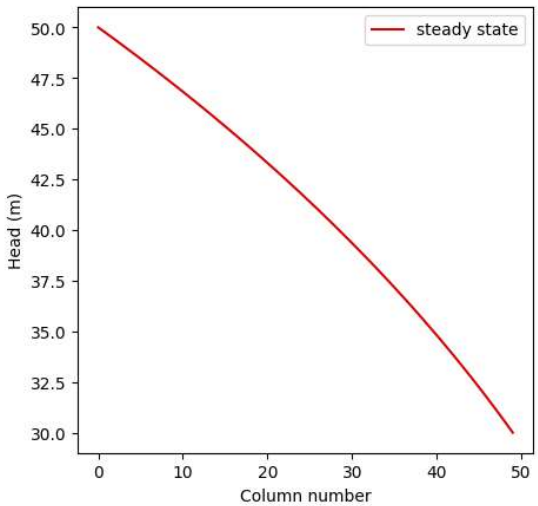
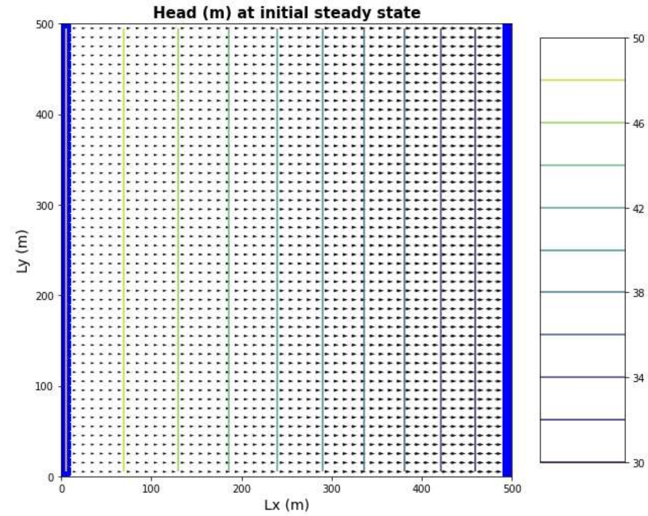
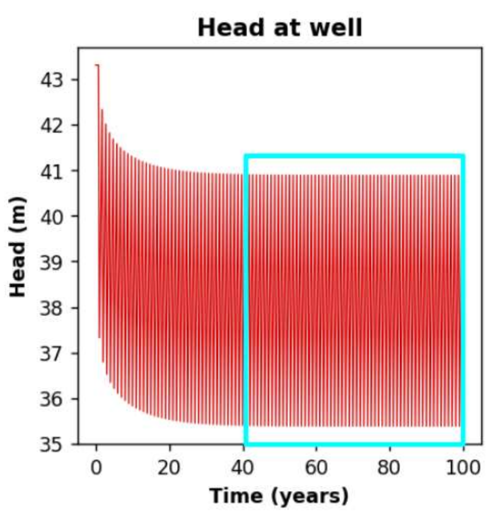
a) The gradient is not uniform for the initial steady state conditions - discuss the influences of recharge and the unconfined condition on this nonlinearity.

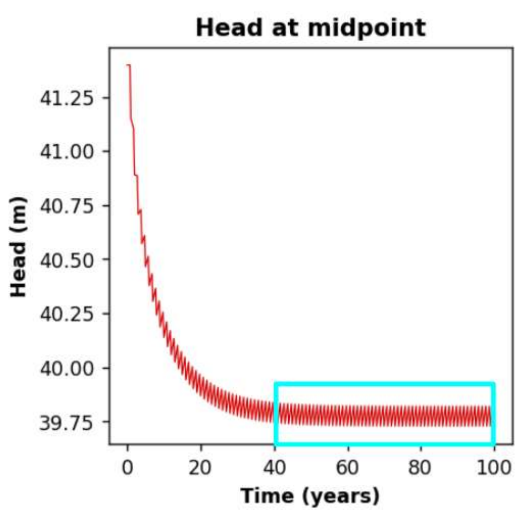




Due to the overall thickness of the aquifer (50 m) vs. the fixed head boundary conditions of 50 m (left-side) and 30 m (right-side), the model has areas that are unsaturated, which MODFLOW represents as changes in saturated thickness of the aquifer. This leads to less area for flow to easily move through, resulting in a build-up in the pressure head towards the left-side of the model as recharge is introduced across the whole domain.

b) Determine if the system has reached steady state - consider a point at the well and another at the center of the domain.

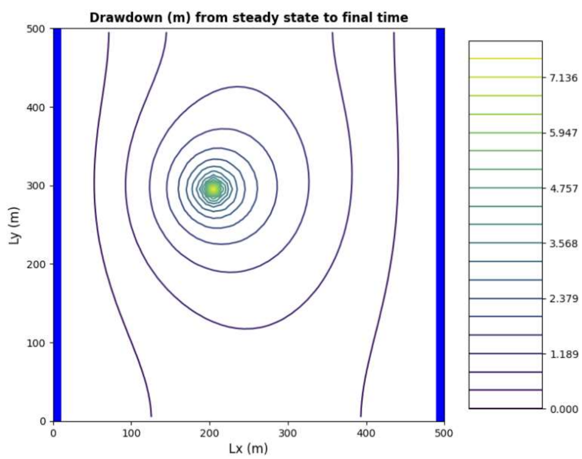


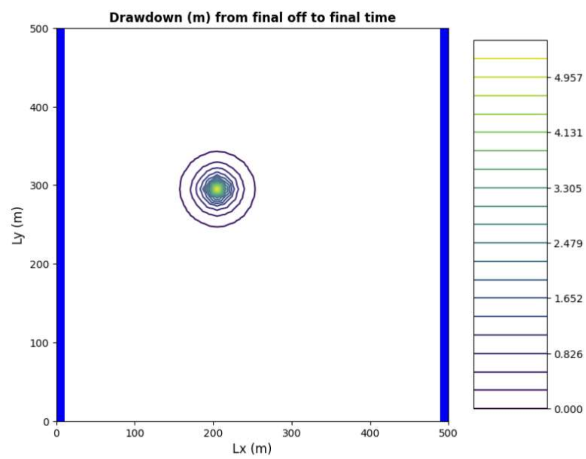


The system has reached a cyclical steady-state by approximately 40 years into the simulation. This was determined by looking at where the min/max values of the head began to stabilize (were consistent between years) and confirmed by zooming in/using built-in numpy functions to compare the values.

c) Find the zone of influence of the well defined in two ways:

- Based on the drawdown from the initial steady state to the end of simulation time (end of final no-pumping stress period).
- Based on the drawdown from the end of the last pump-on stress period to the end of simulation time.





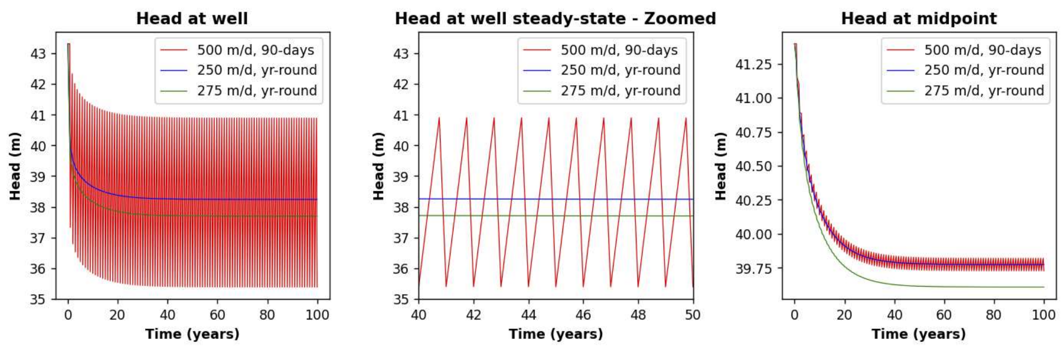
d) How long does it take a point at the center of the domain to reach steady state. At that point, explain how you could divide the domain into a steady and transient part and solve each separately.

As stated previously, the system reaches a cyclical steady-state condition around the 40-year mark into the simulation. Using this information, as well as the drawdown and equipotential/flow vector maps, it can be seen that the domain immediately surrounding the wells zone of influence can be considered the transient portion of the domain (once at the cyclical steady-state) and the remainder of the domain can be seen as a steady-state system (outside of where the domain is influenced by the well).

Figure 1: Red area represents ROUGHLY where the transient portion of the domain would be after reaching the cyclical steady-state condition, and the green area could be represented by steady-state portion of the domain.

e) Find a constant pumping rate (same throughout the year) that matches the head time series at the middle of the domain.

I used a uniform recharge rate of 5e-4 m/d for the whole domain, and calculated the volume of water added to the system over the whole domain (125 m/d). I then inverted this value (to -125 m/d) to use as my initial constant pumping rate. This resulted in a head distribution across the midpoint and well that was higher than the cyclical steady-state average. I then guessed for the next value, increasing the pumping rate to 250 m/d (well, -250 m/d) and the resulting graphs overlapped matched up pretty well.



The average value for the steady-state portion of the cyclical pumping was within 0.1 m/d of the average for the constant pumping at the well, and within 1e-5 m/d at the midpoint of the domain.

f) Find a constant pumping rate (same throughout the year) that matches the head time series at the well, leaving only a regular, repeating seasonal residual. Are the two pumping rates the same?

As shown above, the rates are relatively the same. I attempted to get the head at the well closer by adjusting the 250 m/d by 10 percent (to 275 m/d) which resulted in a much lower head distribution at the well and midpoint. If anything, the rate may only need a slight adjustment to get as close as the distribution at the midpoint, maybe to about 251 m/d or so, but is so negligible that I think it is fine to say 250 m/d satisfies both distributions.

g) Discuss the sources of water captured by this well. If you're up for a challenge, calculate them for the final pump-on period!

Initially, the source of the water capture by the well during the transient portion of the cyclical pumping model is coming mostly out of storage from the rest of the domain. Eventually, once the cyclical model reaches a steady-state, water is no longer pulled from storage (per se) and is instead being sourced from the boundaries of the domain (essentially any water pulled out by the well at this point is being replaced by water from the boundaries and via recharge equivalent to the amount pumped out).

h) Discuss how you would define the capture zone of the well. How is it different than our definitions of capture zone so far in the course?

The capture zone of the well in this model is different from the previous ones due to the cyclical nature of the pumping. I'm not entirely sure on this, but during the transient portion of the model, I'd expect the capture zone to be larger as it is pulling water out of storage from within the domain. Once the model reaches a cyclical steady-state, water that is being withdrawn by the well starts to become sourced from the boundaries of the domain, resulting in the capture zone looking more similar to our previous models (pretty much runs from the stagnation point past the well all the way to the left boundary).