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CEE 370 Environmental Engineering Principles

Lecture #21

Water Resources & Hydrology I: Groundwater

Reading: Mihelcic & Zimmerman, Chapter 7

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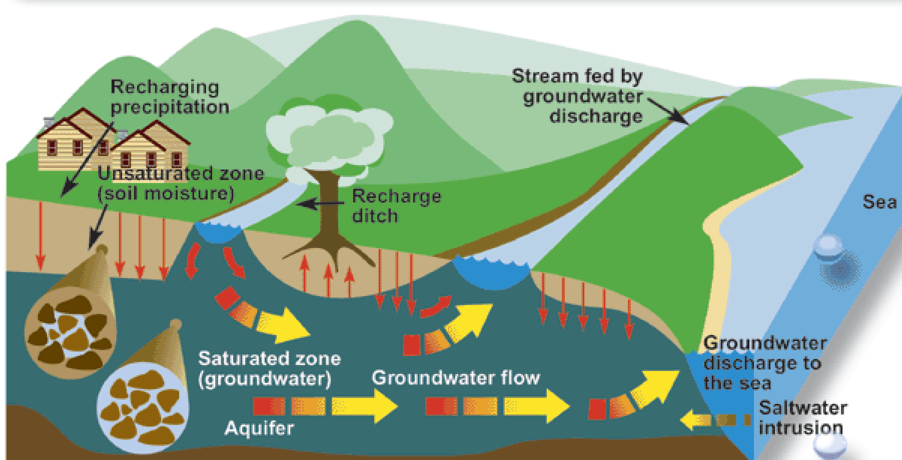
Groundwater flow



http://www.ec.gc.ca/water/images/nature/grdwtr/a5f2e.htm

D&M: Fig 6-19

Subsurface Hydrology

- Aquifers
  - Confined, unconfined, perched, artesian
- Saturated & unsaturated zone
  - Capillary fringe

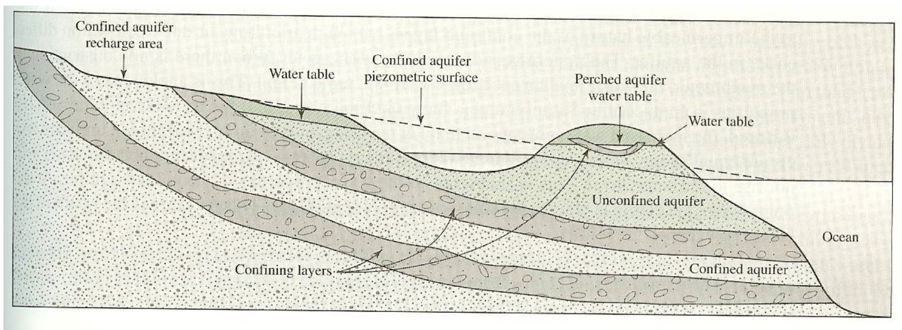
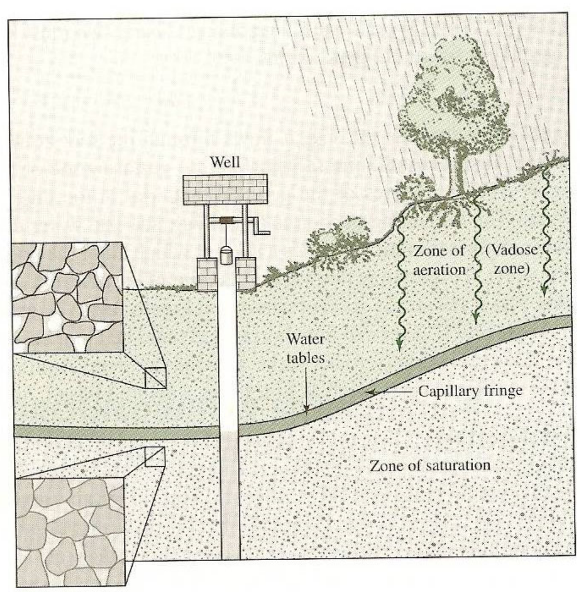


FIGURE 6–20

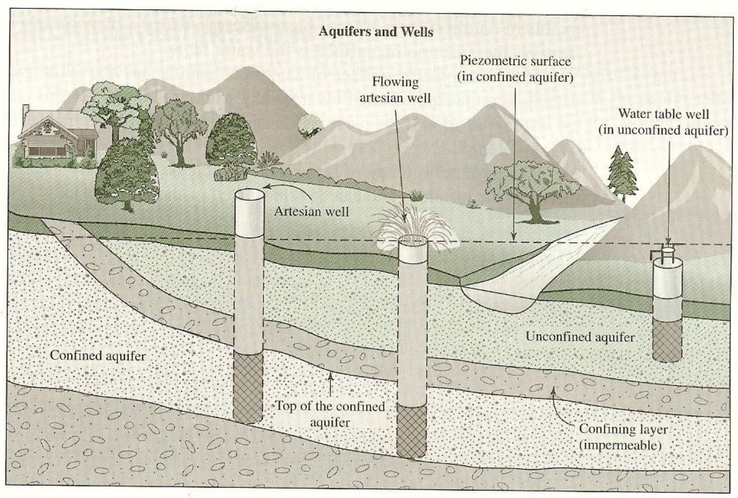
Schematic drawing showing the zones of aeration and saturation and the water table. Note how the surfaces of the soil particles in the zone of aeration are partially covered by water, whereas in the zone of saturation the pores are completely filled with water. Also note that in the unpumped well, the level of water is the same as the water table. (*Source:* Montgomery, C. *Environmental Engineering*, 6th ed. McGraw-Hill, Inc., New York, 2003. Reproduced with permission.)



Artesian vs unconfined

FIGURE 6–22

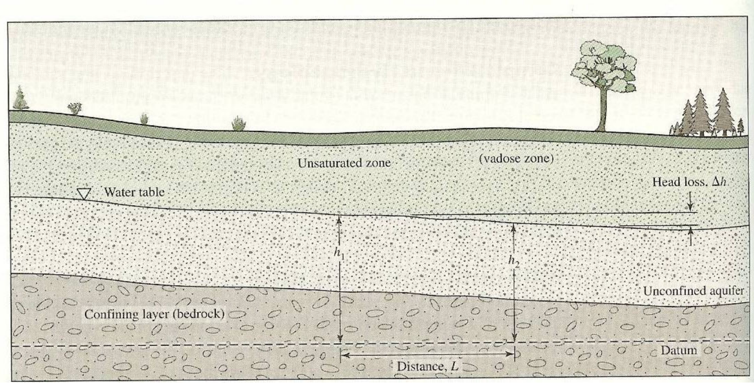
Schematic showing piezometric surface of artesian and flowing artesian wells. Note the piezometric surface for the flowing well is at ground surface. (*Source:* From: *Groundwater—Nature's Hidden Treasure, Environment* Canada, Ottawa, Canada, 1999. http://www.ec.gc.ca/water/en/info/pubs/FS/e_FSA5.htm image: http://www.ec.gc.ca/water/images/nature/grdwtr/a5f3e.jpg



Example

FIGURE 6–23

Schematic showing piezometric surface and datum in an unconfined aquifer.



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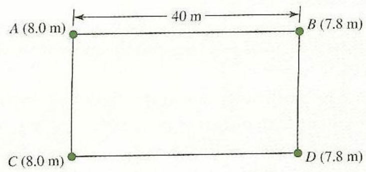
Example A

EXAMPLE 6–6 The head in an unconfined aquifer (Figure 6–23) has been measured at four locations as shown in the following schematic.



Using this information, determine the hydraulic gradient.

Solution The direction of flow is from *AC* to *BD*. The hydraulic gradient can be calculated using Equation 6–11

$$\frac{\Delta h}{L} = \frac{h_2 - h_1}{L} = \frac{8.0 - 7.8\ \text{m}}{40\ \text{m}} = 0.005\ \text{m} \cdot \text{m}^{-1}$$

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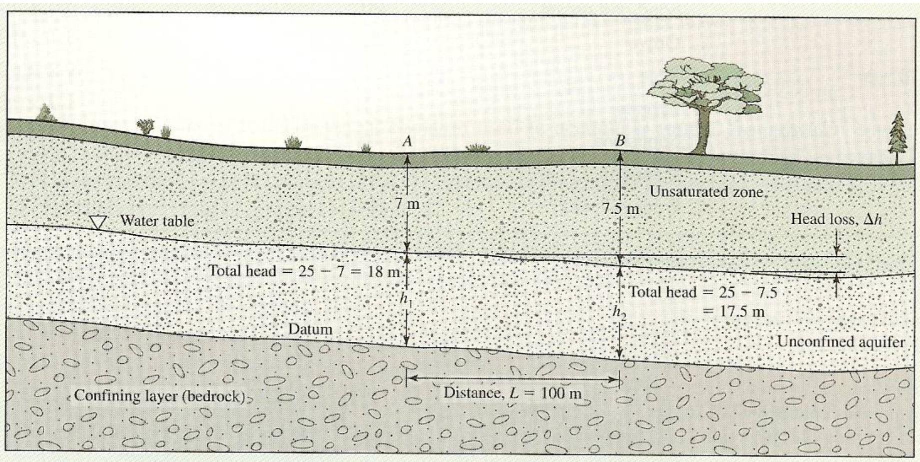
Hydraulic Gradient

- Example B

You are working for a construction company and are building a school. In digging the foundation you find water at 7 m bgs. One hundred meters away, you find water at 7.5 m bgs. Choose the datum as the confining layer that is 25 m bgs. What is the piezometric surface at each point, the direction of groundwater flow, and the hydraulic gradient? *Note:* This assumes that the confining layer is parallel to the surface, which may or may not be true; however, assuming this allows us to simplify a complicated problem.

The first thing we should do is to draw a picture illustrating the problem. Note that at point *A*, the depth to the water table is 7.0 m, whereas at point *B* the depth is 7.5 m. Using the datum given (at 25 m bgs), we can calculate the total head of water at each point.

David Reckhow CEE 370 L#23 8



Point A: Total head $= 25 - 7.0$ m $= 18$ m

Point B: Total head $= 25 - 7.5$ m $= 17.5$ m

The groundwater flow is from point A to B, from the higher piezometric surface to the lower. Using these two piezometric surfaces, the hydraulic gradient can be calculated as

$$\frac{\Delta h}{L} = \frac{h_2 - h_1}{L} = \frac{18.0 - 17.5\ \text{m}}{100\ \text{m}} = 0.005\ \text{m} \cdot \text{m}^{-1}$$

More Definitions

- Aquiclude – impermeable layer
- Aquitard – less permeable than aquifer
- Isotropic – aquifer conditions same in all directions
- Anisotropic – properties differ in different directions
- Homogeneous – characteristics uniform at different spatial locations
- Heterogeneous – characteristics non-uniform
- Springs – areas where water table intersects ground surface

Question

- All else being equal, groundwater flows fastest in an aquifer composed of:
  A. Sand
  B. Loam
  C. Silt
  D. Clay
  E. Granite

Hydraulic Conductivity

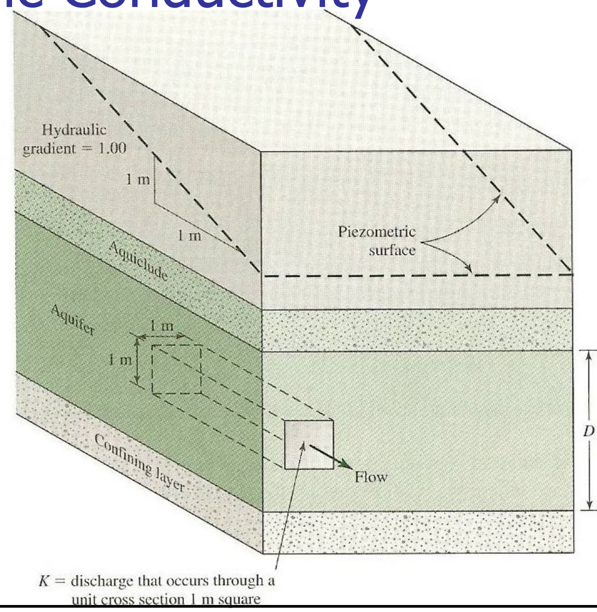
Typical Values of Aquifer Parameters

Aquifer Material	Porosity (%)	Typical Values for Hydraulic Conductivity ($m \cdot s^{-1}$)
Clay	55	2.3×10^{-9}
Loam	35	6.0×10^{-6}
Fine sand	45	2.9×10^{-5}
Medium sand	37	1.4×10^{-4}
Coarse sand	30	5.2×10^{-4}
Sand and gravel	20	6.0×10^{-4}
Gravel	25	3.1×10^{-3}
Slate	<5	9.2×10^{-10}
Granite	<1	1.2×10^{-10}
Sandstone	15	5.8×10^{-7}
Limestone	15	1.1×10^{-5}
Fractured rock	5	1×10^{-8}–1×10^{-4}

Hydraulic Conductivity

FIGURE 7-25

Illustration of definition of hydraulic conductivity (K).



- To next lecture