**Getting Started activities – Conceptual model**

*These questions test your understanding of the aquifer conceptual model. You should run the notebook cell with* `conceptual_model()` *by clicking inside it and then hitting* `Ctrl+Enter`*. Use the widgets as you complete the exercises below.*

1. Use the slider to move the observation well from left to right. Does the water level change? Why/why not?
2. Do the piezometric surface in the confined and unconfined aquifer *have to* match each other?

**Problem Set 1 – Pumping a confined aquifer**

*These questions test your understanding of the Theis solution. You should run the notebook cell with* `confined_aquifer()` *and use the widgets as you complete the exercises below.*

1. Describe how the shape of the piezometric surface has **changed** from its initial position.
2. Explain why the piezometric surface is **steeper** closer to the well.

*Use the sliders to vary the pumping rate and aquifer transmissivity.*

3. Complete the following sentences:
    a. "Increasing $Q$ causes drawdown to increase/decrease. This is because..."
    b. "Increasing $T$ causes drawdown to increase/decrease. This is because..."

*Use the sliders to change the location of the observation well and the time at which drawdown is observed.*

4. Why does the water level in the well change:
    a. with time?
    b. with location?

*Change the keyword in the **Notebook Cell** to* `analysis=True` *and then rerun the cell. The **righthand plot** records water level changes in the observation well over time.*

5. Using the time slider, add more observations to the plot. Does drawdown accelerate or slow with time? Why?
6. Setting the time slider to its maximum value, make changes on the $r$, $Q$ and $T$ sliders. Do the changes on the plot reconcile with your answers to 3A, 3B and 4B above?

*Select the* `semilog` *checkbox to modify how the time axis is plotted.*

7. Describe the shape of the data and reconcile this with the equation above.
8. How is the **gradient** and **intercept** sensitive to changes in $Q$, $T$ and $r$?

*Set the slider positions to $Q$=1500 m$^3$/day, $T$=100 m$^2$/day and $t$=1 day.*

9. Is the piezometric surface displaying any strange behaviour? Can you explain why this occurs?
10. Deselect the `approx.` checkbox to activate the full Theis solution. Explain any changes you observe:
    a. In the cone of depression drawn on the conceptual model.
    b. In the plotted data (increase the time slider to check this one).

*Let's now use the data and an understanding of the Theis solution to calculate the aquifer storage, $S$. Change the input to the* `confined_aquifer()` *function to* `analysis=True` *and then rerun the cell (*`Ctrl+Enter`*). Set $Q$=1500 m$^3$/day, $T$=300 m$^2$/day and $t$=100 days, and observe the righthand plot.*

11. Rearrange the logarithmic approximation above into the form $h = c + m \times \log t$. What are $c$ and $m$?
12. Find the line of best-fit through the logarithmic section of the curve (toggle `approx.` to determine which section this is.)
13. Using your value of $m$, calculate the aquifer transmissivity, $T$. This should be close to the value selected on the $T$ slider.
14. Using your value of $c$, calculate the aquifer storativity, $S$. You should be able to get close to the actual value of $1.9\times10^{-3}$.

**Problem Set 2 – Pumping a semi-confined aquifer**

*These questions test your understanding of the Hantush-Jacob solution. You should run the notebook cell with* `leaky_aquifer()` *and use the widgets as you complete the exercises below.*

*The blue vertical arrows represent the amount of leakage occurring. Vary the $t$ slider back and forth.*

1. How does the amount of leakage change:
    a. Over time?
    b. With distance from the well?
    c. With respect to drawdown?
2. Referring to the analysis plot, is leakage having a strong impact on the drawdown profile?

*Change the value of the hydraulic resistance slider from $10^5$ to $10^4$ days. The aquitard is now 10 times* **less** *resistive to cross flow that before.*

3. Describe the change in shape of the drawdown profile.
4. What does "maximum drawdown" change with?
5. What is the timing of maximum drawdown sensitive to?
6. Speculate on a procedure to calculate $c$ from data collected in a well.

**Problem Set 3 – Pumping a laterally constrained aquifer**

*These questions test your understanding of image wells. Run the notebook cell with* `flow_barrier()` *and use the widgets as you complete the exercises below.*

1. At the flow barrier, the drawdown profile shows a sharp increase. Why does this occur? What are the aquifer conditions to the left and right of the flow barrier?
2. Describe the drawdown and hydraulic gradient at the flow boundary and explain why these make sense.

*Toggle* `image well` *on and off. The grey dashed lines show drawdown profiles computed from a Theis solution for each well.*

3. Verify for a few locations in the pumped aquifer that the realised drawdown (black) is the sum of the two grey curves (real well and image well.)

4. With the image well toggled off, what is the hydraulic gradient at the flow boundary and does this make sense?

*Set the time slider, $t$, to its maximum value.*

5. Comparing the drawdown curve to the Theis solution in Section 1, can you identify any quantitative feature of the curve that indicates a flow boundary?
6. If you were to fit a Theis solution to this curve, would you infer a value of transmissivity that is larger or smaller than the real value?

*Run the notebook cell with* `recharge_source()` *and use the widgets as you complete the exercises below.*

7. At the recharge source, the drawdown profile shows a sharp increase. Why does this occur? What are the aquifer conditions to the left and right of the recharge source?
8. Describe the drawdown and hydraulic gradient at the edge of the recharge source and explain why these make sense.

*Toggle* `image well` *on and off. The grey dashed lines show drawdown profiles computed from a Theis solution for each well (note, the image well is now injecting).*

9. Verify for a few locations in the pumped aquifer that the realised drawdown (black) is the sum of the two grey curves (real well and image well – **remember**, the sum should consider drawdown relative to the **initial piezometric surface**, not ground level.)
10. With the image well toggled off, what is the value of head at the edge of the recharge source and does this make sense?

*Set the time slider, $t$, to its maximum value.*

11. Comparing the drawdown curve to the Hantush-Jacob solution in Section 2, can you identify any quantitative feature of the curve that indicates a recharge source as opposed to aquifer leakage?

**Problem Set 4 – Pumping an unconfined aquifer**

*These questions test your understanding of the Neuman solution. You should run the notebook cells with* `unconfined_aquifer(),` *using the widgets as you complete these exercises. The black dashed line now represents the water table. Set $Q$=1500 m$^3$/day, $T$=100 m$^2$/day and $t$=100 days.*

1. What problems do you notice with the position of the water table? Are the assumptions of the Neuman solution likely to hold?

*Use the $b$ slider to set aquifer thickness to 5 m and set $r$ = 100 m. Use the $t$ slider to vary between 0.251 and 3.98.*

2. How does the water table change during this time? Hence describe the meaning of "delayed" yield.

*Set the $t$ slider to its maximum value and change $Q$=1000 m$^3$/day, $T$=300 m$^2$/day and $r$=200 m.*

3. What two limiting curves approximately describe the drawdown profile at early and late time?
4. Describe the shape of the jump between these two curves. What is its timing of this jump sensitive to?

*5.* How do changes in aquifer thickness affect the early/late-time behaviour of the drawdown curve?