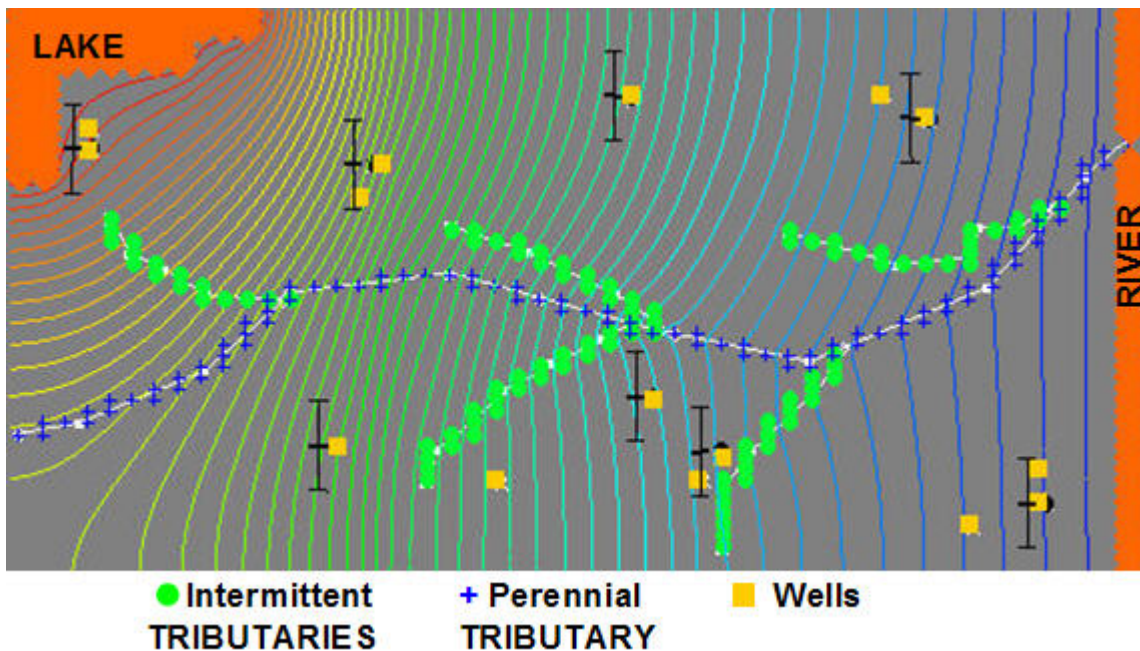


## INTRODUCTION TO GROUND WATER MODELING

This lab is intended to familiarize you with running MODFLOW 2000 within the Graphical User Interface (GUI) Groundwater Modeling Systems (GMS) and interpreting MODFLOW 2000 output files. The models you will be working all represent the same area. A lake is located in the Northwest corner of the model and a tributary runs ~west to east through the center portion of the model terminating in a large river on the east. The lake and the large river are considered to have a sufficient supply of water and capacity for drainage that they can be represented with constant heads. The land surface slopes toward the eastern edge of the model.

Gold squares represent wells, some are pumping, some a not used, and some are wells for monitoring water levels. At the monitor wells, the measured heads are specified as the head under the prevailing conditions with a 95% confidence interval of 10ft (this is indicated by the upper and lower limits of the error bars). Given the current model setup, the measured water levels match the modeled water levels as indicated by the narrow black error bars. If the simulated head differed from the observed a colored bar would appear. If the simulated head was lower then the observed the bar would drop down from the center, otherwise it would be above the center. If the difference was  $\leq$  the 95% intervals the bar would be green, if the difference was greater than that but less than twice that it would be yellow and beyond that it would be red.



## SECTION I

Go to the Model folder and double click on the file Model.gpr. The GMS (Ground Water Modeling System) GUI (Graphical User Interface) should open up this file and you should be looking at a plan view of the model similar to the image above. Get yourself familiar with the model and GMS. Look at the upper left menu and click on the Display | MODFLOW tab to identify the boundary conditions.

Always keep an untouched master copy of your modeling work as it progresses because there is not an undo button in GUIs and if you change something you may not be able to get the model back to its original form.

Set Recharge to a constant value of 0.0001 ft/day. Recharge Scenario (A)

- 1) If not already in the 3D grid module, switch to 3D Grid module (see the lower left bar and note that placing the cursor on any icon will reveal a descriptor of its function).
- 2) In the side bar on the left, open up folders 3D grid data | MODFLOW | RCH | RCH Rate (double click on RCH Rate)
- 3) Select the constant array button
- 4) Enter a value of 0.0001 ft/day (likely it is already set at this value but now you know how to change it later). Note that in MODFLOW recharge is applied only to the active cells. It is not applied to constant head cells (can you surmise why?) nor is it applied to inactive cells (there are no inactive cells in this model).
- 5) Select the OK button
- 6) Switch to the map module (this is the compass on the lower left bar)
- 7) On the upper left menu select Feature Objects | map -> MODFLOW command and say OK to All applicable coverages (this creates the text files required to run the USGS MODFLOW code)
- 8) Switch the Model back to 3D Grid module.
- 9) Save the model (File | Save)

10) From the MODFLOW menu, select run MODFLOW. (An iterative solution to steady state is calculated for the specified properties and recharge rate)

11) Note the resulting heads

12) Have a look from an oblique view using Display | View | Oblique

13) Go back to the plan view

14) Evaluate the budget by selecting Data | Flow Budget. Notice the inflow from constant head cells is from the lake in the northwest and the outflow is to the river. One deduces that from the head pattern but we can confirm it by closing the budget window, clicking on the select cells icon near the top of the icon bar to the left of the map, and drawing a rectangle around just one group of constant head cells or the other and again listing the budget. This budget does not account for ground water flow through the grid where you arbitrarily cut the model so it appears that mass is not balanced, however it is useful for isolating budget terms by zone. You will see this unaccounted water as flow out of the right or bottom and so on depending on the selected cells. Take note of how much ground water is flowing to the river on the right.

**Question 1)** What is the total volume of water entering the system,  $\text{ft}^3/\text{day}$ ? How does this water enter the system and what are the relative volumes ( $\text{ft}^3/\text{day}$ ). Is the river gaining or losing?

**Question 2)** Using the total volume applied through recharge, what is the Effective Uniform Depth (EUD) applied over the entire area of the system  $\text{ft}/\text{day}$ ,  $\text{ft}/\text{yr}$  and  $\text{in}/\text{yr}$ ?

**Question 3)** Is this value different than the constant value you applied to each cell, why? Shouldn't they be the same? Because checking that the output of your model makes sense is one of the single most important things to being a good modeler, check your values and justify them mathematically.

**Question 4)** What is the total volume of water exiting the system,  $\text{ft}^3/\text{day}$ ?. How does this water exit the system and what are the volumes ( $\text{ft}^3/\text{day}$ )? Identify each item in the model.

**NEXT: Set Recharge to constant value of 0.001 ft/day, Recharge Scenario (B)**

**Question 5)** What is the total volume of water entering the system,  $\text{ft}^3/\text{day}$ . How does this water enter the system and what are the relative volumes ( $\text{ft}^3/\text{day}$ ).

**Question 6)** What is the total volume of water exiting the system,  $\text{ft}^3/\text{day}$ ? How does this water exit the system and what are the relative volumes ( $\text{ft}^3/\text{day}$ ). Explain where these features are in the model.

**Question 7)** Why are the models different?

**Question 8)** Besides the obvious that more water is entering the system, why is there this difference?

Think of Darcy's law! Recall the Dupuit model for flow between fixed heads.

**Question 9)** What happens to the error bars and why?

**NEXT: Set Recharge to constant value of 0.05 ft/day, Recharge Scenario (C)**

**Question 10)** What happens if recharge is increased to 0.05ft/day? What are those blue symbols?

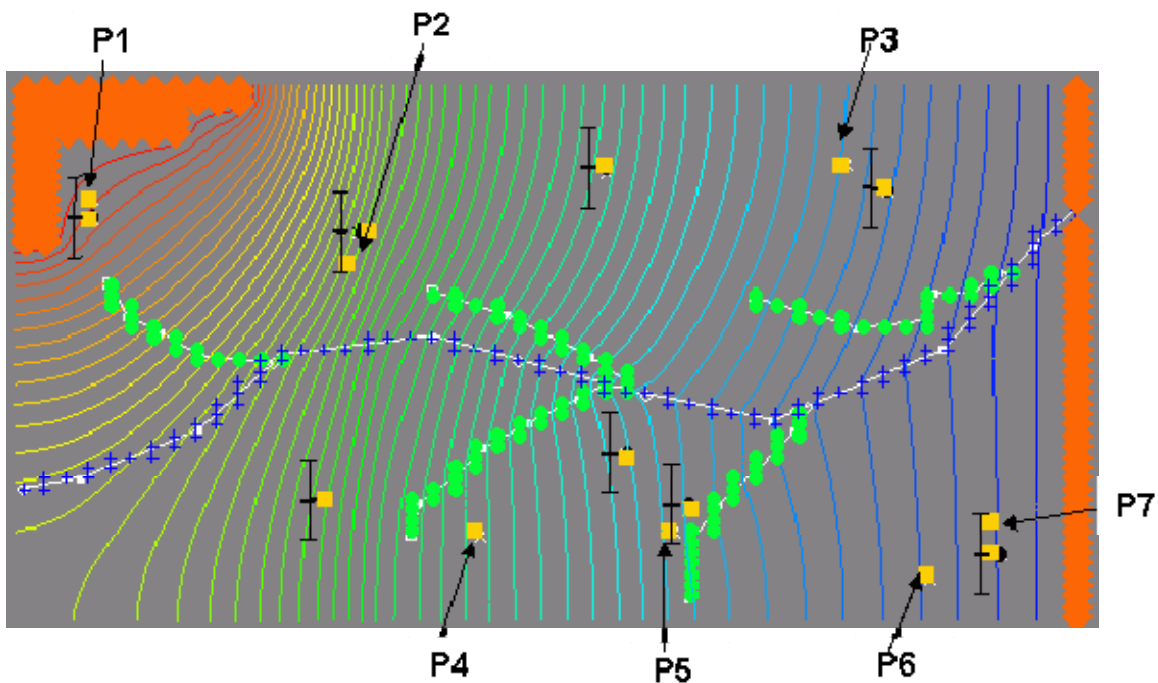
Viewing from the side may help.

## SECTION II

Continue with the same model but reset parameters to those you started with. If you have only made changes as indicated above then you simply need to set the recharge back to 0.0001ft/day and rerun MODFLOW.

- 1) Switch to the Map Module (lower left bar).
- 2) Open the Map data and go to the SourceSinks layer
- 3) The yellow boxes represent wells. Using the Select Points / Nodes tool active (an icon on the bar to the left of the map), double click on any of the wells and view the pop up window. If you double click on the well and nothing happens then you are most likely either not in the Map Module or you are not using the Select Points / Nodes tool. A descriptor appears when you place your cursor over the tools. (Note you could alter the properties of the river or drains by using the select arcs tool and double clicking on an arc. To change the boundary conditions on such features, one would make the Points / Nodes tool active and select the nodes at the end of an arc. Intermediate values are linearly interpolated.)
- 4) In the pop up window for the wells you will see a name for the well and also the flux. Some are named P# and currently have zero flux, while others are named c# and have a -250 flux value. The latter are small community wells providing water for domestic use.
- 5) Under the Source/Sinks folder in the left side bar, select the Observation Wells Coverage. The community wells have been assigned observations. As described earlier, the observed head is specified as the head under the prevailing conditions with a 95% confidence interval of 10ft. We can see that the simulated and observed heads match because the center of the error bar is a narrow black line. If the simulated head differed from the observed a colored bar would appear. If the simulated head was lower then the observed the bar would drop down from the center, otherwise it would be above the center. if the difference was  $\leq$  the 95% intervals the bar would be green, if the difference was greater than that but less than twice that it would be yellow and beyond that it would be red.

6) The production wells are on parcels of land owned by a company that plans to build a factory by the river in the east. Their locations are marked on the figure below. The factory requires 26,000 cubic feet of water per day). Water rights are such that the factory is not allowed to reroute any of the surface water, therefore the factory purchased seven parcels and will drill production wells to withdraw aquifer water and pipe it to the factory. Local residents are concerned that large production wells will adversely affect their community wells and may deplete the stream flow. The local residents hired an attorney to represent their concerns. Water rights in this area forbid the construction of any structure that negatively impacts the aquifer quality or water levels. The law specifically states that an action that causes a decline in water level of over ten feet at any location is considered a “negative impact”. Here is where you come in. The company which built the factory has already spent hundreds of thousands of dollars in the construction phases “maybe they should have spent more in the planning phases”, and needs to prove in court that they can produce (26,000 cubic feet per day) without negatively impacting the aquifer. As the consultant you need to develop a pumping plan that will produce, 26,000 cubic feet per day that results in less than 10ft of drawdown at any of the community wells.





**Question 1)** Why are the fluxes at the community wells negative?

**Question 2)** Double click on several of the production wells and note that they have zero flux. Why?

**Question 3)** Start by distributing the needed flow uniformly at all production wells  $26000\text{ft}^3/\text{day}$  divided by 7 ( $\sim 3715$ ). Run the simulation. Do you see more than 10 ft of drawdown in any of the observation wells?

**Question 4)** Design a pumping regime that can withdraw  $26000\text{ft}^3/\text{day}$  without negatively impacting any of the wells. Consider the boundary conditions and the location of the wells when developing your plan. The maximum capacity of your wells/pumps is 60 GPM gallons/min. Adjust the pumping rates and view the model results until you find an acceptable solution. (Note: while in the source/sink coverage, you can double click on an individual well and change its rate, or you can right click on the source/sink coverage and select attribute table and make a number of adjustments at once there). You may need to click on the observation coverage to see the change in head reflected on the error bars (if the bars extend downward and are green then there is drawdown and it is less than 10ft). Describe your plan below.

**Question 5)** Can you meet the demand of the Factory? If your answer is no, then under 4 above show your design that comes closest to meeting that goal.

**Question 6)** Which Production wells could you pull the most water from and why?

**Question 7)** Do you think this model is fundamentally correct, yes or no, if no then why?

**Question 8)** Recall that water rights are such that the factory is not allowed to reroute any of the surface water and that is why they acquired these wells. Whether your design meets the goal of less than 10 feet of drawdown or not, explain how the stream flows have changed as a result of your pumping plan. Given that, is the law defining negative impact as a decline in water level of over ten feet at any location is sufficient to protect the surface water rights? Could your model be used to prove that there was surface water depletion? Explain why or why not.

### **SECTION III**

Choose something to explore in the model. Explain what you choose to do and describe the result.