2 주 (150 분)

6. Hydrology

Hydrosphere:

Atmosphere:

Water (1) transport substances in our body

(2) plays an important role in the body's thermal regulation system

(3) functions as an important reactant in the food chain

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow \text{metabolic energy} + 6\ CO_2 + 6\ H_2O$$

Water Balance and Residence Time of Water

Table 1.1 Estimate of the Water Balance of the World

Parameter	Surface area $(km^2)\times10^6$	Volume $(km^3)\times10^6$	Volume (%)	Equivalent depth (m)*	Residence time
Oceans and seas	361	1370	94	2500	~4000 years
Lakes and reservoirs	1.55	0.13	<0.01	0.25	~10 years
Swamps	<0.1	<0.01	<0.01	0.007	1–10 years
River channels	<0.1	<0.01	<0.01	0.003	~2 weeks
Soil moisture	130	0.07	<0.01	0.13	2 weeks–1 year
Groundwater	130	60	4	120	2 weeks–10,000 years
Icecaps and glaciers	17,8	30	2	60	10–1000 years
Atmospheric water	504	0.01	<0.01	0.025	~10 days
Biospheric water	<0.1	<0.01	<0.01	0.001	~1 week

SOURCE: Nace, 1971.

*Computed as though storage were uniformly distributed over the entire surface of the earth.

- The dominant water stocks used by humans are (1) ,
  (2) , (3) .
- These water resources constitute a very small fraction of the hydrosphere.
- According to the residence times, groundwater is a nonrenewable resource surface on the other hand freshwater is a renewable.
- Accessible freshwater stocks and flows are irregularly distributed in space and time. To balance the temporal and spatial mismatch between supply and demand, en excessive and complex system of reservoirs, aquaducts, and pumping stations has been developed.

Physicochemical Properties of Water

- An unique material which exists in all three phases over the range of ordinary environmental conditions (e.g., temperatures and pressures)
- High latent heats(잠열) and specific heat (비열)

  latent heats: the amount of energy to cause a phase change (e.g., 334J for melting 1g of ice, and 2450J for evaporation 1g of liquid water)

  specific heat: the amount of energy to heat liquid water (420J for heating 1g of liquid water from 0 to 100^{o}C)

  Especially, high latent heat for evaporation is important in buffering the earth's environment against large temperature changes as shown in humid tropics has less temperature change than the arid deserts.
- The optical properties of water play an important role in affecting climate

  Since the mass of water (transparent) that is heated by sunlight is greater than the mass of soil (opaque), the temperature increase caused by sunlight is much lower for water than soil.

  Incoming solar radiation may be scattered by clods back to space, reducing the heating of the earth's surface; Both water vapor molecules and droplets absorb long-wavelength radiation that is emitted from the earth' s surface, warming the earth. (Why clouds with higher water content looks gray or black? More absorb a incident visible radiation rather than scattering)
- For environmental purposes, water can be considered an incompressible fluid. The density of liquid water can be treated as constant even for wastewater streams (e.g., 1,000 kg/m^3 = 1 kg/L = 1 g/cm^3)
- more dense as a liquid than as a solid

  Lake freezes from top.

  Freezing water bursts pipes.

  Freeze-thaw (expansion-contraction) cycle results in fractures in rocks, concrete, and asphalt.
- Movement of water alters the physical landscape.

Glacial sculpting

Ocean surf and river scour

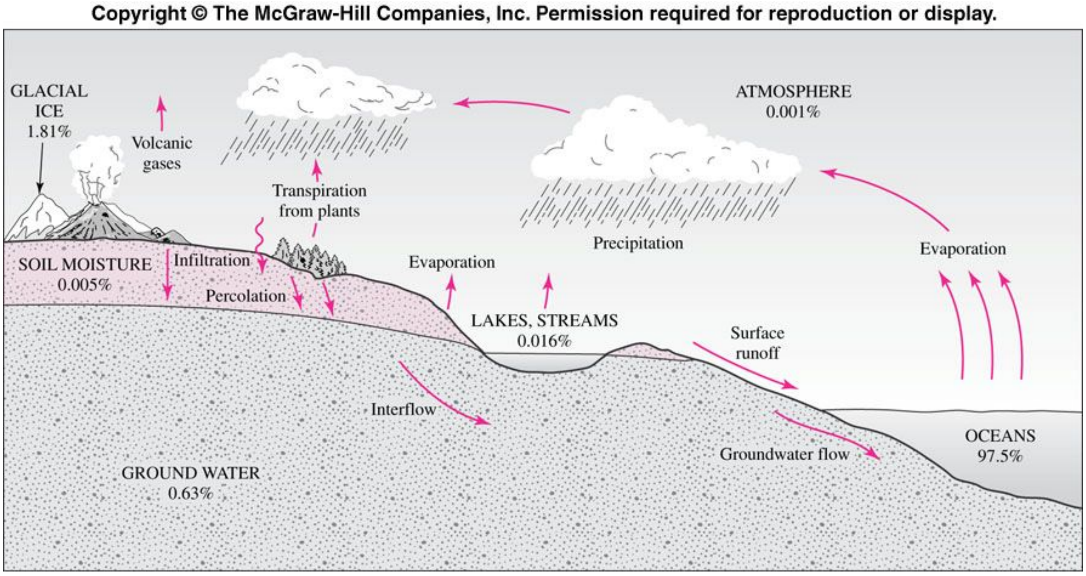
A chemical solvent (even a weak solvent)

- Viscosity of water varies by almost a factor of 3 over the typical range of liquid water temperature

Viscosity affects the rate of movement of water through pipes and through soil, and also the rate of movement of suspended particles through water.

6.1 Hydrologic Cycle

- hydrologic cycle: The movement and conservation of water on earth



- Water transfer to the atmosphere: (1) evaporation + (2) transpiration = evapotranspiration
- Water release from the atmosphere: precipitation (e.g., rain, snow, etc.)
- The net amount (mass) of water that is gained or lost in a water body (e.g., lake) within a given period = "Storage problem"

[Mass rate of accumulation] = [Mass rate in] – [Mass rate out]

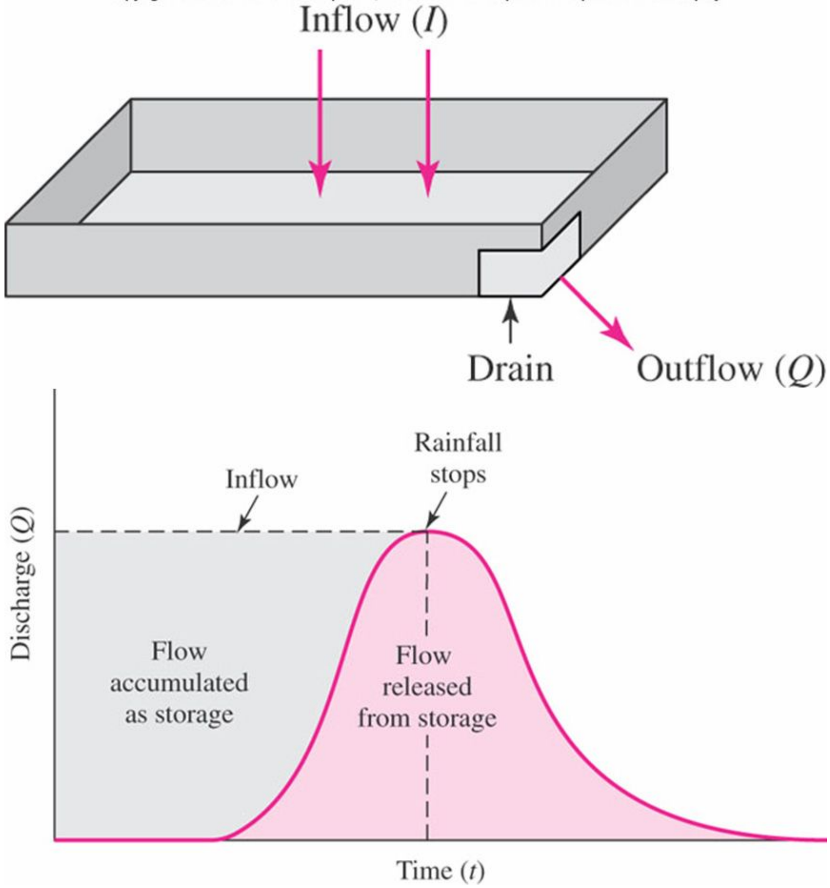
For example, a lake (eq. 6-2, p.191)

Mass rate of accumulation = Flowrate of streams entering lake
+ Rate of precipitation
+ Rate of Runoff
+ Rate of seepage into lake
- Flowrate of streams exiting lake
- Rate of evaporation from water bodies
- Rate of evapotranspiration
- Rate of seepage out of the lake

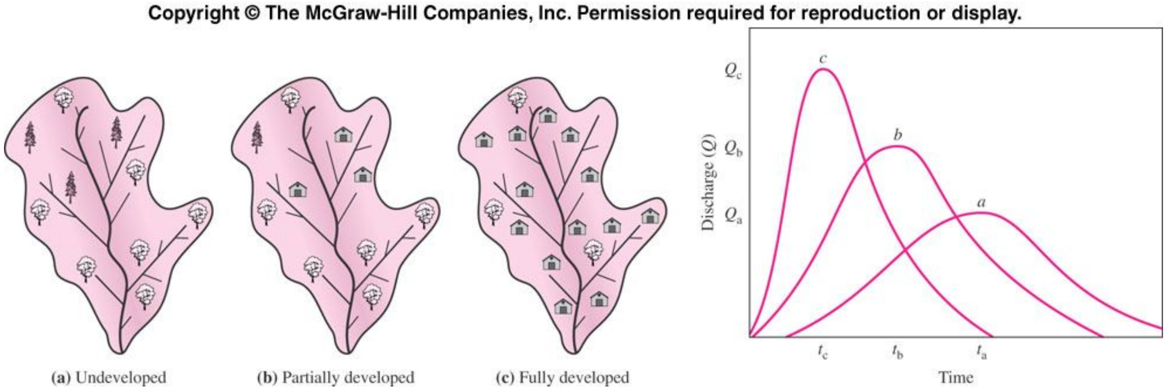
For practical application, dimension conversion is necessary (eq. 6-3, p.192).

EXAMPLE 6–1 Hvarekhshaeta Lake has a surface area of 708,000 m^2. Based on collected data, Drvaspa Brook flows into the lake at an average rate of 1.5 $m^3 \cdot s^{-1}$ and the Vouruskasha River flows out of Hvarekhshaeta Lake at an average rate of 1.25 $m^3 \cdot s^{-1}$ during the month of June. The evaporation rate was measured as 19.4 $cm \cdot month^{-1}$. Evapotranspiration can be ignored because there are few water plants on the shore of the lake. A total of 9.1 cm of precipitation fell this month. Seepage is negligible. Due to the dense forest and the gentle slope of the land surrounding the lake, runoff is also negligible. The average depth in the lake on June 1 was 19 m. What was the average depth on June 30th?

- Hydrograph: a chart in which flow rate is plotted versus time



- The shape of hydrograph depends on the slope of the land, density and type of ground cover, (e.g., degree of development), and time (e.g., seasonal and annual basis).



- Runoff coefficients:

TABLE 6–1 Typical Runoff Coefficients

Description of Area or Character of Surface	Runoff Coefficient	Description of Area or Character of Surface	Runoff Coefficient
Business		Railroad yard	0.20–0.35
Downtown	0.70–0.95	Natural grassy land	0.10–0.30
Neighborhood	0.50–0.70	Pavement	
Residential		Asphalt, concrete	0.70–0.95
Single-family	0.30–0.50	Brick	0.70–0.85
Multi-units, detached	0.40–0.60	Roofs	0.75–0.95
Multi-units, attached	0.60–0.75	Lawns, sandy soil	
Residential, suburban	0.25–0.40	Flat (< 2%)	0.05–0.10
Apartment	0.50–0.70	Average (2–7%)	0.10–0.15
Industrial		Steep (> 7%)	0.15–0.20
Light	0.50–0.80	Lawns, heavy soil	
Heavy	0.60–0.90	Flat (< 2%)	0.13–0.17
Parks, cemeteries	0.10–0.25	Average (2–7%)	0.18–0.22
Playgrounds	0.20–0.35	Steep (> 7%)	0.25–0.35

Source: Joint Committee of the American Society of Civil Engineers and the Water Pollution Control Federation. *Design and Construction of Sanitary and Storm Sewers* (ASCE Manuals and Reports on Engineering Practice No. 37, or WPCF Manual of Practice No. 9), American Society of Civil Engineers, New York, (1969), p. 51.

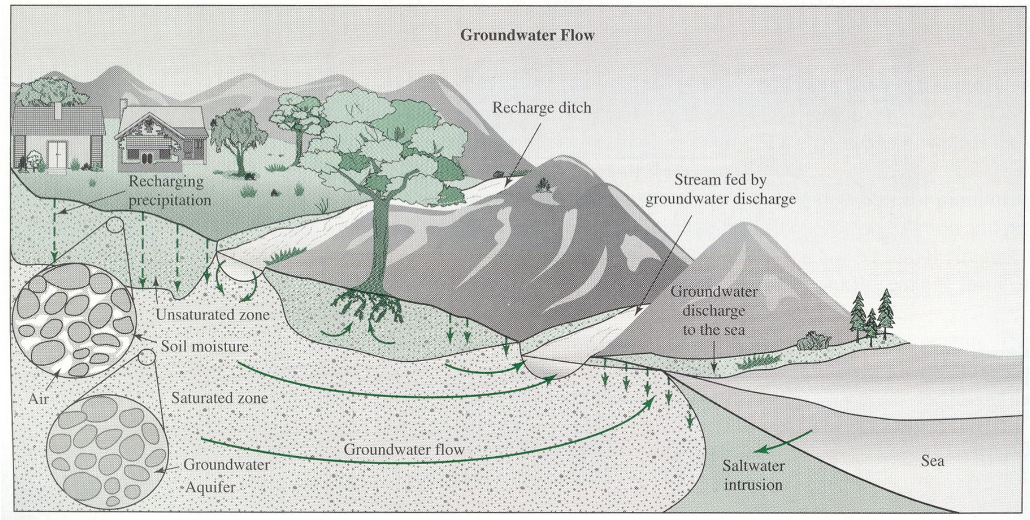
6.2 Measurement of Precipitation, Evaporation, Infiltration, and Streamflow

(reading assignment)

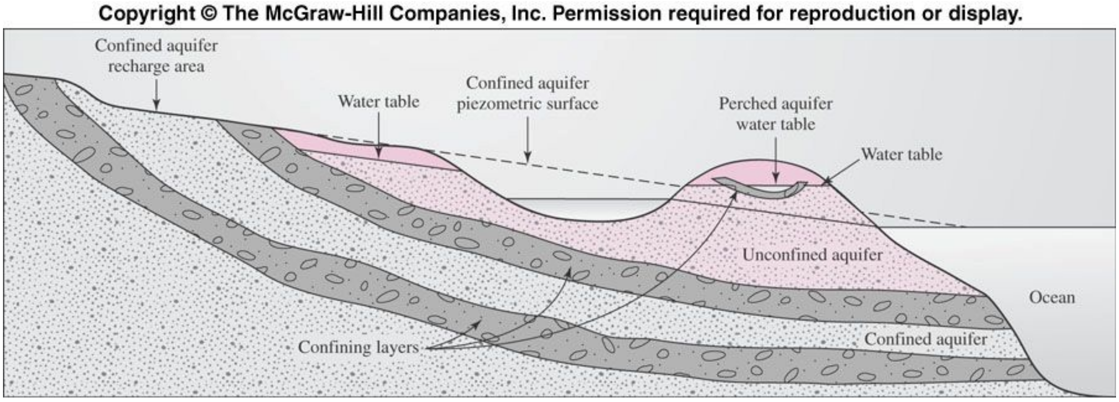
6.3 Groundwater Hydrology

FIGURE 6–18

Elements of groundwater flow. (*Source: The Nature of Water, Groundwater—A Major Link in the Hydrologic Cycle.* Environment Canada, Ottawa, Canada.
site: www.ec.gc.ca/water/en/nature/grdwtr/e-link.htm
image: http://www.ec.gc.ca/water/images/nature/grdwtr/a5f2e.htm)



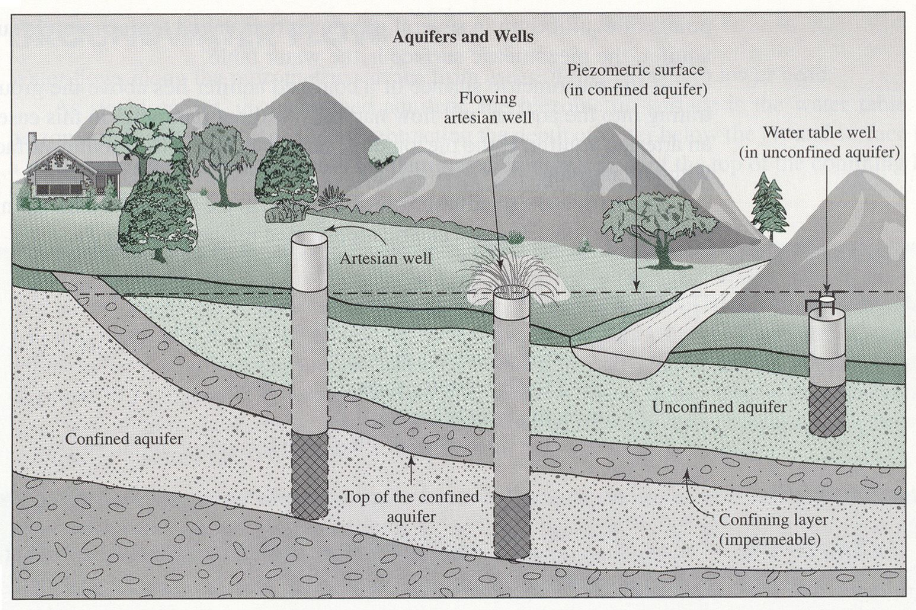
- Aquifers



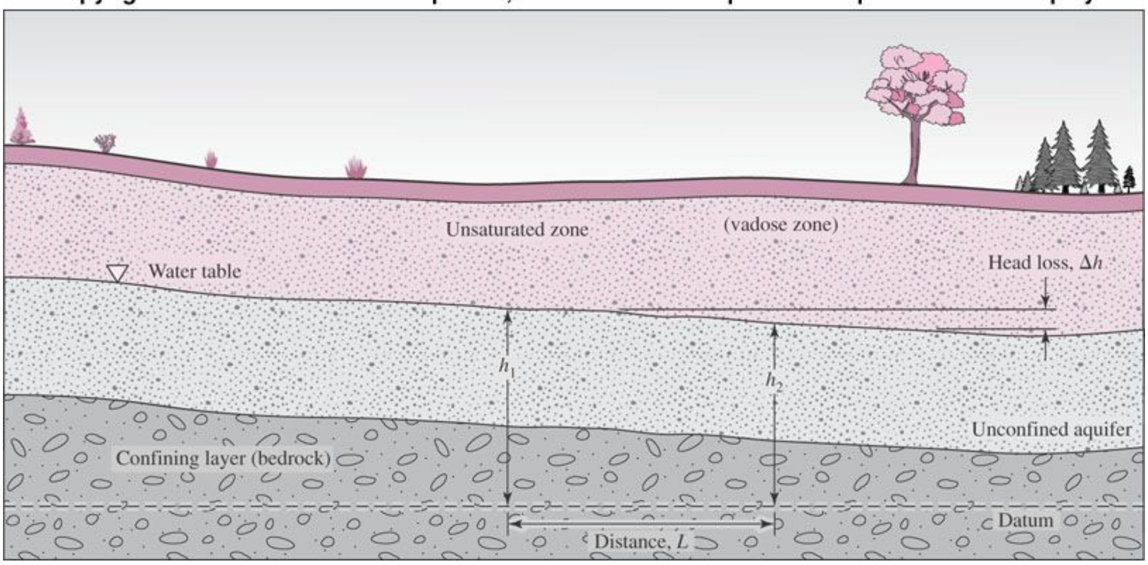
- Piezometric surface and head

FIGURE 6–22

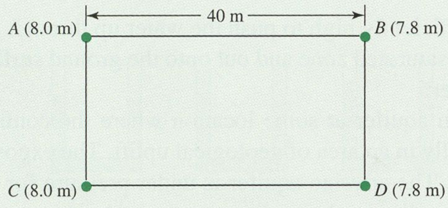
Schematic showing piezometric surface of artesian and flowing artesian wells. Note the piezometric surface for the flowing well is at ground surface. (*Source:* From: *Groundwater—Nature's Hidden Treasure, Environment Canada*, Ottawa, Canada, 1999. http://www.ec.gc.ca/water/en/info/pubs/FS/e_FSA5.htm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



- Groundwater flow



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.

EXAMPLE 6–8 Let's assume that in the previous example, the aquifer is coarse sand and that the cross-sectional area of the aquifer, through which water flows is 925 m^2. What is the Darcy velocity of groundwater in this aquifer? What is the specific discharge?

EXAMPLE 6–9 The geological material in the column shown in Figure 6–25 is coarse sand. The piezometric surfaces, $h_1 = 10$ cm and $h_2 = 8.0$ cm. The distance between the two points where h_1 and h_2 were measured is 10.0 cm. The cross-sectional area is 10 cm^2. What is the linear velocity of the water flowing through the column?

6.5 Surface water and Groundwater as a Water supply

FIGURE 6–27

(a) Percentage of the population served by drinking-water system source. **(b)** Percentage of drinking-water systems by supply source. **(c)** Number of drinking-water systems (in thousands) by size. **(d)** Population served (in millions of people) by drinking-water system size. (*Source: 1997 National Public Water Systems Compliance Report.* U.S. EPA, Office of Water. Washington, D.C. 20460. (EPA-305-R-99-002). (*Note: Small systems serve 25–3300 people; medium systems serve 3301–10,000 people; large systems serve 10,000+ people.*)