a.

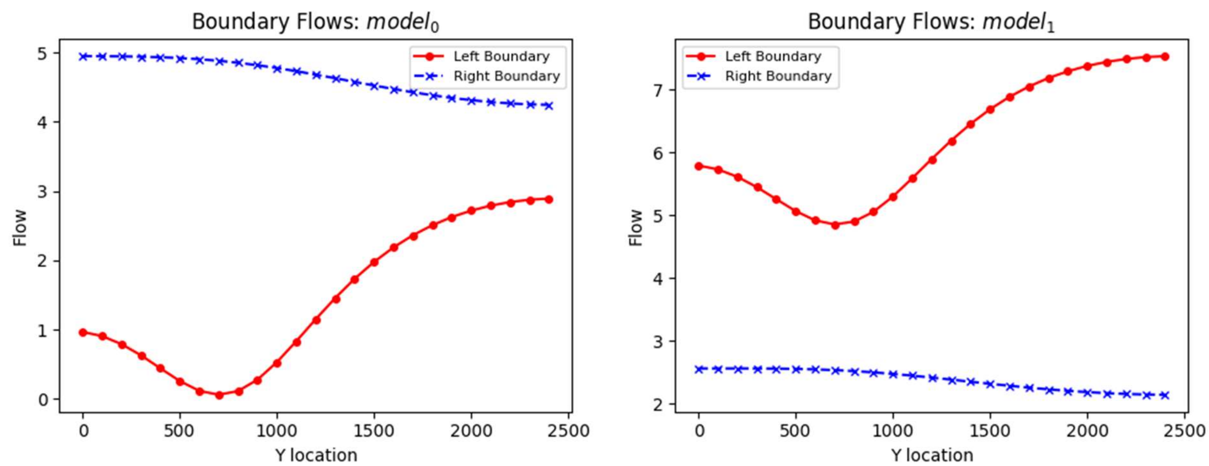

Figure 1: Left figure ($model_0$) shows flow with only Local Recharge and the Head left/right boundary conditions. The right figure ($model_1$) shows the same model, except with ET active at a rate of 5e-5 m/d and an extinction depth of 3 m.

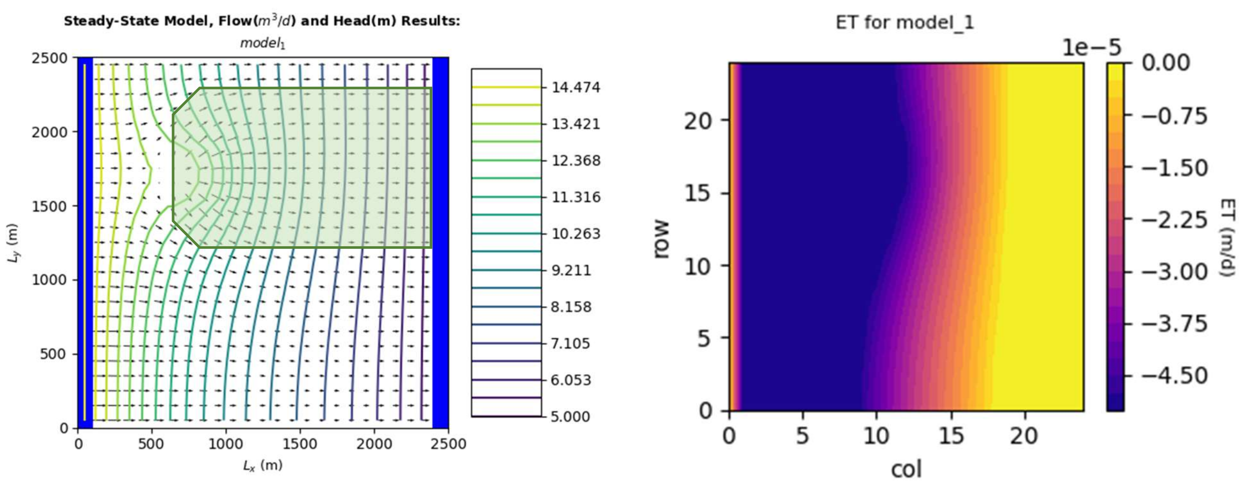

Figure 2: Green shaded area on the equipotential/flow vector map (left figure) shows the potential area impacted by contamination via only recharge from the initial model. Right figure shows the ET flux for the initial model at steady state, represented as a negative flux out of the system.

b.

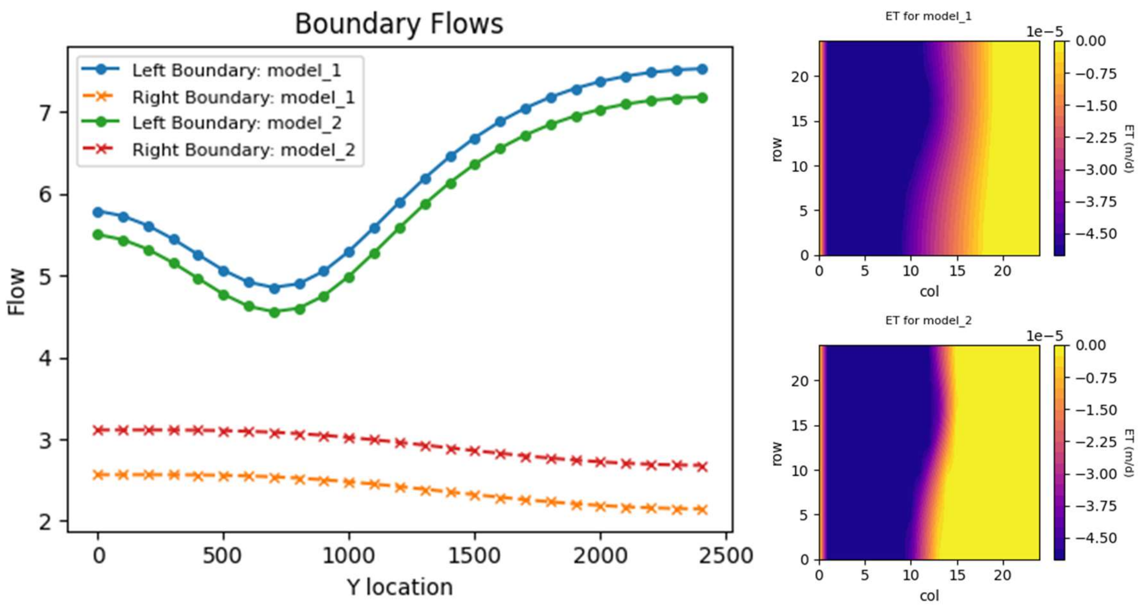

Figure 3: The left figure shows model_1 and model_2, with model_1 run with an ET extinction depth set at 3 m, and model_2 was run with an ET extinction depth set at 1 m. The right figures show the ET flux plan view for both model_1 and model_2.

When you change the extinction depth of ET (all else kept the same), the magnitude of flow is greater along the right boundary for the shallower extinction depth, with a reduced magnitude for the left boundary flow. As the extinction depth decreases, ET is "pulled" from the model in a smaller area, resulting in a sharper cutoff between 100% and 0% ET (model_1 shows a smaller gradient/larger range over which the ET values vary, whereas model_2 shows a sharp cutoff towards the middle of the model).

c.

MODFLOW puts constraints on the ET flux dependent upon the head within each cell of the system and the extinction depth used for ET. After calculating the constraints and weighting the system, MODFLOW treats ET as a system wide negative flux where it meets the constraints put in place. It appears to be a simple linear relationship for the percentage of ET used in each cell; e.g. for 3 m extinction depth and 10 m thick layer, head above 10 m has 100% ET, head between 7-10 m has a linear range of 0-100% ET, and below 7 m of head has 0 % ET flux.

MODFLOW's method kind of makes sense in comparison to my real-world understanding of ET; Evaporation and Transpiration both draw water out of GW systems in different ways, but ultimately have a similar affect on the groundwater. Evaporation draws moisture out of the sub-surface (if available) via a phase-shift from liquid to gas if conditions allow and Transpiration transports water out of the sub-surface via plant root-uptake dependent on the root infiltration depth and water requirements of the vegetation. The extinction depth in MODFLOW for ET is kind of a mediator between these two processes, representing a blending of maximum depth affected by evaporation and the average root depth for vegetation in the model.

d.

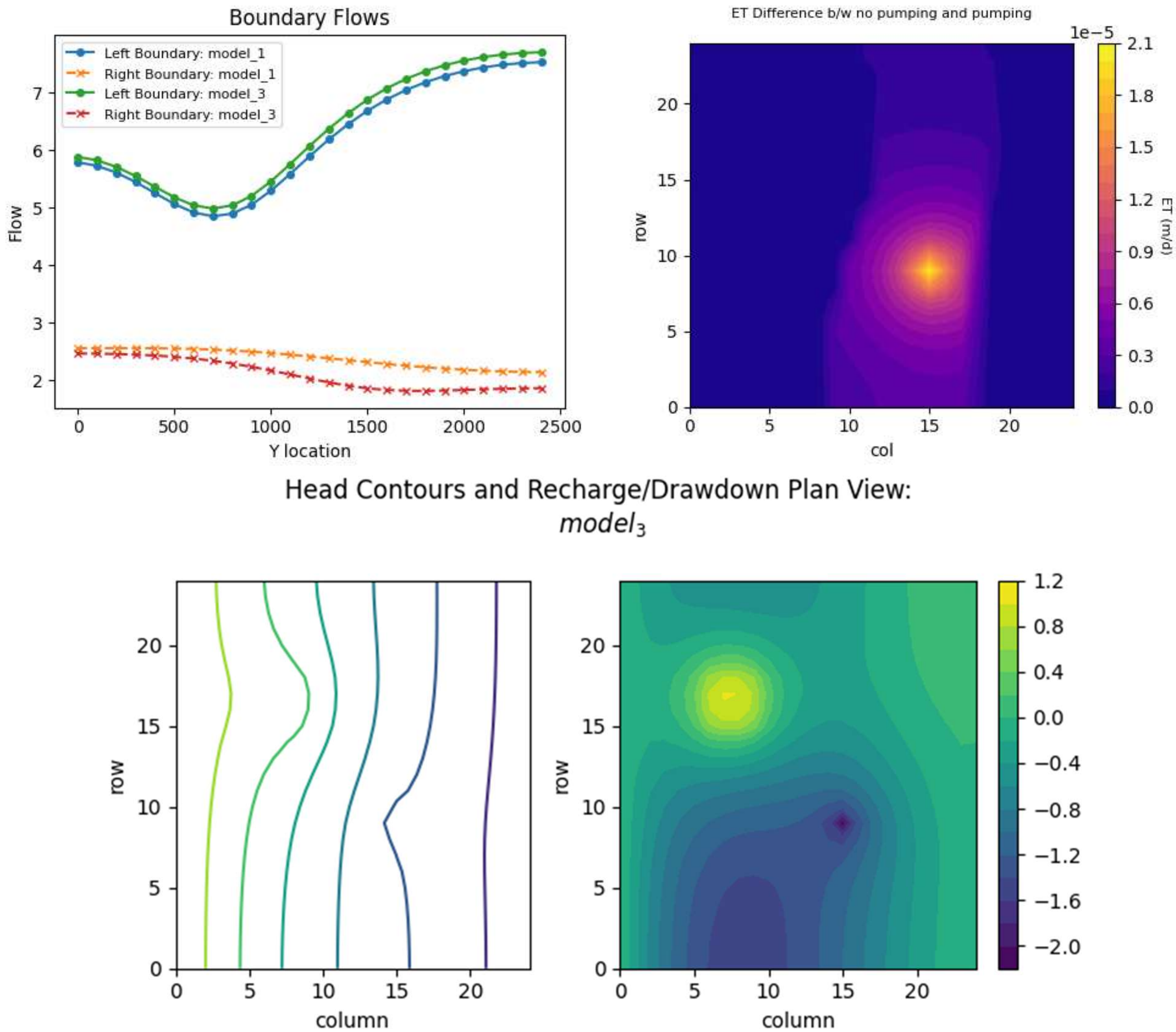

Figure 4: Top left figure shows the model_1 and model_3 left and right boundary flows, showing the difference between a system undergoing ET with (model_3) and without (model_1) an active well present. The top right figure shows the difference in ET flux between these two models, with 0 representing no change and anything above that (up to 2.1e-5) representing a reduction in ET due to pumping (remember, initial ET flux is negative at is represents a flux out of the system). The bottom figure shows the plan view head contours of the system with the active well, as well as a generalized recharge/drawdown contour map, which shows where the head values are different than a steady-state, no ET, no recharge, no pumping system (still with constant heads of 15 m on the left and 5 m on the right).

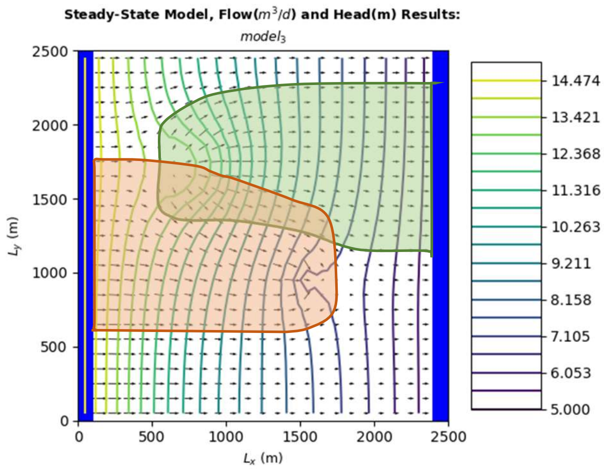

Figure 5: Equipotentials and flow vectors for model_3, which has local recharge, ET, and a well pumping. The orangish-brown area represents the approximate area of well capture, and the green zone represents the area affected by the local recharge from irrigation.

When the well is added to the model, it distorts the area affected by recharge by "stretching" it in the vertical direction towards the well (as indicated by the flow vectors in figure 5). However, the well capture zone is not fully represented within the ET difference map between the pumping/non-pumping models; there is an immediate difference in ET around the well, essentially representing the regions where pumping has reduced the head in the system enough to reduce/eliminate ET contributions to flux/flow.

A simple, perfect, mass balance equation for flow within a system is usually written as:

$$Q_{in} - Q_{out} = 0$$

In our system this can be split up into each of the relevant components, resulting in:

$$Q_{left} + Q_{recharge} - Q_{right} - Q_{ET} - Q_{well} = 0$$

This can then be rewritten to solve for the contribution of each to the well:

$$Q_{well} = Q_{left} + Q_{recharge} - Q_{right} - Q_{ET}$$

Summing the flows in python results in:

$$Q_{well} = \ 158.4\frac{m^3}{d} + 80.0\frac{m^3}{d} - 52.6\frac{m^3}{d} - 165.8\frac{m^3}{d} = \ 20.0\frac{m^3}{d}$$

Which matches the input for the well pumping rate. In terms of contribution of each to the well, only on the inputs side, the left boundary contributes ~%66.44 to the well draw and the recharge ~%33.56.

(***SIDE NOTE: I wasn't sure if I should do percent contributions only in regard to inputs, or if I should include the outputs as well. If I were to include the outputs in this calculation, I would get the percent by dividing the individual summed flows by the sum of the absolute values of each contributor. ***)