

# GROUNDWATER EXERCISE USING THE SAND TANK MODEL

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## **Objectives:**

When you complete this exercise, you will be able to:

1. identify the following in a groundwater model and on a drawing:
  - a. confined aquifer
  - b. unconfined aquifer
  - c. water table
  - d. potentiometric surface
  - e. cone of depression
  - f. hydraulic head
  - g. hydraulic gradient
2. describe the nature and significance of each of the terms in #1 (above).
3. calculate the hydraulic gradient in an aquifer.
4. define the terms of the Darcy equation, and use the equation to develop inferences about an aquifer.
5. describe how groundwater and surface water are interconnected.

## **Activities:**

We will meet the objectives above by studying the performance of water flowing in a model designed to demonstrate groundwater principles.

## **BACKGROUND - GROUNDWATER**

### Groundwater occurrence

The part of the soil mantle and permeable bedrock where water fills all of the pores is called the zone of saturation. Water in this zone is called groundwater. A geologic formation capable of storing, transmitting and yielding groundwater to wells is called an aquifer. Groundwater in the zone of saturation comprises most of the globe's usable fresh water supply.

An aquifer that has no confining layer between the land surface and the saturated zone is an unconfined aquifer. The top of the saturated zone in an unconfined aquifer is the water table.

An aquifer sandwiched between impervious or slowly permeable materials is a confined aquifer. Confined aquifers may be exposed to the surface at some point. That part of the aquifer exposed to the surface would then be unconfined.

The imaginary upper surface caused by hydraulic pressure in the confined aquifer is the potentiometric surface. The potentiometric surface is the level to which water would rise in an unpumped well put into the confined aquifer. A confined aquifer is sometimes called an artesian aquifer. An artesian well is a well into a confined aquifer. A flowing artesian well occurs if the potentiometric surface of the aquifer is above the ground surface.

The hydraulic head in a groundwater system (an aquifer) is measured as the height above a reference level. It is the sum of the pressure from the weight of overlying water (pressure head), and the potential energy resulting from elevation (elevation head). Hydraulic head is usually determined by subtracting the depth to water in a piezometer or monitoring well from the elevation at the top of the piezometer or well casing (top of casing, or TOC) [hydraulic head = TOC – depth to water].

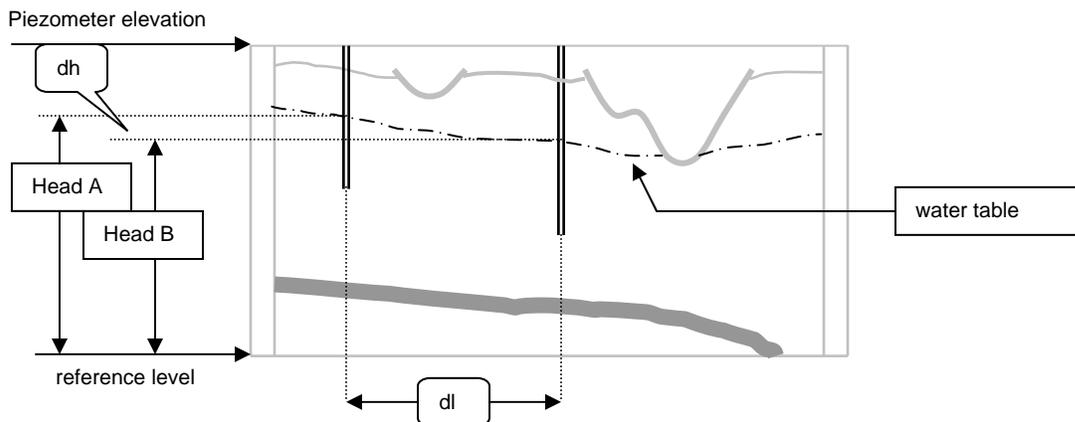
When a well is pumped for an extended period of time, a cone of depression forms in the water table of an unconfined aquifer, or an imaginary (or virtual) cone of depression in the piezometric surface of a confined aquifer. Water is being removed from the aquifer at a faster rate than it is replenished -- this causes a localized drop in the pressure surface. When pumping is stopped, water, if it is available, will move back in and the cone of depression will disappear.

### Groundwater movement

The rate of groundwater movement is governed by the permeability of the aquifer, and by the potential gradient. The potential gradient in an aquifer is measured as the difference in hydraulic head at different points in the aquifer.

Think of the potential gradient as a change of hydraulic head (dh) over a change in distance (dl).

That is: potential gradient =  $dh/dl$



Velocity of groundwater movement is calculated using the Darcy equation. The Darcy equation is expressed as:

$$v = K(dh/dl)$$

$v$  = the rate of flow (ft/day)

$K$  = hydraulic conductivity ( $ft^3/ft^2/day$ )

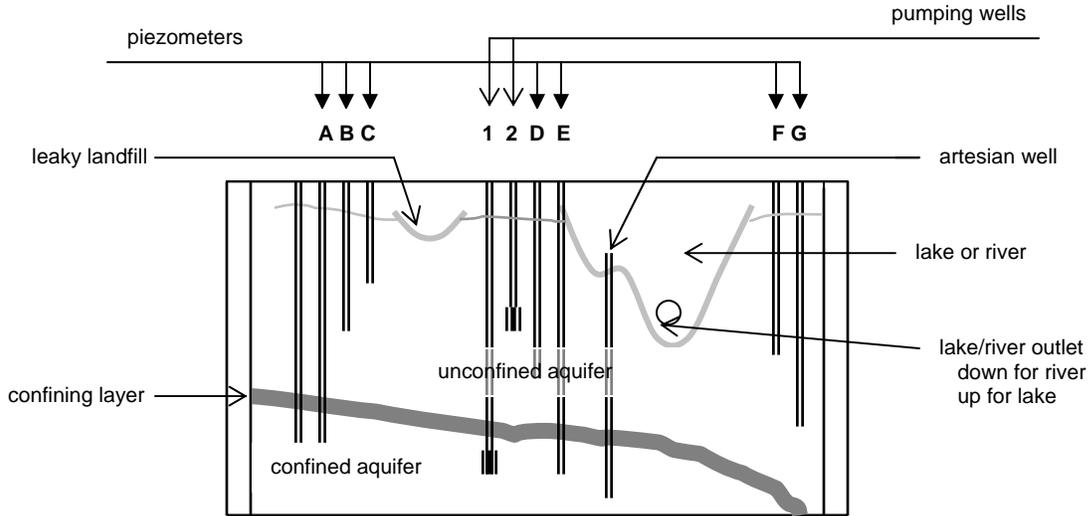
$dh/dl$  = potential gradient (ft/ft)

Hydraulic conductivity (K) is a function of the aquifer characteristics. It is usually measured in the field using pumping tests, or in the laboratory using an undisturbed sample of the aquifer material.

The potential gradient in an unconfined aquifer can be determined by measuring the slope of the water table. In a confined aquifer, the hydraulic gradient can be calculated by measuring the gradient of the potentiometric surface.

**Exercise:**

We will be using the model illustrated below for our study of groundwater.



We will provide local “precipitation” by filling the model from the side reservoir with a water bottle. We will start all investigations with the model completely filled with water, and with no flow occurring.

Getting started

Before starting any activities, leave the lake/river outlet closed (tube turned up), and the artesian well capped (put a plug in the opening). Start the model filling by inverting a filling bottle over the reservoir at the left end of the model (farthest from the river/lake outlet). Inject dye into all of the piezometers, making sure that no air bubbles are injected.

Groundwater in the unconfined aquifer

- 1) With the model filled:
  - a) Measure the head at the surface of the saturated zone in the unconfined aquifer (for this part you need only measure piezometers B and D).  
*[ remember:  
 head = top of casing (TOC) – depth to water]*

Piez-ometer	Head h = TOC – depth (cm)	TOC (cm)	Depth to water (cm)
B			

D			
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b) Calculate the potential gradient of the unconfined aquifer under conditions of no flow.

[remember: potential gradient =  $dh/dl$ ]

potential gradient =  $(\text{head}_B - \text{head}_D) / \text{length between B and D}$

head<sub>B</sub> – head<sub>D</sub> : \_\_\_\_\_ cm

length B to D: \_\_\_\_\_ cm

potential gradient \_\_\_\_\_ cm

2) open the lake/river outlet, wait a few minutes for the flow in the unconfined aquifer to stabilize. With water flowing:

a) measure the head on the water table under conditions of flow

Piez-ometer	Head $h = \text{TOC} - \text{depth}$ (cm)	TOC (cm)	Depth to water (cm)
B			
D			

b) Calculate the potential gradient of the unconfined aquifer under conditions of flow.

[potential gradient =  $(\text{head}_B - \text{head}_D) / \text{length between B and D}$ ]

head<sub>B</sub> – head<sub>D</sub> : \_\_\_\_\_ cm

length B to D: \_\_\_\_\_ cm

potential gradient \_\_\_\_\_ cm

3) Why does the gradient differ in the unconfined aquifer after the outlet is opened?

#### Groundwater in the confined aquifer

1) With the cap in the artesian well, and the lake/river outlet open:

- a) Measure the head at the potentiometric surface of the confined aquifer under conditions of no flow:

Piez-ometer	Head $h = \text{TOC} - \text{depth}$ (cm)	TOC (cm)	Depth to water (cm)
A			
E			

- b) Calculate the potential gradient of the confined aquifer under conditions of no flow:

[potential gradient =  $(\text{head}_A - \text{head}_E) / \text{length between A and E}$ ]

head<sub>A</sub> – head<sub>E</sub>: \_\_\_\_\_ cm

length A to E \_\_\_\_\_ cm

potential gradient \_\_\_\_\_ cm

- 2) Remove the plug from the artesian well, allow flow to stabilize. With water flowing:

- a) Measure the head at the potentiometric surface of the confined aquifer under conditions of flow:

Piez-ometer	Head $h = \text{TOC} - \text{depth}$ (cm)	TOC (cm)	Depth to water (cm)
A			
E			

- b) Calculate the potential gradient of the confined aquifer under conditions of flow:

[potential gradient =  $(\text{head}_A - \text{head}_E) / \text{length between A and E}$ ]

head<sub>A</sub> – head<sub>E</sub>: \_\_\_\_\_ cm

length A to E \_\_\_\_\_ cm

potential gradient \_\_\_\_\_ cm

- 3) Why does the gradient differ in the confined aquifer after the artesian well is opened?

Groundwater flow and aquifer permeability

Comparing the sand aquifer and the gravel aquifer, (without reference to whether or not they are confined or unconfined), and looking at the Darcy equation [ $v = K(dh/dl)$ ], consider the following questions:

- 1) If the velocity of water flow in each of the aquifers were the same, what does the difference in potential gradient between the two aquifer materials tell you about the hydraulic conductivity in the aquifers?
  
  
  
  
  
  
  
  
  
  
- 2) If the potential gradient were the same in each aquifer, in which would the water flow faster?

Groundwater extraction

Place the plug back in the artesian well. Leave the lake/river outlet open.

- 1) Use a siphon tube as a “pump” to pull water from pumping well #2.
  - a) measure the head at the water table under conditions of well pumping

Piez-ometer	Head $h = \text{TOC} - \text{depth}$ (cm)	TOC (cm)	Depth to water (cm)
B			
D			

- b) Which piezometer was most affected by pumping? Why?
  
  
  
  
  
  
  
  
  
  
  - c) Were piezometers A and E affected by pumping? Why or why not?
  
  
  
  
  
  
  
  
  
  
- 2) Use a siphon tube to pull water from pumping well #1
  - a) Measure the head at the potentiometric surface during conditions of pumping

Piez-ometer	Head $h = \text{TOC} - \text{depth}$	TOC (cm)	Depth to water (cm)
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	(cm)		
A			
E			

- b) Which piezometer was most affected by pumping? Why?
- c) Were piezometers A and E affected by pumping? Why or why not?

Pollution from land use

Put the plug in the artesian well, and leave the lake/river outlet open. Place dye in the leaky landfill, and observe the effect on the water pumped from the pumping wells and the water in the river.

- 1) Presence of dye in pumping well #1
- 2) Presence of dye in pumping well #2
- 3) Presence of dye in river water
- 4) Presence of dye in the aquifer

Explain what you see.

Tracing the direction of groundwater flow

The dye in the piezometers leaves a trace in the aquifer showing the direction of flow. Observe the flow lines resulting from the piezometer dye and explain what you see.