

# Hydrology II

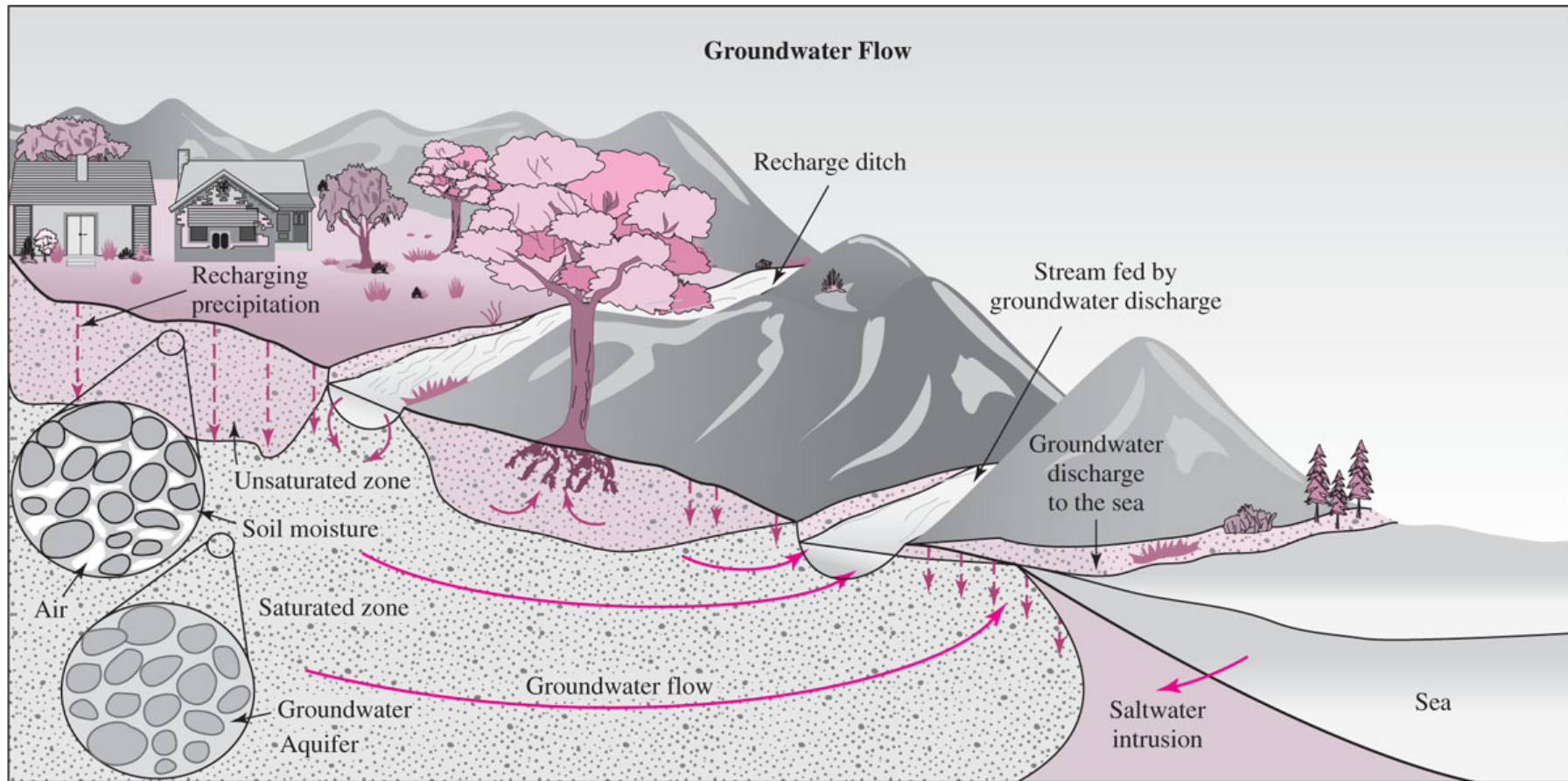
# Today's lecture

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- Groundwater hydrology
- Aquifers
- Piezometric head and surface
- Hydraulic gradient
- Darcy's Law

# Groundwater hydrology

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# Groundwater hydrology

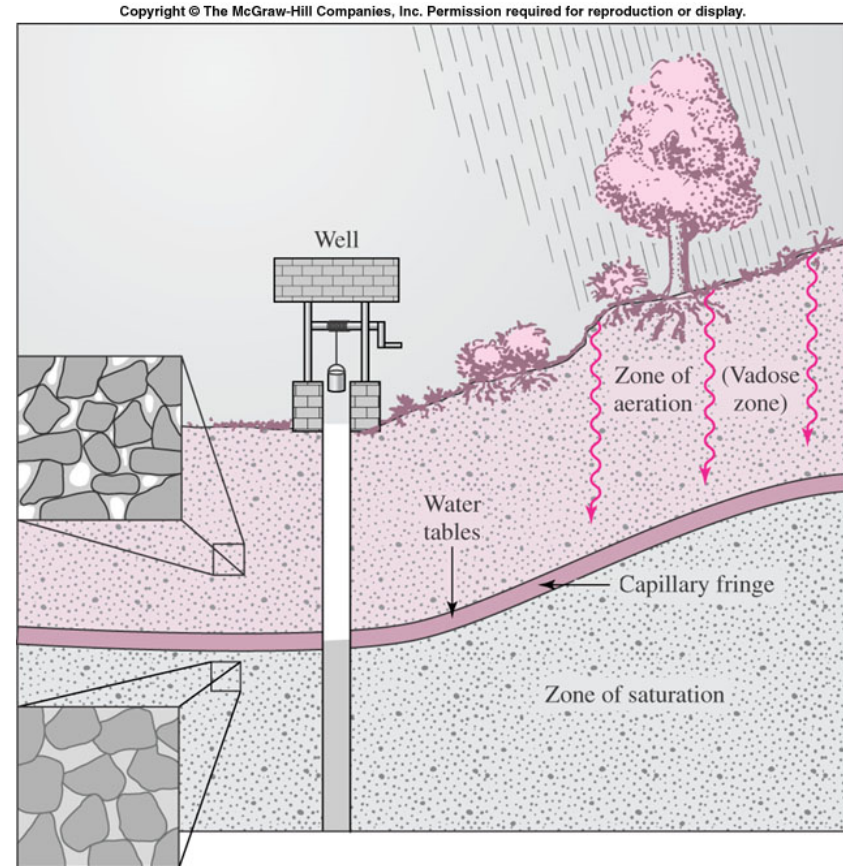
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- Unsaturated zone (vadose zone): the voids in the soils are partially filled with water (the remaining portion is filled with air)
- Saturated zone: all voids in the soils are filled with water
- Groundwater: the water in the saturated zone
- Aquifer: the geologic formation through which water can flow horizontally and be pumped (ex: sand, sedimentary rocks, limestone, etc.)

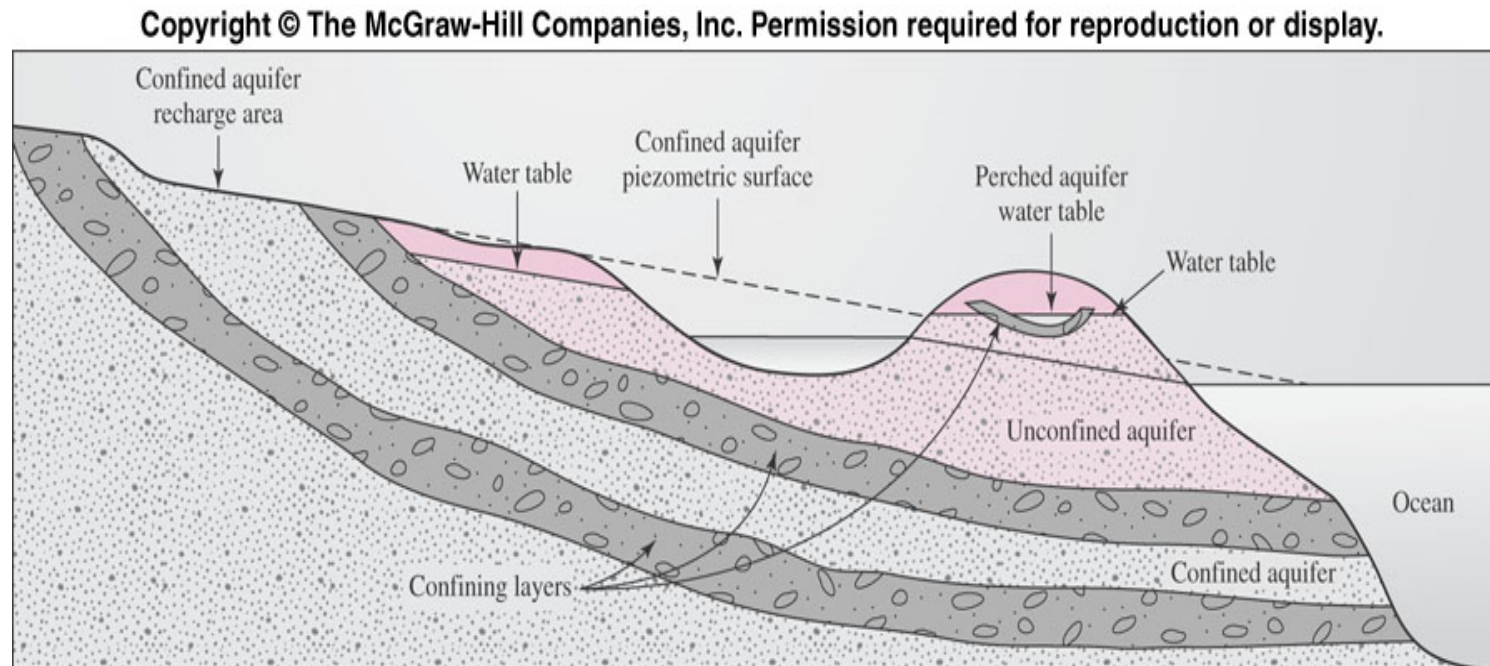
# Unconfined aquifer

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- Unconfined aquifer: an aquifer of which upper surface of its saturated zone is not confined by an impermeable layer
- Water table: The upper surface of the saturated zone in an unconfined aquifer
- Capillary fringe: the zone where capillary action occurs (the soil draws water above the water table)



# Confined aquifer



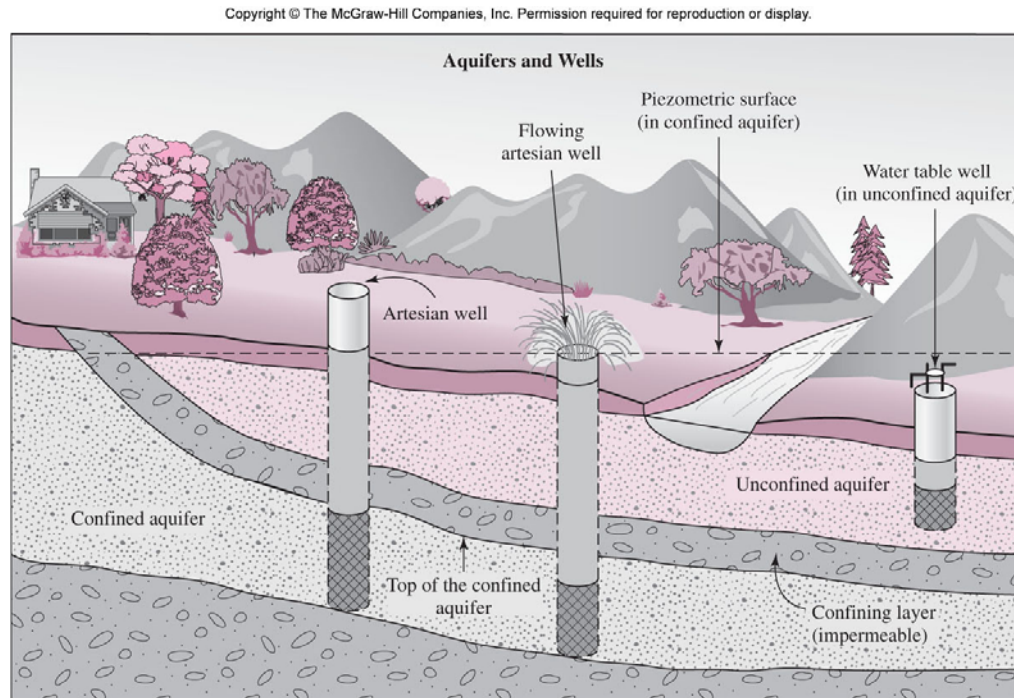
- Confined aquifer: an aquifer bounded by impermeable layers both at the top and the bottom

# Piezometric head and surface

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- Piezometer: a small tube device installed vertically into an aquifer
- Piezometric head: the height of the water in a piezometer → a measure of the pressure
- Piezometric surface: an impaginary plane drawn through the piezometric head of several piezometers

# Piezometric head and surface



- Unconfined aquifer: piezometric surface = water table
- Confined aquifer: piezometric surface is higher than the top end of the aquifer



# Groundwater flow

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- Keep in mind that:
  - (Of course) surface water flows from higher to lower elevation
  - Groundwater flows from areas of higher head to lower head
- Hydraulic gradient,  $\Delta h/L$

$$\frac{\Delta h}{L} = \frac{h_2 - h_1}{L}$$

$h_2$  = the head at location 2

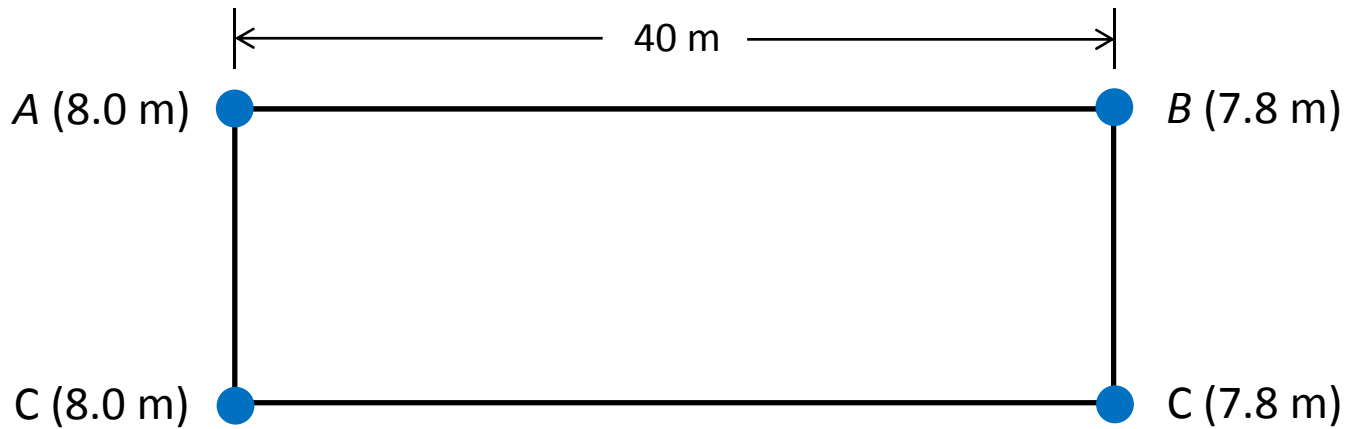
$h_1$  = the head at location 1

$L$  = the linear distance between location 1 and 2

# Hydraulic gradient

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Q: The head in an unconfined aquifer has been measured at four locations as shown in the following schematic:



Determine the direction of the flow and the hydraulic gradient.

# Darcy's Law

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$$v = K \frac{\Delta h}{L}$$

$v$  = Darcy velocity (specific discharge) [L/T]

$K$  = hydraulic conductivity [L/T]

The flow velocity is proportional to the hydraulic gradient and the hydraulic conductivity

In terms of the flow rate of groundwater,

$$Q = vA = \left( K \frac{\Delta h}{L} \right) A$$

$Q$  = flow rate [L<sup>3</sup>/T]

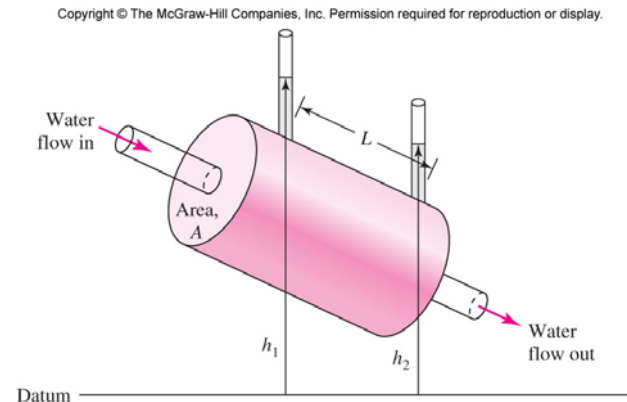
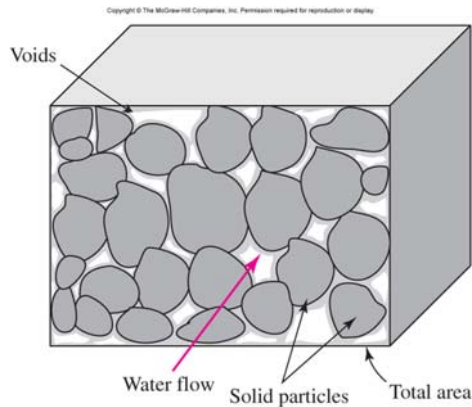
$A$  = cross-sectional area [L<sup>2</sup>]

# Darcy's Law

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Darcy's velocity  $v = Q/A$

This is **NOT** a real velocity: the groundwater flows only through the voids (pores), not the entire cross-sectional area



# Seepage velocity & porosity

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- The average linear velocity (**seepage velocity**),  $v'$

$$v' = \frac{v}{\eta} \quad \eta = \text{porosity [-]}$$

- Porosity: the ratio of the volume of voids (pores) in the aquifer material to the total volume

# Typical values of aquifer parameters

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

Sources: Davis, M., D. A. Cornwell. *Introduction to Environmental Engineering*, 3rd ed. McGraw-Hill, New York (1998). Todd, D. A. *Groundwater Hydrology*, 2nd ed. John Wiley and Sons, New York (1980)

# Groundwater flow

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**Q:** While investigating the ground near Bldg. 35, you found water at 7 m below ground surface (bgs). One hundred meters away, you found water at 7.5 m bgs. Choose the datum as 25 m bgs. The aquifer is coarse sand which has a porosity of 30% and the hydraulic conductivity of  $5.2 \times 10^{-4}$  m/s. The cross-sectional area of the aquifer is  $925 \text{ m}^2$ . Determine the i) piezometric surface at each point, ii) the direction of groundwater flow, iii) the hydraulic gradient, iv) the Darcy velocity, v) the flow rate, and vi) the seepage velocity.

# Reading assignment

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Textbook Ch 7 p. 276-285