Groundwater Movement--A Closer Look

The previous page described groundwater movement in general terms, but there is more to it than that. Many factors influence groundwater movement such as hydraulic head, hydraulic gradient, and velocity which was based on Darcy's Law. (Described below.) Other influencing factors include soil and aquifer properties, aquifer type, geology, and topography.

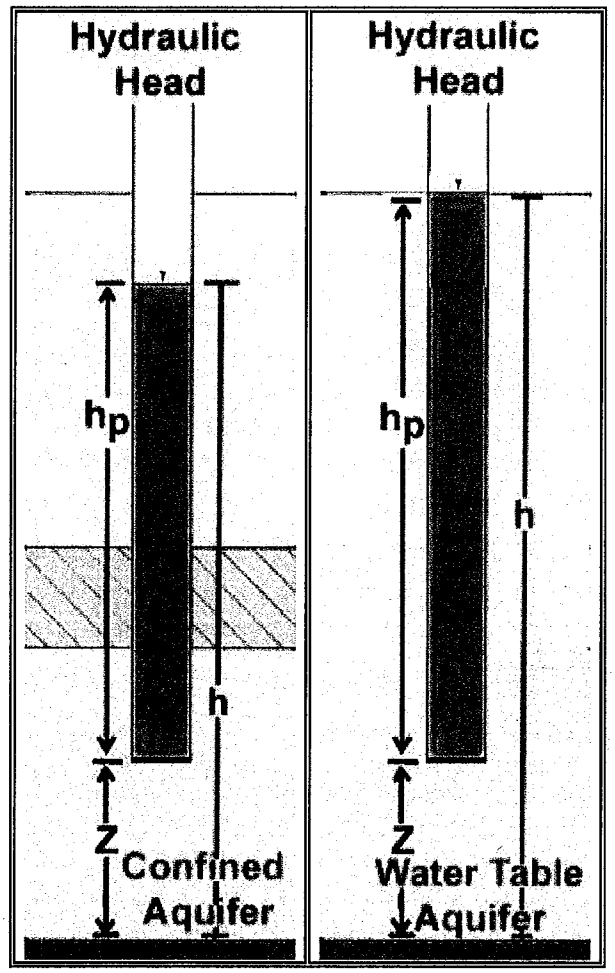
Hydraulic Head

H is a measure of the mechanical energy that causes groundwater to flow. Hydraulic head (h) can be calculated two ways:

1. the sum of pressure head (h_p) and elevation head (z), or $h=(h_p + z)$.

2. the difference between the land surface elevation and depth to water, or h=(land elevation - depth to water)

The pressure head (h_p) is the height that water rises in a *piezometer* (a well that is open only at the top and bottom of its casing). The elevation head (z) is the elevation of the bottom of the piezometer or measuring point in feet above sea level.



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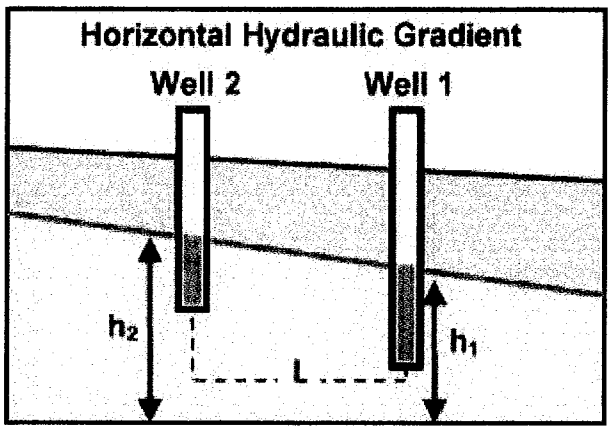
Hydraulic Gradients

Horizontal hydraulic gradient is simply the slope of the *water table* or *potentiometric surface*. It is the change in hydraulic head



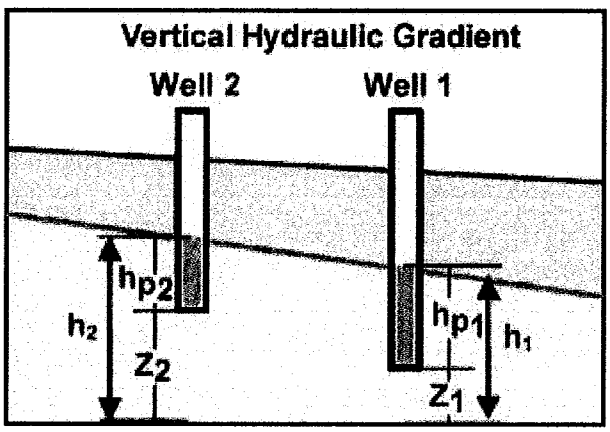
over the change in distance between the two monitoring wells or dh/dl.

In mathematical terms, horizontal gradient is rise over run.

dh/dl= difference in head / horizontal distance between wells= $(h_2 - h_1) / L$

In Portage County, the horizontal gradient of the water table for:

- Sand-Plain Province is 3-25 feet per mile
  - Stevens Point & Plover=20 ft/mi
  - Bancroft-moraine=15-25 ft/mi
  - west of Bancroft=5 ft/mi
  - Almond-Arnott=almost flat
- Drift Province is 5-40 feet per mile [4]



Vertical hydraulic gradient is

dh/dl = difference in head / vertical distance between wells= $(h_2 - h_1) / (z_2 - z_1)$

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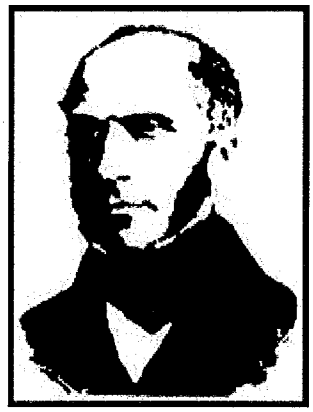
Darcy's Law

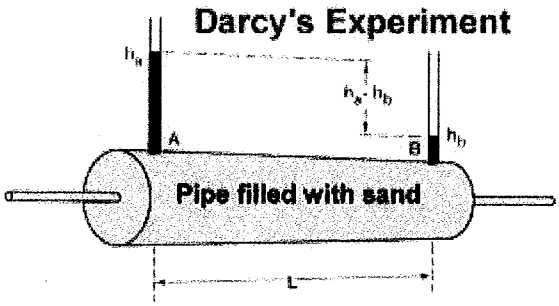
Henry Darcy was a French engineer who studied the movement of water through sand

in 1856. He found that the rate of water flow through a tube is proportional to the difference in the height of the water between the two ends of the tube, and inversely proportional to the length of the tube. He also discovered that flow was proportional to a coefficient, K, which is called *hydraulic conductivity*.

$Q \sim h_A - h_B$ and $Q \sim 1/L$ and $Q \sim K$



Darcy's Law is the resulting equation: $Q = KA[(h_A - h_B) / L]$ OR $Q = KA(dh/dl)$



(Modified from C.W. Fetter, 2)

where:

Q=volume of water flow in ft^3/day
K=hydraulic conductivity in ft/day
A=cross-sectional area in ft^2
dh/dl=hydraulic gradient

Although Darcy's Law was based only on slowly moving groundwater in confined aquifers, most of the laws (equations) developed for other aquifer conditions were derived from Darcy's equation.

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Velocity of Groundwater Movement

Based on Darcy's work, we can estimate the velocity of water or how fast the water is moving between points. Velocity is calculated by using hydraulic conductivity, porosity, and hydraulic gradient. $V=(K / n) (dh / dl)$, where: n=porosity.

In Portage County in the Sand-Plain Province, groundwater moves about:

- 3 ft/d in the Stevens Point & Plover area
- 1 ft/d west of Bancroft. [4]

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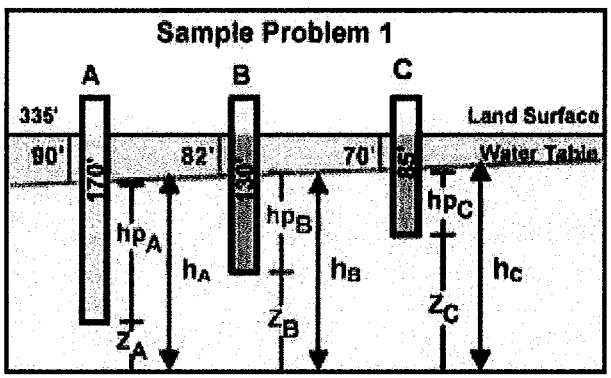
Using Numbers to Explain the Above Concepts

All of these words may be a little hard to understand, so let's use some numbers.

Problem 1

Data from three piezometers located within a few feet of each other is as follows:

	A	B	C
Elevation at land surface (ft)	335	335	335
Depth of monitoring well (ft)	170	130	85
Depth to water (ft below surface)	90	82	70



a. What is the hydraulic head (h) at each? (surface elevation - depth to water)

A=335-90=245 ft
B=335-82=253 ft
C=335-70=265 ft

b. What is the pressure head (h_p) at each? (depth of well - depth to water)

A=170-90=80 ft
B=130-82=48 ft
C=85-70=15 ft

c. What is the elevation head (z) at each? (land elevation - depth of well)

A=335-170=165 ft
B=335-130=205 ft
C=335-85=250 ft

d. What is the **vertical** hydraulic gradient between Well A and Well B? [(head $_B$ - head $_A$) / (depth well $_A$ - depth well $_B$)]

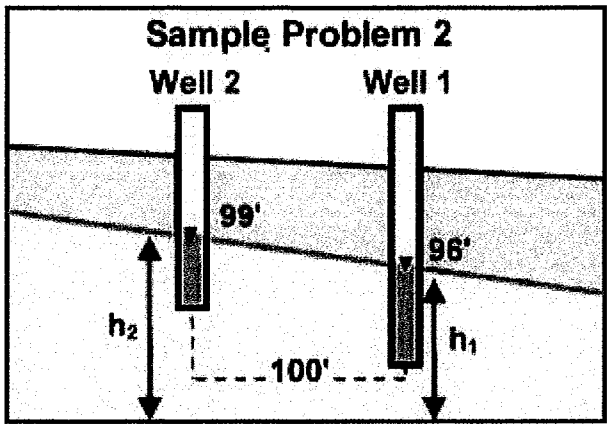
[(253-245) / (170-130)]=8/40 or 0.2 OR

[(head $_B$ - head $_A$) / (z_B - z_A)]
[(253-245) / (205-165)]=8/40 or 0.2

Problem 2

Two wells are located 100 feet apart in a sand aquifer with a hydraulic conductivity of 0.04 feet per day and 35% porosity. The head of well 1 is 96 feet and the head of well 2 is 99 feet.

a. What is the **horizontal** hydraulic gradient between the wells?



[(head $_2$ - head $_1$) / L

[(99-96) / (100)]=3/100 or 0.03

b. What is the velocity of water between the two wells?
V= (K / n) (dh / dl)

V= (0.04 ft/d / 0.35) (0.03)=0.0034 ft/d

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To learn more about other influencing factors on groundwater movement, click on one of the following: soil and aquifer properties, aquifer types, geology, and topography.

(*Italicized words* defined in the glossary.)

(Source for most of page: Applied Hydrogeology, third edition, by C.W. Fetter, 1994. [2]*)*

water cycle | groundwater defined | groundwater movement | groundwater storage | groundwater uses | contaminants | protection actions

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