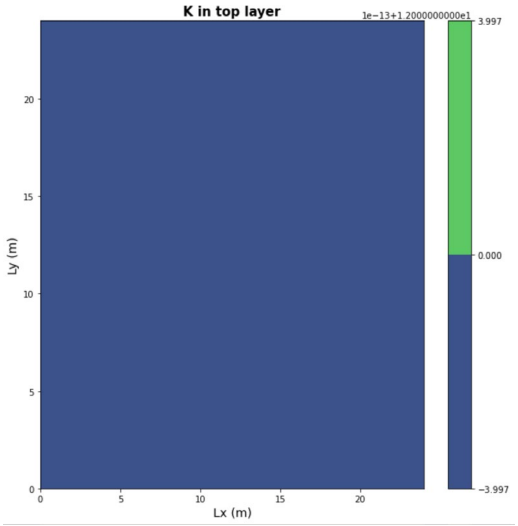
Most representative Case

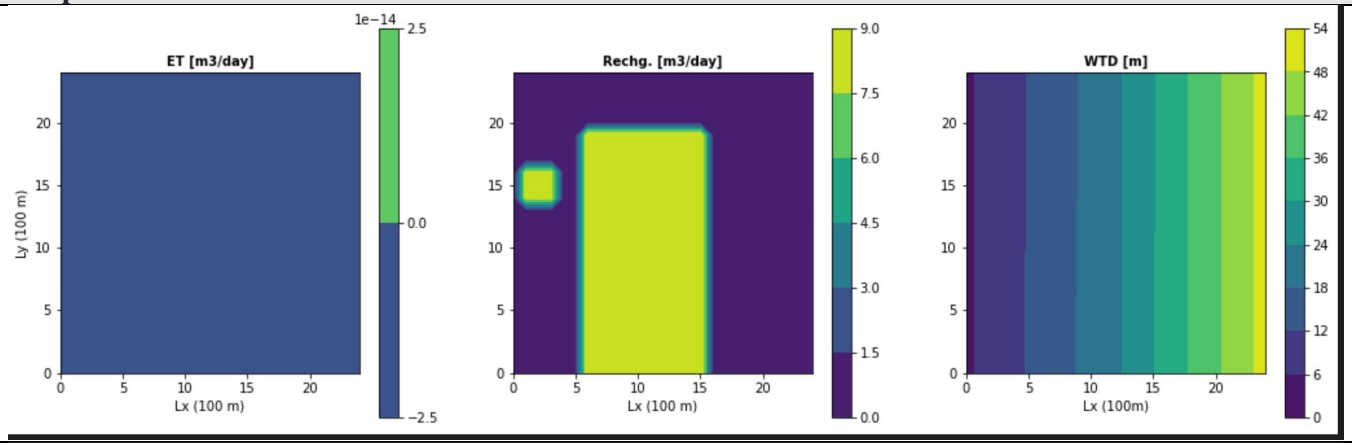
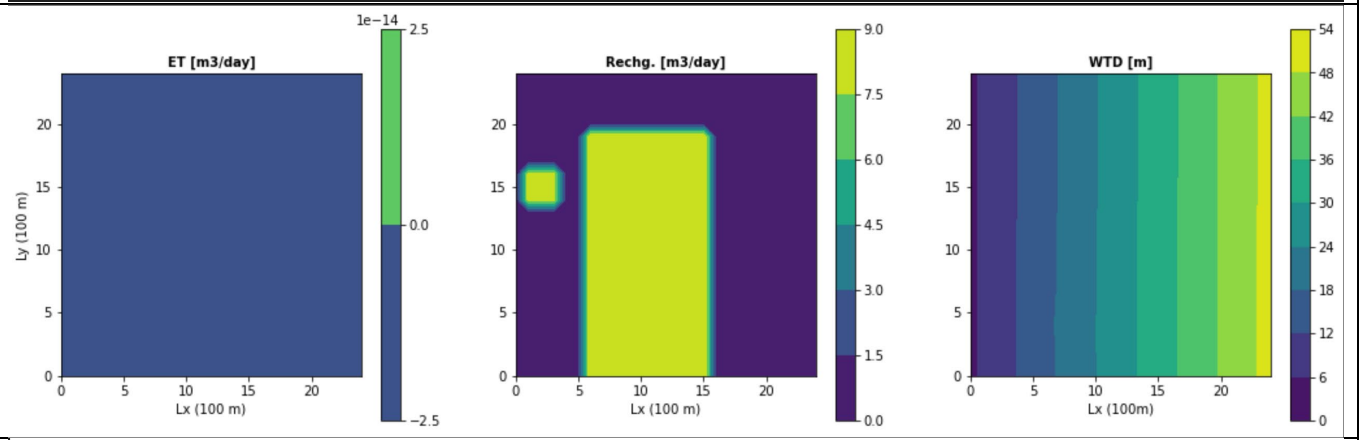
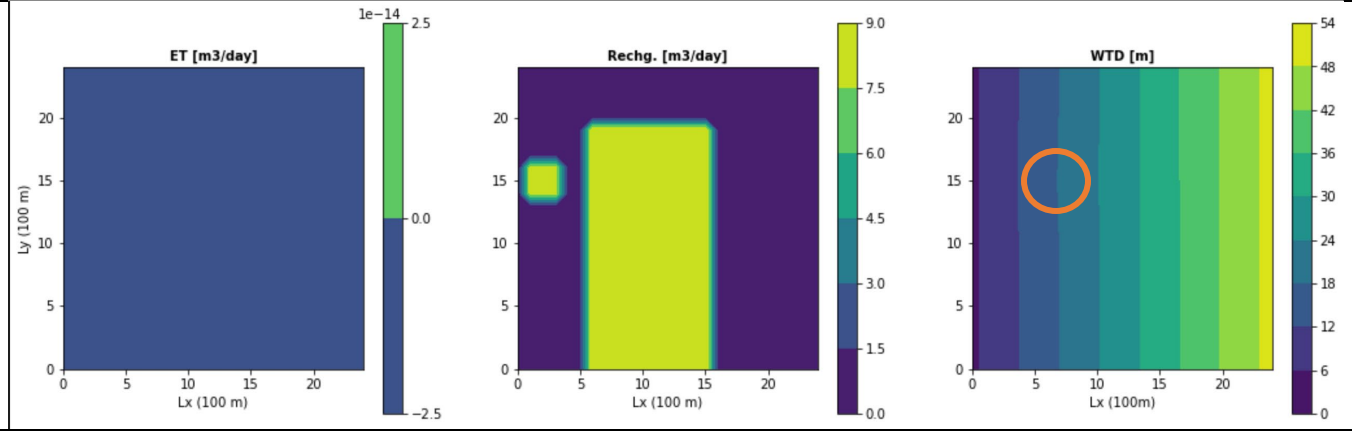


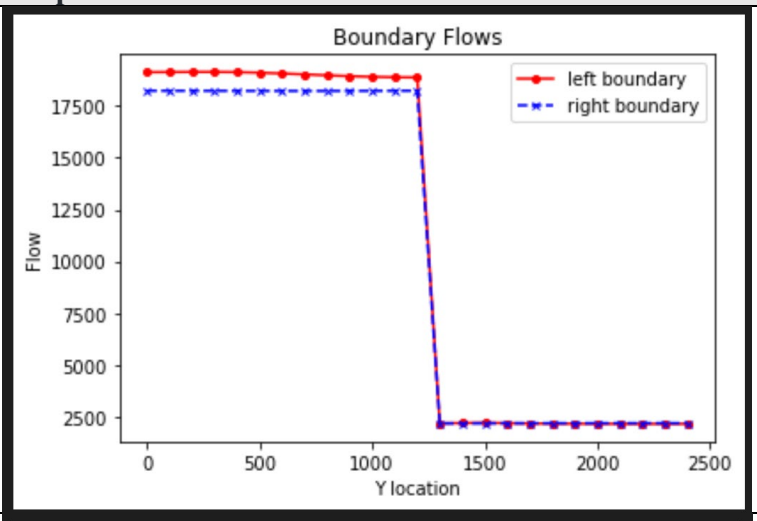
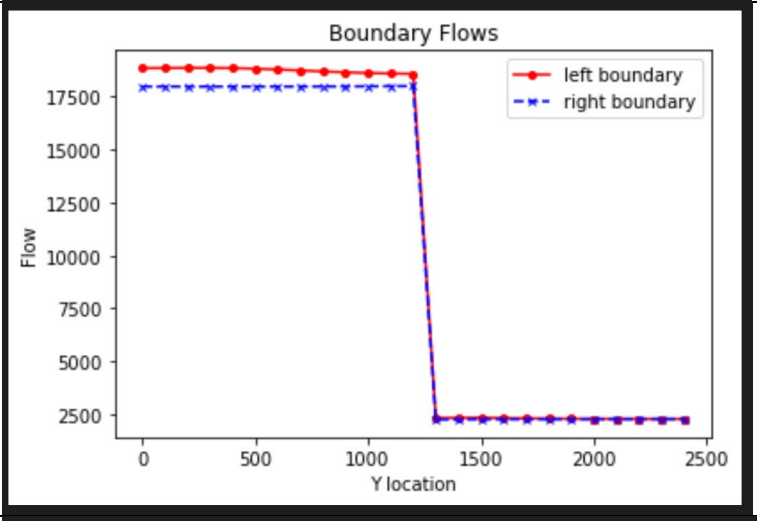
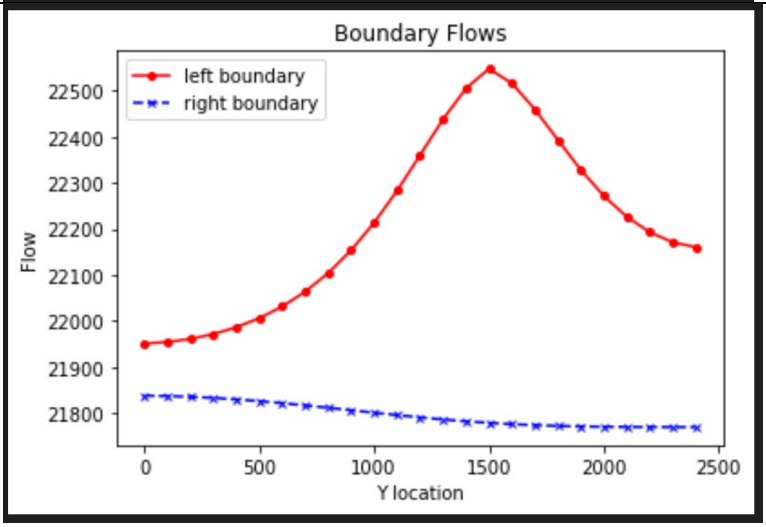


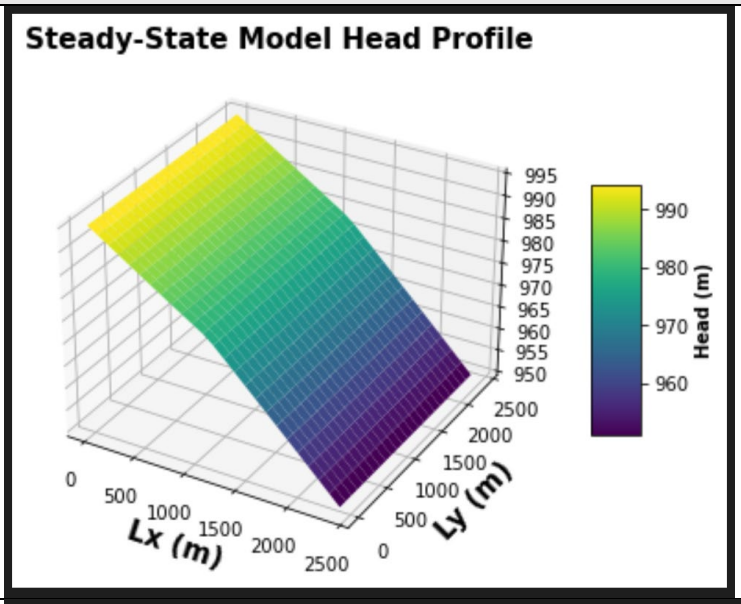
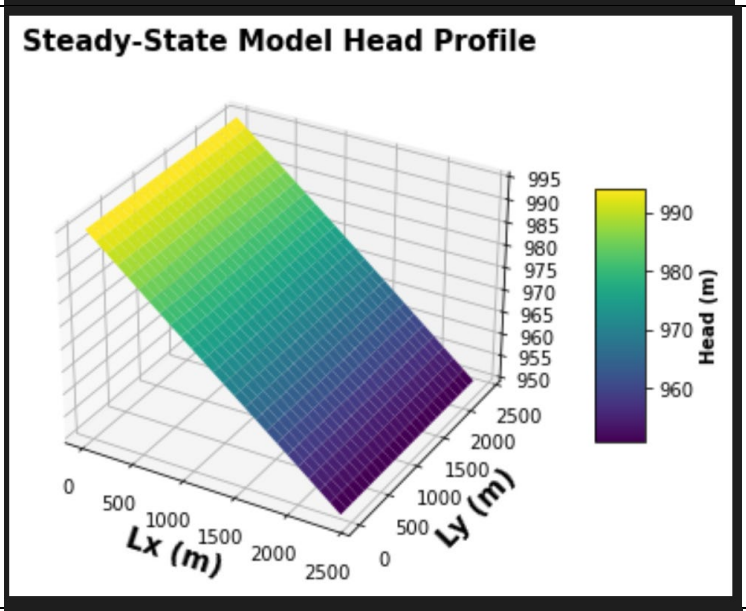
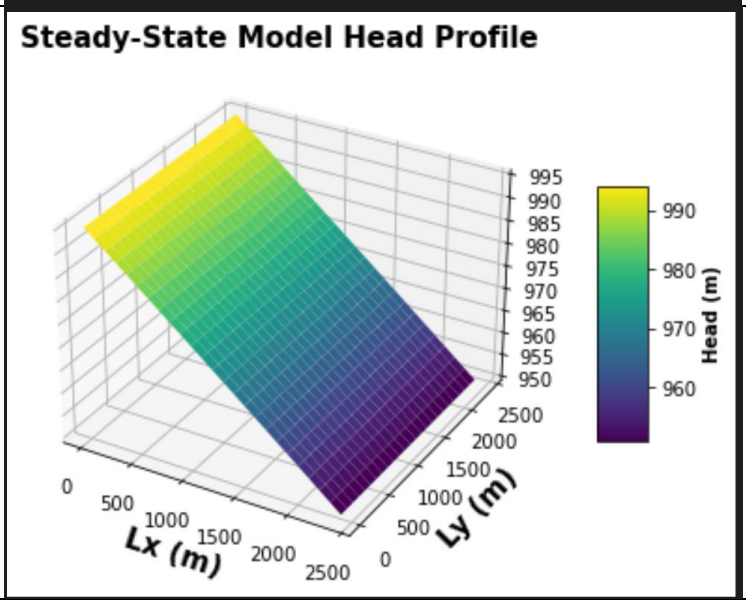
Worse Case

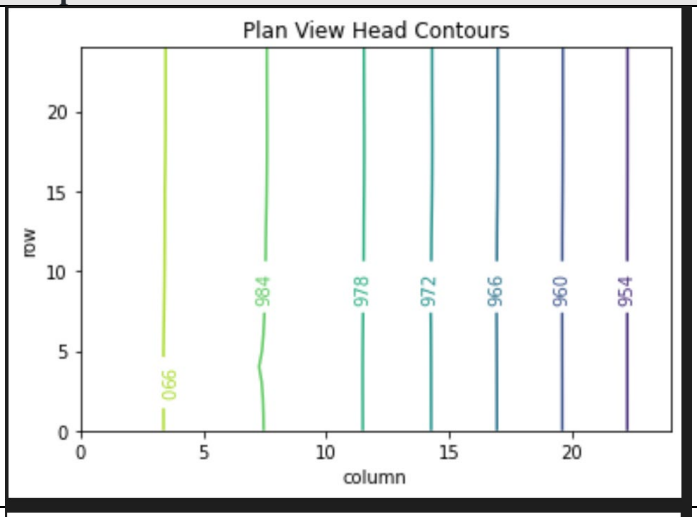
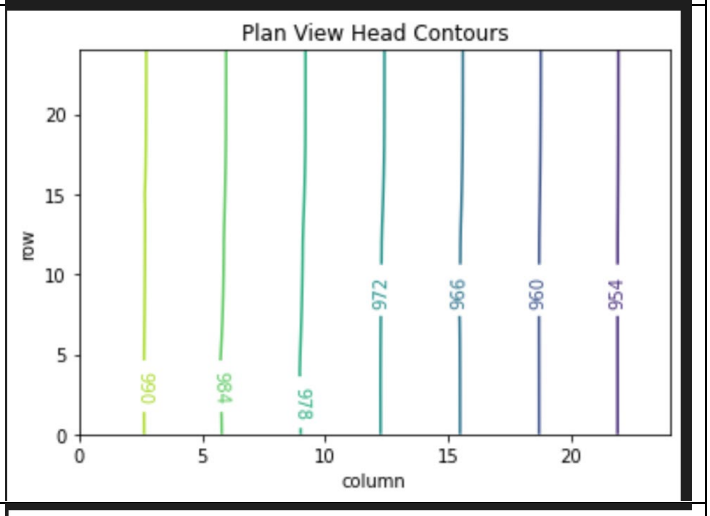
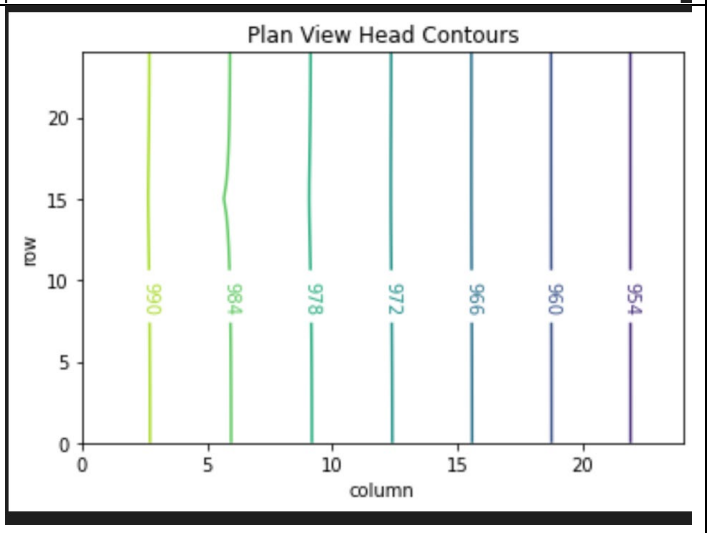

Constant head boundary: ztop - 5m
Constant head boundary: ztop - 50m
ncolumns
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500
0 2500
1 2400
2 2300
3 2200
4 2100
5 2000
6 1900
7 1800
8 1700
9 1600
10 1500
11 1400
12 1300
13 1200
14 1100
15 1000
16 900
17 800
18 700
19 600
20 500
21 400
22 300
23 200
24 100
Direction of flow
K= 12 m/d
Z = 1000 m
Z = 0
observation wells
pumping wells
Red cells = constant head boundary
Grey cells = ACME farms
Purple Cells = Wildcat Farms

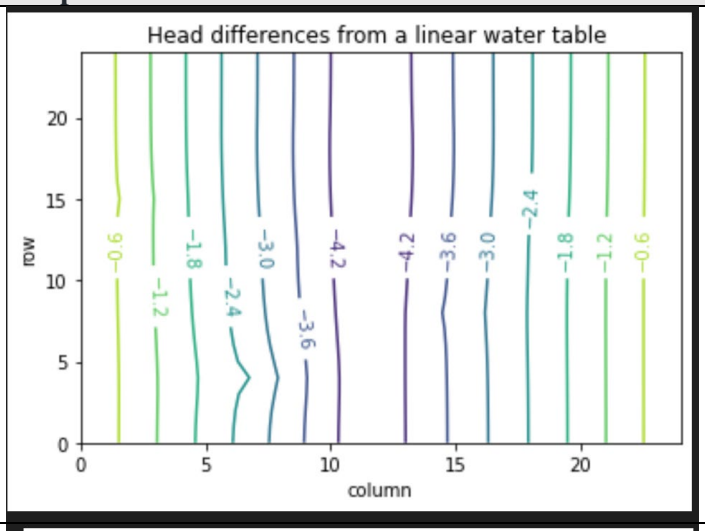
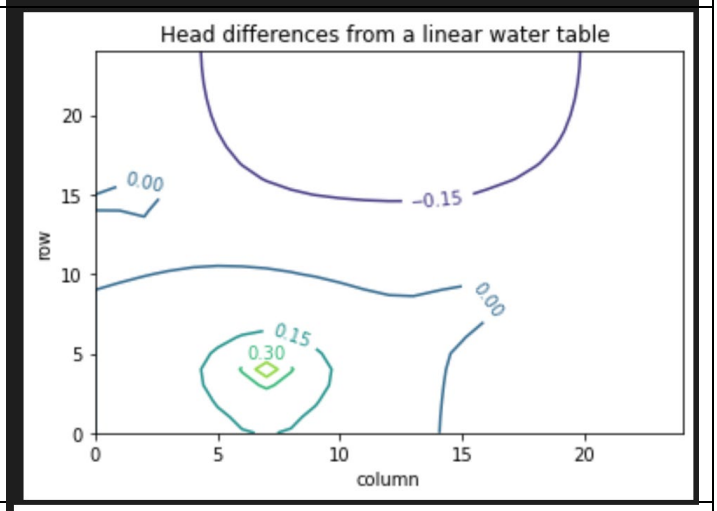
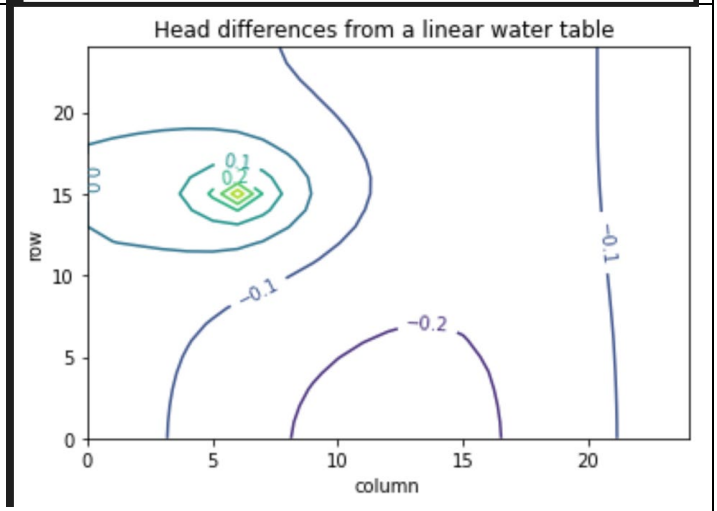
Case	Output	Explanation
Representative		• These 3 graphs show how the K fields differed between runs • The most representative case was 4 different K fields determined by the observation wells • The better case was having only 2 K fields with the top half averaged using the observation wells in the top quadrant and the bottom half averaged using the observation wells in the bottom quadrant. • The worse case was a high K value (12 m/d) used for the entire domain.
Better		
Worse		

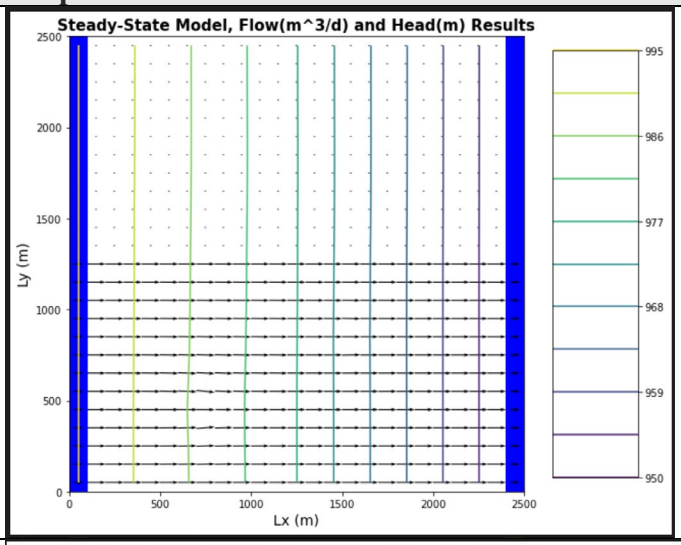
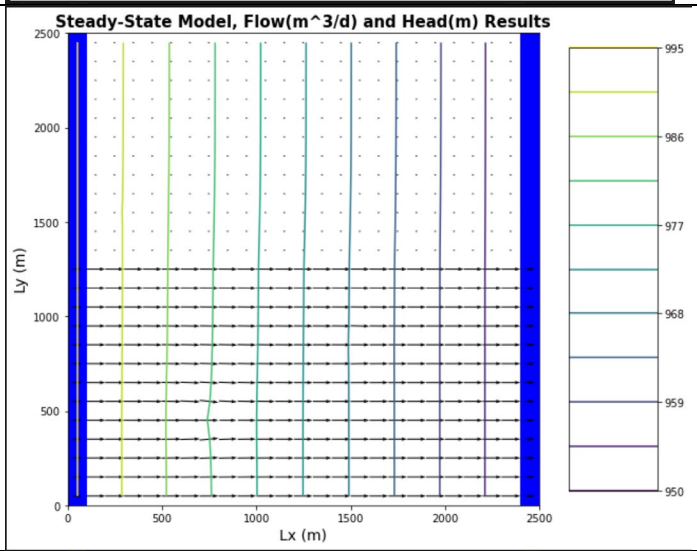
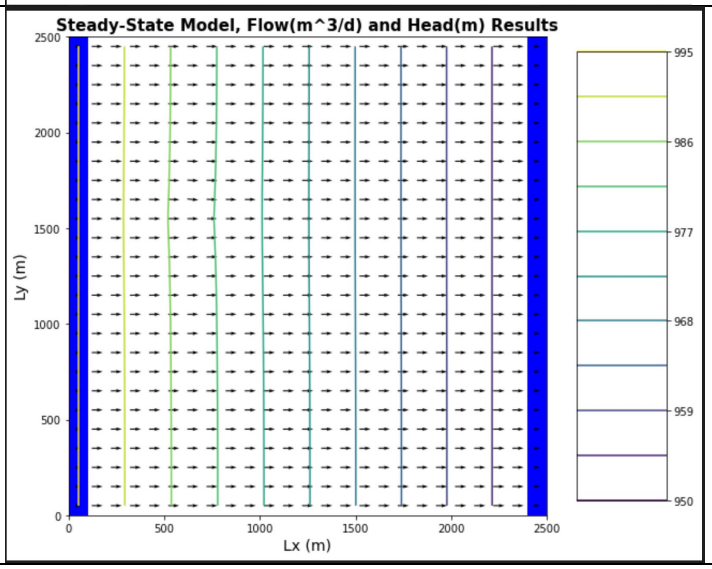
Case	Output	Explanation
Rep.		• These 3 graphs show the ET rate, recharge rate, and Water table depth. • Our ET and recharge rate were never changed between scenarios, so their outputs remain the same. • The WTD graph shows only minor differences, even in the worse case where there was a pump pumping 12,117 m3/d 300 meters from wildcat farms. • A circle has been added that shows the main difference in the worst-case scenario • Wildcat farms WTD never drop below 6-12 m.
Better		
Worse		

Case	Output	Explanation
Representative		• These three graphs show the boundary flows • There is little to no difference between the rep. case and better case. This is because the pumping wells did not change location and therefore the boundary flows did not change either. We see high flux from 0-1200 m in the Y location because that is where there was high K. Then we see low flow from 1300 to 2400 m where there is low k. • The worse case had a high flow exactly where ACME farm was pumping 12,117 m3/d (i.e., at 1600 m at the Y location).
Better		
Worse		

Case	Output	Explanation
Representative		• These 3 graphs show the head profile along our domain. • We see that there is very little difference in our head profile, no matter where the pumping is happening at the rate at which pumping is occuring. • This was a “problem” I noticed. Either the model would break, or else there would be very little change in head.
Better		
Worse		

Case	Output	Explanation
Representative		• These 3 graphs show the plan view head contours. • We can see some minor effects of pumping in the rep case and the worse case. • Overall, very little change is noticed between the graphs.
Better		
Worse		

Case	Output	Explanation
Representative		• These 3 graphs show the head differences from a linear water table • These graphs are the only graphs that really show clear differences in pumping (in my opinion) from the 3 scenarios. • The representative case we see that there is low head in the middle from the two pumps at ACME farms pumping • The better case we see some small head differences from the pumping at ACME farms as well as at Wildcat farms (though the difference is labeled “0.00” at Wildcat farms….) • The worse case clearly shows where ACME is pumping close to wildcat. It appears that they pump so much that they tap into the boundary condition and therefore have no issues pumping at such a high rate.
Better		
Worse		

Case	Output	Explanation
Representative		• These 3 graphs show the flow in our system • The representative case and better case are essentially the same. This makes sense since the averaged K values and the 4 separate K values are pretty close overall. • The worse case had a high K everywhere so flow occurred more evenly throughout our system.
Better		
Worse		

Glossary questions

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.

    - Saturated flow is a system where there is only 1 fluid present (typically water). Variably saturated flow may have more than 1 fluid (typically water and air). Saturated flow is easier to solve as we can use Darcy's Law and it is a linear equation. With unsaturated (or variably saturated flow) we must use Richards equation or other more complex formulas to solve the flow and it requires use of nonlinear equations and models.

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.

    - Boundary conditions are what occur at the boundaries of our transport domain and need to be specified for each process that is simulated. An internal source/sink is a process occuring inside our model. Examples: BC- constant head or inactive cells at the edges of our model. Source/sink- Wells drawing water from inside of our domain boundary.

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?

    - Forecast uncertainty is the error associated with a forecast prediction. Therefore, forecast uncertainty in a groundwater model would be the assumptions we make in our model to predict some feature of our groundwater system. To make a prediction as robust as possible we would want to make as few assumptions as possible. For any assumptions we do make, they should be based on the best information available.