Dear Wildcat Farms,

We here at BSBS consulting firm have completed our assessment of 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.
* 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 the crops resulted in additional recharge over the irrigated land.
  + Total Water Needed (Efficiency Rate) = Consumptive Use

Total Water Needed = Consumptive Use/Efficiency Rate

* + Excess Irrigation = Total Water Needed – Consumptive use
  + 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.
* 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
* The consumptive water use for Alfalfa in Arizona is 74.3 inches/year which converts to 0.0052 m/d
* The net recharge in non-irrigated areas within this area is 1e-4 m/day

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

We have provided 3 scenarios for you, a representative case, worst case, and better 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 |

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

**A picture containing chart

Description automatically generated**

Better Case

**A picture containing bar chart

Description automatically generated**

Worse Case

**Graphical user interface

Description automatically generated**

|  |  |  |
| --- | --- | --- |
| **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 * 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 flow * 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** |
| **Case** | **Output** | **Explanation** |
| Representative | Chart, surface chart  Description automatically generated | * 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 | Chart, surface chart  Description automatically generated |
| Worse | Chart, surface chart  Description automatically generated |

|  |  |  |
| --- | --- | --- |
| **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 evidence of pumping (in my opinion). * 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 of constant head or inactive cells at the edges of our model. Wells drawing water out at the center of our domain.
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. I think therefore forecast uncertainty in a groundwater model would be the assumptions we make un 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 and the assumptions we do make should be based on the best information available.