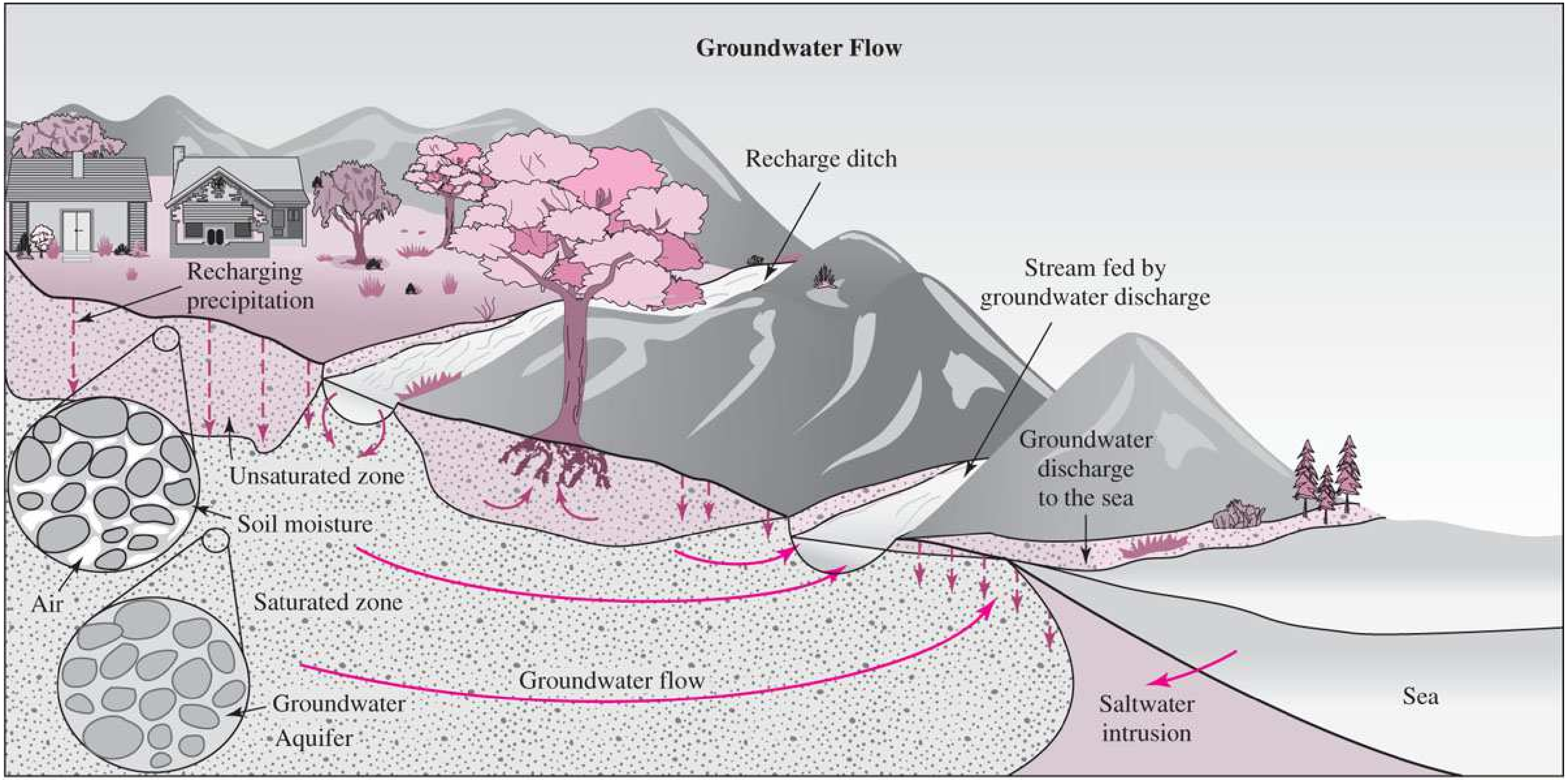
Groundwater hydrology

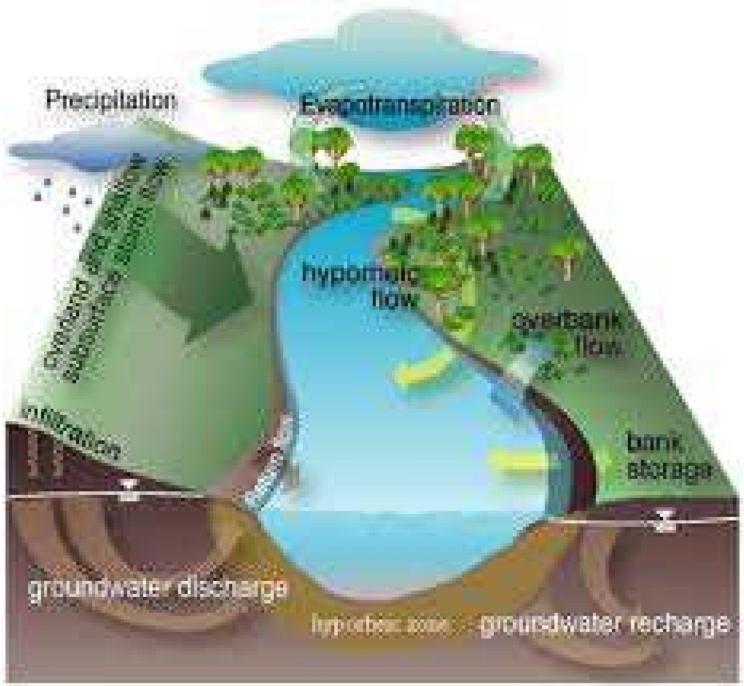


Groundwater hydrology

- 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.)

Groundwater hydrology

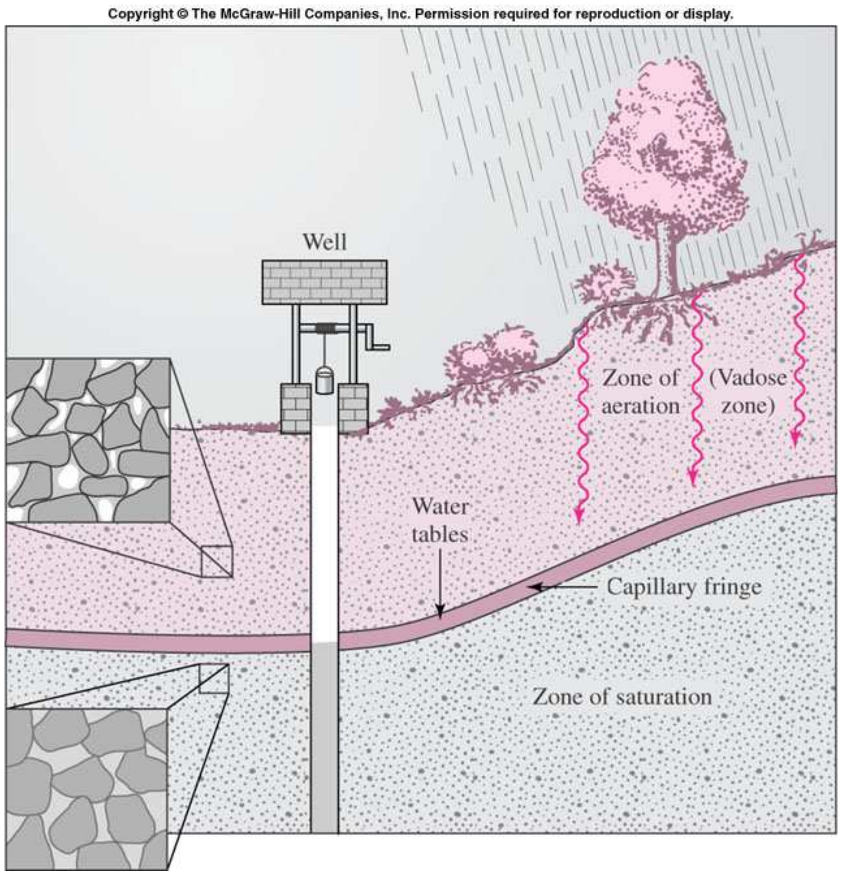
- Hyporheic zone
  - A region beneath and alongside a stream bed, where there is mixing of shallow groundwater and surface water
  - Important for:
    - Exchange of substances (e.g., nutrients, dissolved O_2, contaminants) between groundwater and surface water
    - Aquatic ecosystem – e.g., fish spawning, benthic invertebrates, microbes



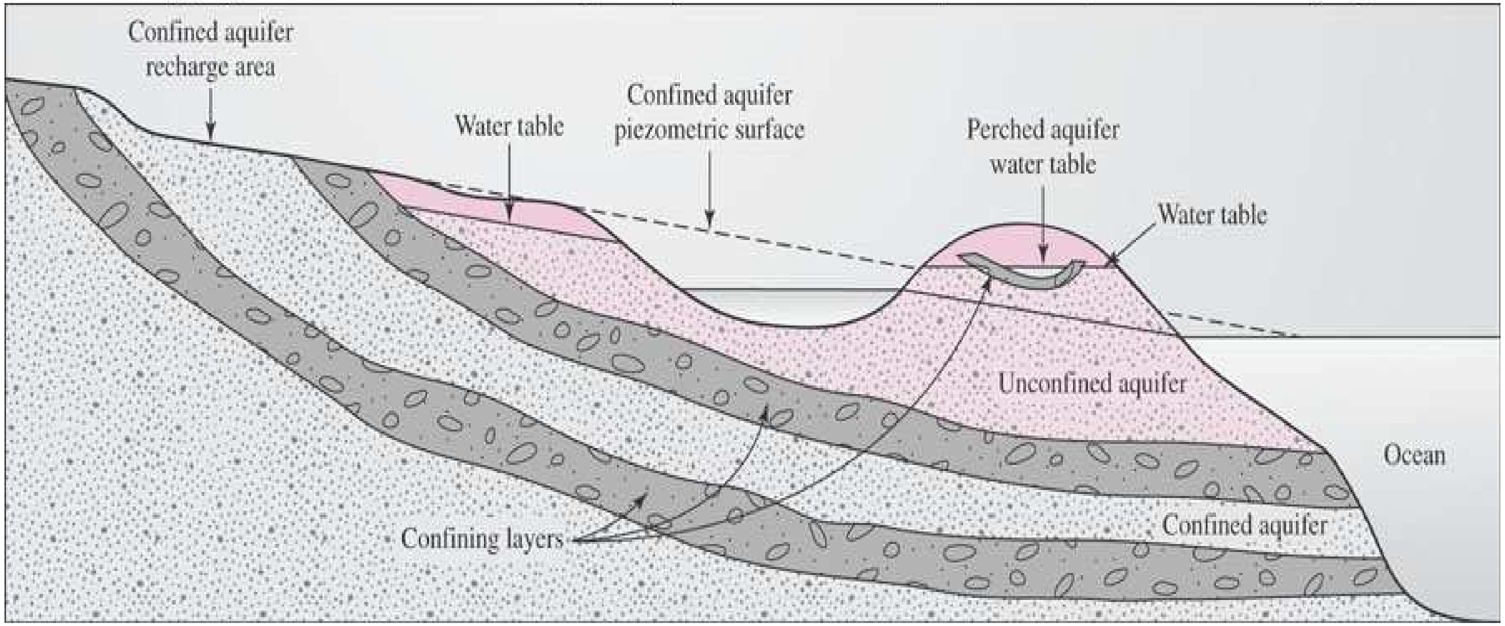
http://www.madrimasd.org

Unconfined aquifer

- **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

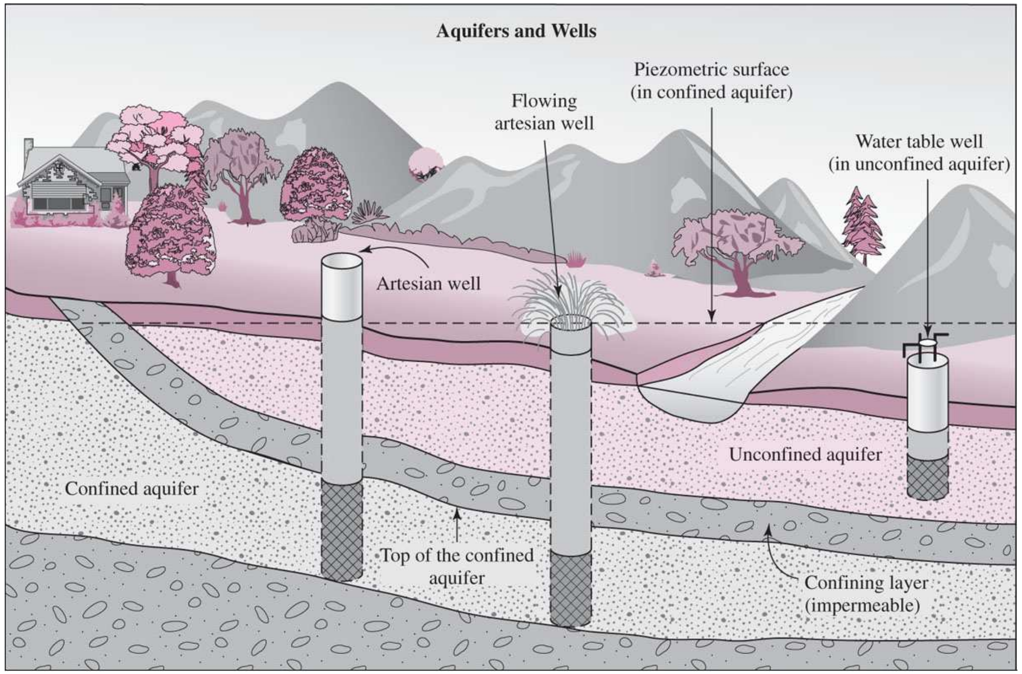


- **Confined aquifer**: an aquifer bounded by impermeable layers (called as confining layers) both at the top and the bottom
- Confining layers: *aquicludes* or *aquitards*

Piezometric head and surface

- 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

- 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

Darcy's Law

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

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,

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

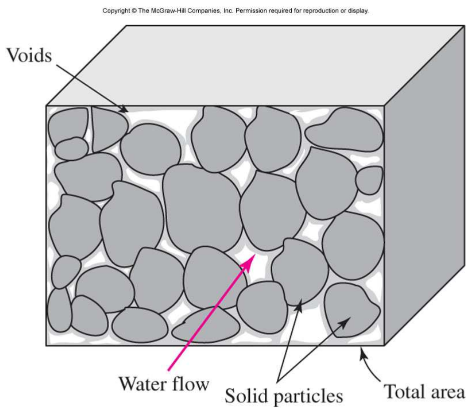
Q = flow rate [L^3/T]

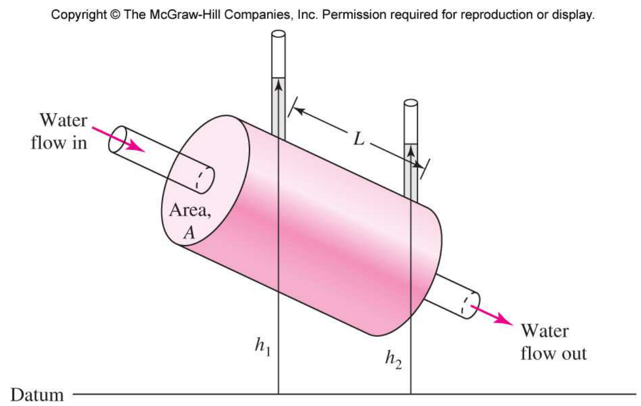
A = cross-sectional area [L^2]

Darcy’s Law

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

- The average linear velocity (**seepage velocity**), *v′*

$$v' = \frac{v}{\eta}$$

η = porosity [-]

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

Typical values of aquifer parameters

Typical Values of Aquifer Parameters

Aquifer Material	Porosity (%)	Typical Values for Hydraulic Conductivi[ty] ($m \cdot s^{-1}$)
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}

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

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 5.2×10^{-4} m/s. The cross-sectional area of the aquifer is 925 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

Textbook Ch 7 p. 276-285