I. Objectives

1. Conduct experiments to observe groundwater flow.
2. Observe and interpret how different kinds of sediments hold and transmit water.
3. Observe and interpret the relationship between water table and water level in a well.
4. Observe and interpret how pumped wells affect water flow and the water table around them.
5. Observe and interpret how point source pollution affects groundwater and how it reacts to nearby groundwater pumping.
6. Observe and interpret surface water and groundwater interactions.

II. Introduction

The model we are using today represents a 2½-dimmensional cross-section of an aquifer. An **aquifer** is a water-bearing geologic formation that can store and yield usable amounts of water. The water stored in an aquifer is known as **groundwater.**

Working cooperatively in groups, follow the directions and answer the questions. If time allows, also complete sections 6 and 7, otherwise, those sections are to be completed as homework. Before beginning each part of the lab, review all of the procedures and questions.

III. Materials

Groundwater model, hand pump, water bottles, diluted green food coloring, water

IV. Prelab Definitions

1. pore space

2. water table

3. recharge

4. aquifer

5. unconfined aquifer

6. confined aquifer

7. impermeable

8. unsaturated (sediment)

9. cone of depression (about a well)

10. aquiclude

11. artesian spring

12. stream terrace

V. Lab Procedure

Part 1. Aquifer Basics

1. **Fill the left recharge column of the model**. As the column is filling, pay attention to which layers allow the water to move fastest and slowest.

2. Through which layer did the groundwater move most quickly? Why? Describe the material in that layer.

3. Through which layer did the groundwater move most slowly? Why? Describe the material in that layer.

4. Based on your answers to the questions above, which layer is the most productive aquifer? Why?

5. What material characteristics produce productive aquifers?

6. **Saturate the lower 4/5 of the model** (~2 inches below the top edge) and establish a level water table.

7. List two ways of identifying the location of the water table:
   a.

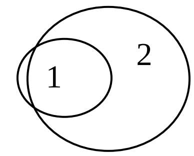
   b.

8. On copy 1 of the groundwater flow model draw and/or label:
   a. level in each well
   b. the water table line for the entire model
   c. the saturated zone
   d. the unsaturated zone

Part 2. Injection Wells – Contamination

1. **Inject dye into all 3 injection wells** until a quarter-sized amount is visible in each location. Observe what happens to the dye for one minute.

2. On copy 1 of the groundwater flow model, draw circles to indicate the initial dye locations/areas (label area #1) and then area filled by dye after one minute (label area #2).



3. Why does the contamination spread over time?

4. **Create a simple hydraulic gradien**t (flow direction) by adding more water to the left recharge column until it is 4/5 full, while using the pump to keep the right column 1/2 full. Continue injecting dye. Observe what happens to the dye for about two minutes.

5. On copy 1 of the groundwater flow model, draw the flow paths of the dye after doing this for several minutes (label flow paths #3).

6. What is now causing the contamination to move?

7. Empty the vacuum flask. Keep most of the model saturated, and **begin pumping water from the deep pumping well**. Add more dye. Observe the movement of the dye for 1 minute.

8. On copy 2, draw the flow paths of the dye (label flow paths #4).

9. Has the dye entered this well after pumping? Explain your answer.

10. Empty the vacuum flask. Keeping most of the model saturated, **begin pumping water from the shallow pumping well**. Observe the movement of the dye for 2-3 minutes.

11. On copy 2, draw the flow paths of the dye (label flow paths #5).

12. Has the dye entered this well after pumping? Explain.

13. Which well was contaminated more quickly from pumping? Why?

14. Contamination can come from multiple sources. Looking at the model, identify any other realistic sources of contamination. How would the effects differ from those just observed?

15. Using dye, contaminate this new source and observe flow paths as you continue pumping from the shallow well. Draw these flow paths on copy 2 (label flow paths #6).

Part 3. Pumping Wells

1. Saturate the lower 4/5 of the model and establish a level water table. Put a water bottle on both sides if necessary.

2. **Create a "cone of depression" by continued pumping from the shallow well**. Carefully observe the water level in all the monitoring wells as it falls to the level of pumping. It changes rapidly so work quickly!

3. On copy 3 of the groundwater model, mark the water level or water table in all the wells before and after pumping from the shallow well. Label the saturated and unsaturated zones. Explain the change in the water table.

4. Is there any sand being pumped up through the wells? Why not? Why is this important?

5. Make sure that your water bottles are recharging both outer columns.

6. Calculate rate of extraction or flow from the shallow well in mL/min and gal/min. (Hint: start by emptying the flask. You will need to measure the volume of water extracted over a given interval of time. The small beaker may help to accurately measure your volume. 1 gal ~ 3.8 L). Include your calculations and the answer below.

Part 4. Surface Water – Groundwater Interactions

1. Saturate the lower 4/5 of the model and establish a level water table

2. On copy 4 of the groundwater model, draw the water table (label it as WT#1), paying particular attention to its level in the lake/river structure.

3. Explain the interaction between the water table and the body of water (lake, stream, etc.). How is the surface water body being filled? How does groundwater interact with surface water?

4. Remove the water bottle. Pump water out of the right column of the model. Observe the effects on the water table and stream.

5. On copy 4, draw the new water table (label it WT#2).

6. Based on what you observed in this demonstration, explain what has happened to the Santa Cruz River and why it no longer flows perennially.

Part 5. Contamination Clean-up

1. Clean up your contaminated groundwater model before turning in the lab. By the end of class, remove all the dye and nearly all the water from the model. First, pump 1-2 liters of water from the shallow well and the right column, then start draining water out by using blocks to raise the left side of the model 2 in.

2. How did you clean up the contaminated groundwater? What might be a problem with your method of cleanup?

3. What does this process indicate about potential cleanup in real aquifers?

Part 6. Aquifer Storage

1. Calculate the potential maximum water storage this aquifer can hold based on the **interior volume** dimensions (L x H x W) of the plastic model. Complete column C of Table 1.

   Total volume = Max water storage (in^3):

2. Now re-calculate the potential water storage by taking the volume occupied by solid materials into consideration. The **pore spaces,** or the empty spaces between grains, not taken up by solid materials, are the only places water can be stored. The **porosity** of a material is a ratio of the pore volume, or **pore space**, to the total volume.

$$\text{Porosity} = \frac{\text{Volume}_{\text{pores}}}{\text{Volume}_{\text{total}}}$$

   The total volume was calculated in Part 6. The porosity of the different materials in the groundwater model is required to determine the pore space volume and find an accurate storage potential. Here are some common values:

   - gravel = 25%
   - sand = 35%
   - clay = 50%

   Why is clay % so large?

3. Relative Volume: Considering the different materials within the aquifer, approximate what percent of the aquifer consists of sand, clay and gravel. Complete Table 1.

Table 1 Aquifer Relative Volumes

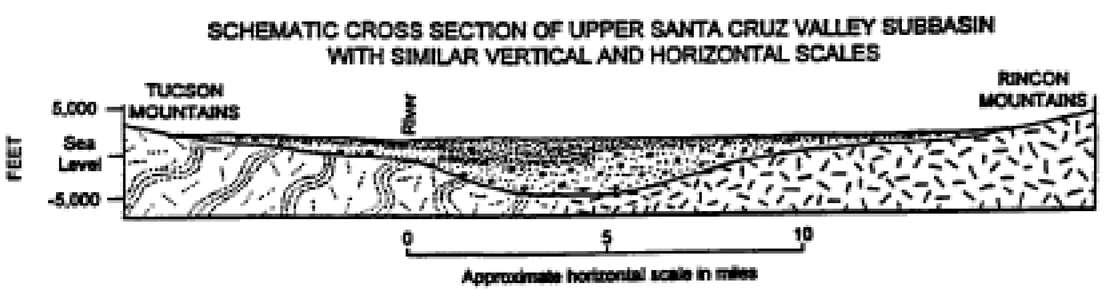
	A	B=A/100	C	D=B * C
	Rel. Volume %	Frac. Vol	Total Volume	Rel. Volume - in^3
Gravel	%			
Sand	%			
Clay	%			
Total	100%	1.0		

4. Relative Porosity: Now we will take the typical porosities into account to find the relative volume of porosity for each unit. Add these to calculate the total porosity. Complete Table 2.

Table 2 Relative Porosities

	D	E	G=D * E	H=G/ ΣG
	Rel. Volume - in^3	Porosity	Rel. Porosity- in^3	Frac. Porosity
Gravel		0.25		
Sand		0.35		
Clay		0.50		
Total		total porosity:	Σ=	average =

5. Now that aquifer storage at the model scale has been calculated, extrapolate this water storage availability to the Tucson Basin Aquifer. The approximate spatial extent of the Tucson basin is 20 miles wide (east to west) by 30 mi long (north to south). On average the water table is 400 ft below the surface and the aquifer extends to 11,000 ft below the surface in the center of the basin, however, safe and feasible pumping only extends to 1,200 ft below the surface.



6. Assuming an aquifer with an average **porosity** found above, how much water can the Tucson Basin hypothetically store? (Hint: convert mi to ac (640 ac = 1 mi^2), then solve for af using the depth info, then use the model effective porosity (above) to estimate aquifer storage).

   Basin area (ac):

   Volume of potential storage (af):

   Aquifer storage (corrected for porosity, af):

7. The actual available storage in the Tucson Basin is between 60 and 70 Maf. Is your answer higher or lower than this range? Explain why your value is different.

8. Using the basin area calculated above, **calculate the recharge rate** into the aquifer if the Tucson Basin receives, on average, 12 in/year, but only 25% of this water actually reaches the aquifer.

   Area (ac):

   Volume of rain (af):

   Recharge amount (af):

   Again your answer should be higher than the actual annual average of 61,000 af.

9. Considering the characteristics of the Tucson Basin watershed, what is the main reason actual recharge is less than your calculation? How does this influence recharge patterns? (Review our discussion of urbanized watersheds if necessary).

Part 7: Conclusions & Feedback

1. Explain how groundwater use might affect surface water flows.

2. What aspects of this exercise helped you understand groundwater the most?

3. What aspects of this exercise are unclear?

Lab courtesy of Dr. Jim Washburne