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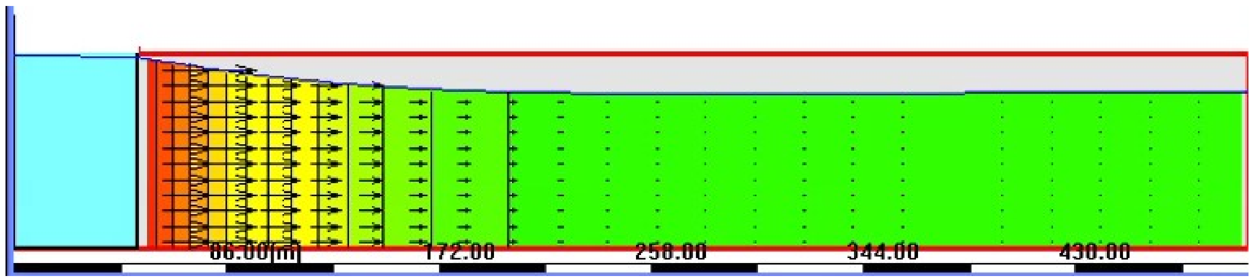
# Student Exercise – Stream Aquifer Interaction

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This exercise explores the impact of stream stage fluctuations on adjacent aquifer systems (both unconfined and confined). Part I involves qualitatively describing the key parameters and relationships controlling groundwater response to stream fluctuations through the analysis of (vertical cross-section) profile models. Part II presents the mathematical framework of stream-aquifer interaction, giving students the opportunity to quantify groundwater dynamics and infer aquifer properties from observational data.

Students will answer all the critical questions that follow (or a subset, depending on the Instructor's discretion). A possible format for delivering student work is to submit a short, organized response (or Memo) that includes:

- A summary of the basic information covered in this exercise;
- Responses to all assigned questions;
- A discussion of broader implications (management and societal implications); and
- Any necessary technical material, appended as a Memo attachment.

## PART 1 – KEY PARAMETERS AND RELATIONSHIPS

To complete this Part, visit the Stream-Aquifer Educational Videos available in the MAGNET4WATER Digital Library: [https://www.magnet4water.com/education-videos.html](https://www.magnet4water.com/education-videos.html). A series of 2D (vertical) profile models with slightly different parameterizations is presented in the different subtabs.

Take a moment to visit the various subtabs to get a feel for the different simulations. The streams are assumed to be fully-connected to the aquifer system (no stream-bed resistance), and therefore the head in the aquifer immediately adjacent to the stream is always equal to the stream stage. We also assume that stream stages fluctuate relatively quickly (e.g., full oscillation in about 1 day).

**Question 1**

**1a. Under what conditions is it safe or not safe to assume a stream is – for all practical purposes – fully connected to the aquifer system?**

**Question 2**

**Briefly describe the setup/design of the profile models.** For example, what are the important parameters requiring input values? What are the model dimensions and grid resolutions?

We will next systematically compare head patterns for different parameterization to look at the effects of different aquifer properties on resulting head patterns.

## Effects of Aquifer Storage Properties

First, we will look at the impact of 'static' properties of aquifer systems – the ability of water to store or release water in response to stress (in this case, fluctuating boundary conditions controlled by stream stage oscillations).

Go to the 'Unconfined Aquifers w/ Different Specific Yields' subtab and study the presented models. Note that the key (and only) difference between the models is the specific yield values utilized.

**Question 3**

**4a. Based on the specific yield values, what might be the dominant material in each aquifer system?**

**4b. Describe the size of the response zones for the three different models.**

**4c. Generalize the impact of specific yield on the size of the response zone.**

Go to the 'Confined Aquifers w/ Different Storage Coeff' subtab and study the presented models. Note that the key (and only) difference between the models is the storage coefficient values utilized.

**Question 4**

**4a. Describe the size of the response zones for the three different models.**

**4b. Generalize the impact of the storage coefficient on the size of the response zone.**

Go to the ‘Unconfined & Confined Aquifers’ subtab and study the presented models.

**<u>Question 5</u>**

**3a. In which model does the ‘signal’ from the stream propagate further into the aquifer system (this is the *response* zone).**

**3b. In your own words, explain why the response zone is different for unconfined vs. confined aquifers.** (What is the physical basis for the observed relationships?)

## Effects of Dynamic Aquifer Properties

Now we will explore the impacts of ‘dynamics’ aquifer properties – the ability of the aquifer to transmit water through the system.

Go to the ‘Unconfined Aquifers w/ Different T’ subtab and study the presented models. Note that the key (and only) difference between the models is the transmissivity values utilized.

**<u>Question 6</u>**

**6a. Based on the transmissivity values, what might be the dominant material in each aquifer system?**

**6b. Describe the size of the response zones for the three different models.**

Go to ‘Confined Aquifers w/ Different K’ subtab and study the presented models. Note that the key (and only) difference between the models is the hydraulic conductivity values utilized.

**<u>Question 7</u>**

**7a. Describe the size of the response zones for the three different models.**

**4b. Generalize the impact of transmissivity/conductivity on the size of the response zone. Provide a physical basis for the generalized relationship(s).**

## Effects of Stream Properties

In this section, you will investigate the impact of: i) the frequency of stage fluctuations; and ii) the depth of penetration of the stream into the aquifer system.

Go to 'Boundaries of Different Frequencies of Variability' subtab and study the presented models. Note that the key (and only) difference between the models is the period of oscillation values utilized.

**Question 8**

**8a. Why might we expect to see sudden or periodic fluctuations in stream stages?**

**8b. Describe the size of the response zones for the three different models.**

**8c. Generalize the impact of stage oscillation frequency on the size of the response zone.**

Go to 'Boundaries of Different Aquifer Penetration subtab and study the presented models. Note that the key (and only) difference between the models is the relative depth of penetration of the streambed into the aquifer system.

**Question 9**

**8a. Why might we expect to see streams penetrating into different depths into an aquifer system?** (In other words: When would we see very little penetration? When we see full/almost full penetration?)

**8b. Describe the size of the response zones for the three different models.**

**8c. Generalize the impact of streambed penetration on the size of the response zone.**

**Question 10**

**Now that you have systematically compared the effects of different factors, rank them in terms of importance (most impactful to least impactful).**

# PART II – MODELING WITHIN A MATHEMATICAL FRAMEWORK

Governing equation: 2D Aquifer Equation

Assuming a slight change in T doesn't affect T….and therefore T is constant:

**Question 11**

**Under what conditions can we safely assume a slight change in head does not affect T?** Use mathematics and/or conceptual sketches in your explanation.

## Sudden (Instantaneous) Change in Stream Stage

Boundary conditions: at t=0, h=0; for t>0, at x=0, h=$h_0$ and at x=∞, ∂h/∂x=0 (or h=0). Solution w/ BCs is:

erfc -> error function, similar to exponential decay, $h_o$ is the amount of change in head in surface water body

"diffusive increase" of head in aquifer with time… -> hydraulic diffusivity coefficient … controls water table evolution of an unconfined aquifer (or, the propagation of pressure wave in a confined aquifer).

## Periodic (Sinusoidal) Stage Fluctuations

Context: periodic fluctuations in stage:

ω is the frequency of oscillation

With BCs: @ t=0, h=0; for t>0 at x=0, , at x=∞, ∂h/∂x=0

Solution w/ BCs:

$h_m(x)$ depends on the aquifer properties:

$t_o$ is the time lag:

The "propagation velocity" is therefore:

**<u>Question 12</u>**

**12a. Based on your understanding of hydrologic processes, provide at least 2 reasonable values of ω that one might use to represent periodic stream stage fluctuations.**

**12b. Explain how the magnitude of ω impacts $h_m(x)$.** Consider: variation of $h_m(x)$ along x-direction; how closely $h_m$ resembles $h_0$. **Is this consistent with what you observed in Part I?**

**12c. Discuss how the lag-time is impacted by ω and T/S.**

Consider: if we are given lake stages and heads at a monitoring well, we can inversely determine T/S (T, S). We would need to set up a modeling network to sample T/S, T, S at each sampling point. We would then linearize the equation describing head fluctuations in response to periodic stage oscillations:

Plot on a semi-log plot (vertical axis: log-scale; horizontal axis: linear scale)

Y-intercept: $\log(h_0)$

Slope:

## Baseflow Recession & Recovery

Context: end of wet-season through all of the dry-season…essentially, no recharge, with a water table that is declining with time.

Question we want to answer: How does distribution change with time? How does baseflow from aquifer to stream change with time?

Water table shape assumed to be represented by

Boundary Conditions: for t=0, h=; at x=0, h=0; at x=L (where L is the lateral distance from the groundwater divide to the stream), $\partial h/\partial x=0$

Solution w/ BCs:

## Question 13

**How does a larger aquifer transmissivity impact h(x,t)? Is this consistent with what you observed in Part I?**

With a solution for h(x,t), we can derive an expression for baseflow, $Q_{base}$. First, get expression for $\partial h/\partial x$ from h(x,t):

Evaluate at x=0:

(Recall that J is the hydraulic head gradient.) Therefore,

We expect maximum baseflow at t=0:

Often, it is useful to define a response time, $t_r$:

So that:

## Question 14

**Discuss the impacts of the aquifer properties and/or geometry on the rate of decline of baseflow (rate of baseflow recession).**

Context: We now want to estimate the size of the "mound" that is created during the wet season (i.e., during recharging conditions). Note that the mound extends beyond the basin divide to the next major discharge area.

Governing Equation:

$\varepsilon$ is the mean recharge; note that this is a steady-state analysis;

Perform two integrations:

also, assuming T is constant, we can write:

Let us approximate:

Thus:

Shape of the mound is a quadratic expression!

Note that the maximum mound height occurs at the groundwater divide (x=0):

If we integrate across the mound, we can get the average head across the mound:

**Question 15**

**Based on this analysis, which parameter is most important in terms of the mound size (max. height and volume)?**