Water quality I

Today's lecture

- Sources of water pollutants
- Types of water pollutants
- Oxygen demand: ThOD, COD, BOD

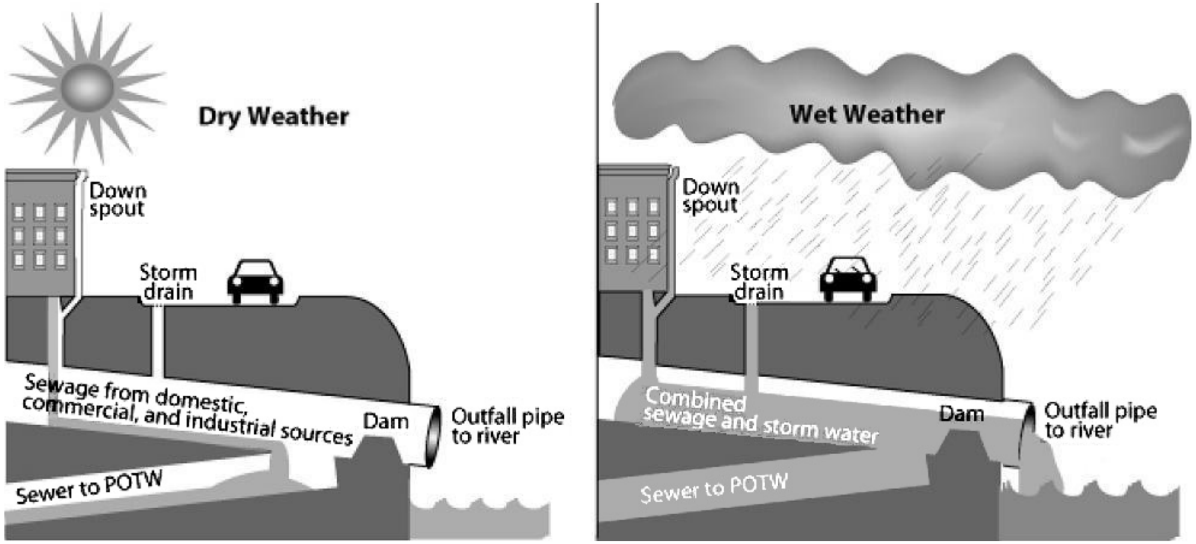
Sources of water pollutants

- **Point sources**: collected by a network of pipes of channels and conveyed to a single point of discharge
  – ex: domestic sewage, industrial wastewater

- **Nonpoint sources**: have multiple and diffuse discharge points
  – ex: urban and agricultural runoff

Combined sewer overflow (CSO)

- A nonpoint pollution problem
- Combined sewer system (↔ separate sewer system)
  - The sewage mixed with the storm water may go directly to the river (**C**ombined **S**ewer **O**verflow)
  - Generally no longer constructed in the developed world, but old cities may still have the combined sewer



USEPA (2004)

Types of water pollutants

Oxygen-demanding material

- Any substances that can be oxidized in the water resulting in the consumption of dissolved molecular oxygen (DO)
- Mostly biodegradable organic matter, but also includes inorganics (ex: ammonia)
- Low DO poses a threat to fish and other higher forms of aquatic life that requires oxygen
- Major source: human waste, food residue, industry (esp. food-processing & paper industries)

Nutrients

- Major: nitrogen (N) & phosphorus (P)
- Excessive nutrients → excessive algal growth
- Major source: agricultural runoff, human and animal excrement, P-based detergents, fertilizers, food-processing wastes
- Agricultural runoff may cause significant nutrient loadings to the water

Pathogens

- Bacteria, viruses, protozoa, and helminthes
- Excreted by diseased persons or animals
- Occurrence of pathogens in drinking water may cause outbreaks of gastrointestinal infections

1993 Milwaukee Cryptosporidiosis outbreak

The 1993 Milwaukee Cryptosporidiosis outbreak was a significant distribution of the Cryptosporidium protozoan in Milwaukee, Wisconsin, and the largest waterborne disease outbreak in documented United States history. The Howard Avenue Water Purification Plant was contaminated, and treated water showed turbidity levels well above normal. It was one of two water treatment plants for Milwaukee. The root cause of epidemic was never officially identified; initially it was suspected to be caused by the cattle genotype due to runoff from pastures. It was also thought that melting ice and snowmelt carrying *Cryptosporidium* may have entered the water treatment plants through Lake Michigan. MacKenzie et al. and the CDC showed that this outbreak was caused by *Cryptosporidium* oocysts that passed through the filtration system of one of the city's water-treatment plants, arising from a sewage treatment plant's outlet 2 miles upstream in Lake Michigan.

Milwaukee Cryptosporidiosis outbreak (cont'd)

This abnormal condition at the water purification plant lasted from March 23 through April 8, after which, the plant was shut down. Over the span of approximately two weeks, 403,000 of an estimated 1.61 million residents in the Milwaukee area (of which 880,000 were served by the malfunctioning treatment plant) became ill with the stomach cramps, fever, diarrhea and dehydration caused by the pathogen. At least 104 deaths have been attributed to this outbreak, mostly among the elderly and immunocompromised people, such as AIDS patients.

(*Wikipedia, 2014*)

Suspended solids (SS)

- Particles carried by water
- When the water flow slows down, most SS settle down, but colloidal particles do not settle readily
- Cause turbidity in water and may destroy habitat for benthic organisms

Salts

- Often measured as total dissolved solids (TDS)
  - TDS measurement: (i) filter the water sample, (ii) evaporate water by heating the filtered water sample, (iii) weigh the solids remaining after evaporation
  - Most of the dissolved solids in water are salts

- Evaporation of water from reservoirs, canals, and during application to plants increases salinity

- Increased salinity causes reduction in crop yield & threats to aquatic life

Pesticides

- Herbicides, insecticides, fungicides, …
- Kills herbs, insects, fungi, … → why not toxic to humans?
- Migrates to surface water by runoff; to groundwater by infiltration

PESTICIDE MOVEMENT IN THE ENVIRONMENT

Pesticides have the potential to move after they are first applied. Where they go and how long they may last can depend on many factors. The combination of the following factors influences pesticide movement.

PLANTS

Some pesticides are not easily taken up by plants, and some plant types take up pesticides more than others.

- PLANT UPTAKE
- SOIL BINDING
- PESTICIDE USED
- PLANT TYPE

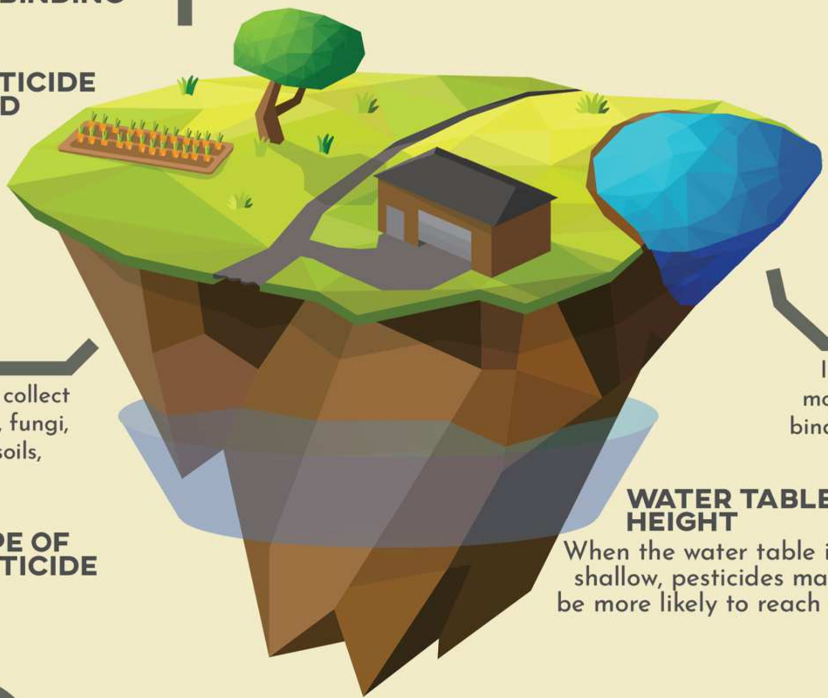
AIR

Increasing temperature, sunlight, and rain may increase pesticide breakdown. This and other weather conditions affect the potential for pesticide movement.

ENVIRONMENTAL CONDITIONS

DROPLET SIZE

- SMALL DROPLETS CARRY FURTHER BUT DISSIPATE FASTER
- LARGE DROPLETS FALL FASTER BUT STAY ON TARGET BETTER



SOIL

Some soils hold onto pesticides more easily, or collect water so pesticides don't move as far. Bacteria, fungi, and other microbes vary across locations and soils, which can also affect pesticide breakdown.

- TYPE OF PESTICIDE
- SOIL TYPE
- SOIL CHEMISTRY
- MICROBIAL COMMUNITY

NATURAL WATER

If a pesticide does reach water, it may not move as much as you think. Some pesticides bind tightly to sediment where they settle out.

WATER TABLE HEIGHT
When the water table is shallow, pesticides may be more likely to reach it.

- LAND PROFILE
- SEDIMENT BINDING
- WATER MOVEMENT

For more information about pesticides or their movement in the environment, contact us M-F 8am-12pm PST at 800-858-7378.

npic NATIONAL PESTICIDE INFORMATION CENTER

Pharmaceuticals and personal care products (PPCP)

- Of recent interest
- Substances used by humans and pets for health or cosmetic reasons and the products used to boost growth or health of livestock
- Sources: human activity, residues from manufacturing, residues from hospitals, illegal drugs, drug use to animals (antibiotics and steroids)


Drug Facts
Active ingredient
Purpose
Triclosan 0.10% ....Antibacterial hand soap
Use • for handwashing to decrease bacteria on the skin
Warnings
For external use only
Keep out of reach of children. In case of accidental ingestion, drink a glass of water to dilute. If eye contact occurs, rinse thoroughly with water.
Directions • wet hands and forearms. Apply 5 ml or palmful to hands and forearms. Scrub thoroughly for 30 sec. and rinse.
INACTIVE INGREDIENTS: WATER, SODIUM LAURYL SULFATE, SODIUM LAURETH SULFATE, LAURAMINE OXIDE, ALCOHOL DENAT., SODIUM CHLORIDE, PPG-26, PEG-8 PROPYLHEPTYL ETHER, PEI-14 PEG-10/PPG-7 COPOLYMER, PHENOXYETHANOL, METHYLISOTHIAZOLINONE, FRAGRANCE, YELLOW 5, RED 33.

Endocrine disrupting chemicals (EDCs)

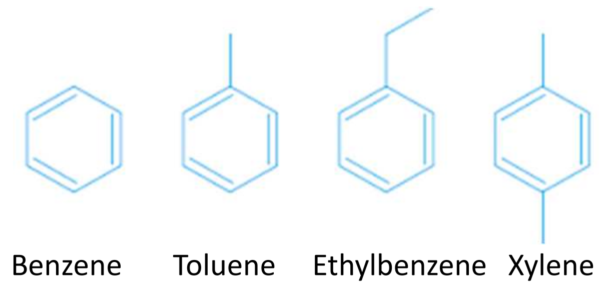
- Compounds mimicking hormones
- Examples:
  - polychlorinated biphenyls (PCBs): coolant, insulator, plasticizer
  - atrazine: pesticide
  - phthalates: plasticizer
  - bisphenol A (BPA): making plastics
  - natural and synthetic estrogen
    - contraceptive pills: 17α-ethynylestradiol (EE2)

- May cause adverse effects at relatively low concentrations
- Can interfere with the regulation of reproductive and developmental processes or alter the normal physiological function of the endocrine system

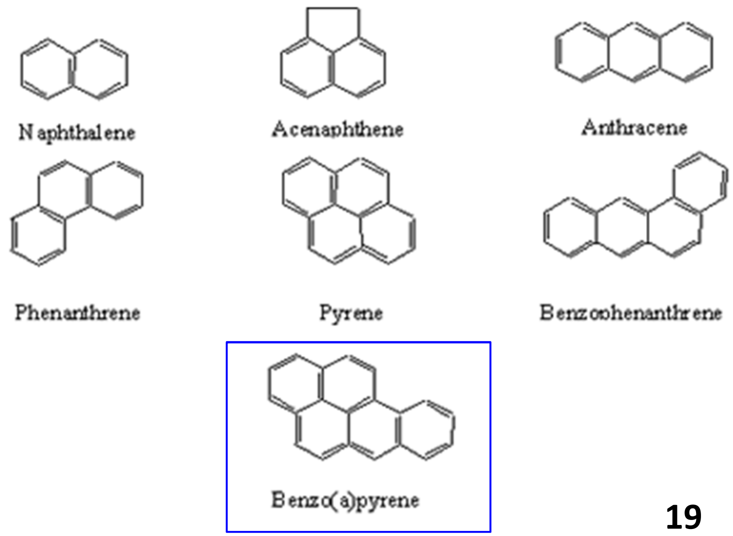
http://shopping.naver.com

Other toxic organic chemicals

- **BTEX**
  - **<u>B</u>**enzene, **<u>T</u>**oluene, **<u>E</u>**thylbenzene, **<u>X</u>**ylene
  - Spills from gasoline and other petroleum products

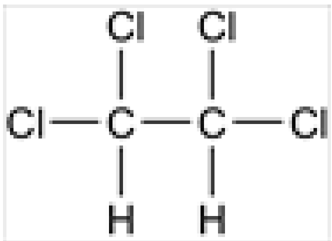


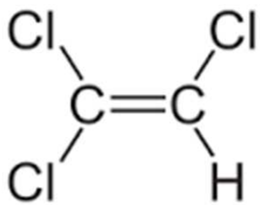
- **Polycyclic aromatic hydrocarbons (PAHs)**
  - Compounds with two or more fused benzene rings
  - Some are carcinogenic
  - Incomplete combustion, petroleum

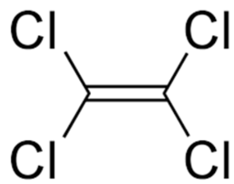


Other toxic organic chemicals (cont'd)

- **Chlorinated ethenes and ethanes**
  - Tetrachloroethane (**TCA**), trichloroethylene (**TCE**), tetrachloroethylene (**PCE**)
  - Solvents for dry cleaning and metal washing







***per**chloroethylene*

Arsenic

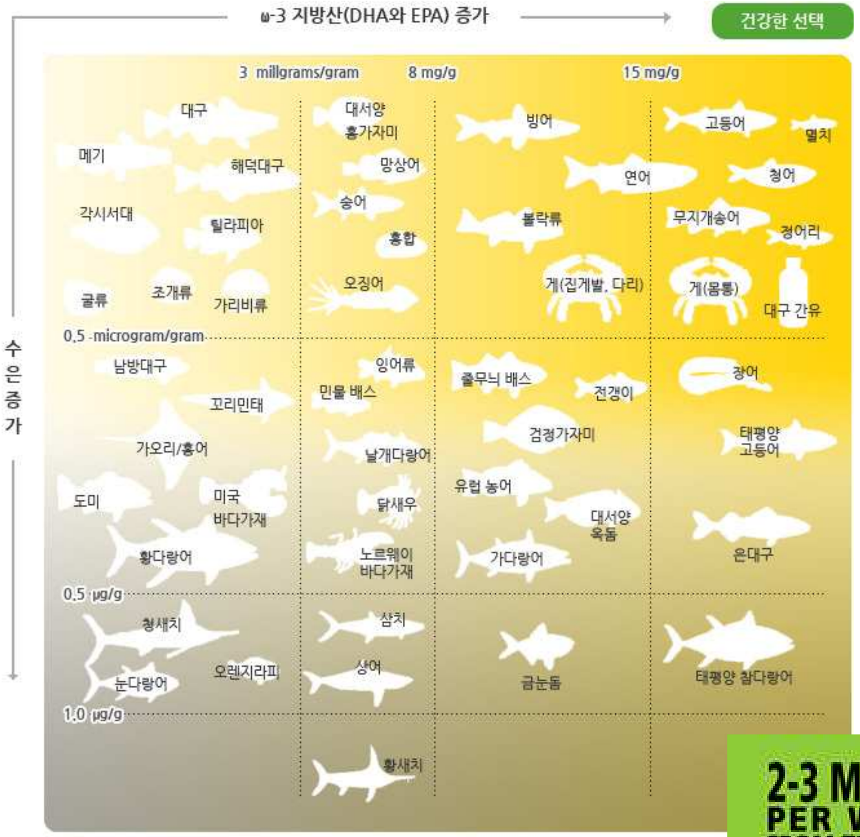
- Neither metal nor non-metal, but metalloid
- Source: mineral dissolution from weathered rocks and soils, mainly from iron oxides or sulfide minerals → arsenic contamination is often **a naturally occurring problem**
- Human carcinogen
- Significant groundwater contaminant in many regions of the world (ex: 33-77 million of Bangladesh's 125 million people are at risk of As poisoning from groundwater)
- Exist in quite high levels in Korea as well!

Toxic metals

- Cadmium (Cd), Chromium (Cr), Copper (Cu), Nickel (Ni), Lead (Pb), Mercury (Hg)

- Sources: industrial waste, wastewater treatment plants, stormwater runoff, mining operations, smokestack emissions, etc.

- Some heavy metals bioaccumulate and biomagnify (ex: mercury in tuna)



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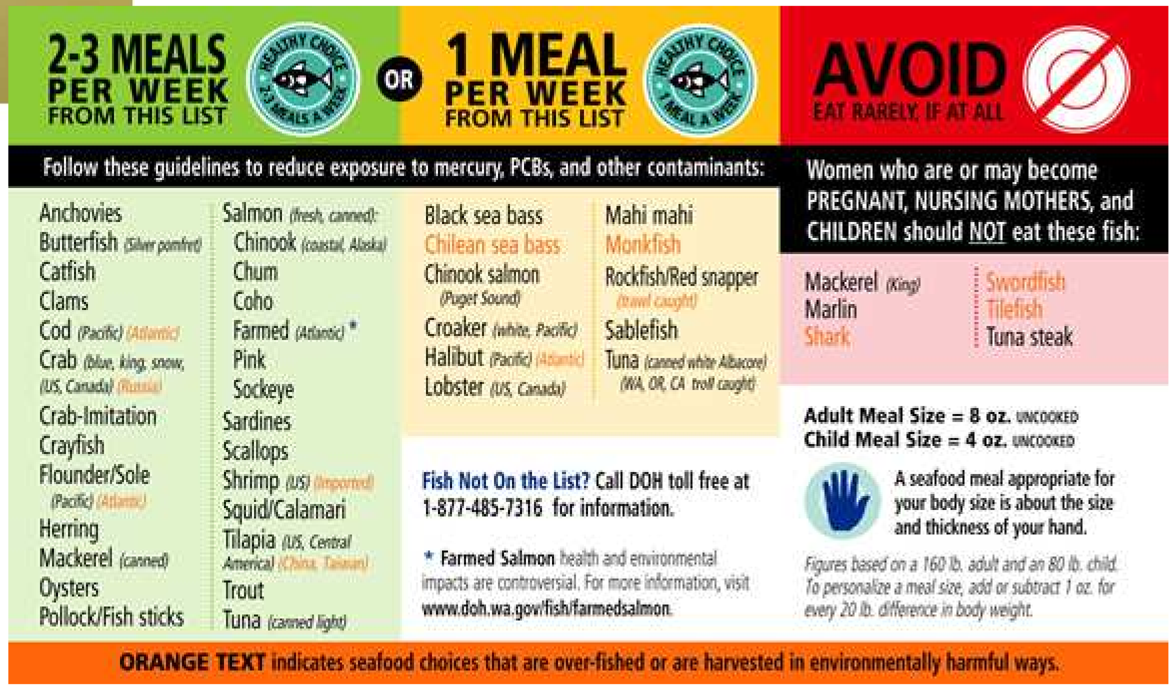

Toxic metals (cont'd)

- **Acid mine drainage (AMD)**
  - Water in mine operations gets acidic by a series of geochemical and microbial reactions
  - Generally metal solubility increases as pH lowers
  - Water contamination, ecosystem destruction, corrosion of infrastructure

- Outbreaks: recall from your middle school class!
  - Minamata, Japan – mercury
  - Toyoma, Japan – cadmium (itai-itai disease)

Heat

- Water used as coolants is discharged to the receiving waters
- May destroy the aquatic ecosystem
- Temperature increases → <u>decrease in oxygen solubility</u> and <u>enhanced microbiological activity</u> → oxygen depletion in rivers

Nanoparticles

- Particles of < 100 nm in dimension
- Examples
  - Naturally occurring humic material
  - TiO_2 particles in paints, varnishes, paper, plastics, creams, etc.
  - Carbon nanoparticles in tires, tennis rackets, video screens, etc.
  - Protein-based nanomaterials in the production of soaps, shampoos, and detergents
- Rapidly increasing production
- Toxicity and fate not well known

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Oxygen demand

- Indicators needed to predict the extent of oxygen depletion and to maintain sufficient levels of DO in rivers and streams

- **Theoretical oxygen demand (ThOD)**
  – the amount of oxygen required to oxidize a substance to CO_2 and H_2O calculated by stoichiometry
  – the chemical composition of the substance should be known

Theoretical oxygen demand

Q: Compute the ThOD of 108.75 mg/L of glucose ($C_6H_{12}O_6$).

Chemical oxygen demand (COD)

- A measured quantity – does not depend on the knowledge of the chemical composition of the substances in the water

- The organic compounds in a water is oxidized by a strong oxidizing agent such as potassium dichromate (K_2CrO_7) or potassium permanganate ($KMnO_4$)

- The difference between the amount of oxidizing agent at the beginning and the end of the test is used to calculate COD

Biochemical oxygen demand (BOD)

- The oxygen demand is measured by a bioassay
- The water sample is inoculated with bacteria that degrade organic matter in water
- The difference in DO in the water sample at the beginning and end of the test is used to calculate BOD

ThOD vs. COD vs. BOD

ThOD ≥ COD > BOD

- ThOD ≥ COD: some organic compounds may not be oxidized even with a strong oxidizing agent
- COD > BOD

  During BOD measurement:

  - some carbon is not oxidized, but used for bacterial growth
  - some organic compounds are non-biodegradable, so not degraded
  - some portion of biodegradable organic matter is converted to non-biodegradable materials

Suggested readings

[ENG] pp. 395-411

[KOR] pp. 381-399

Next class

Water quality II

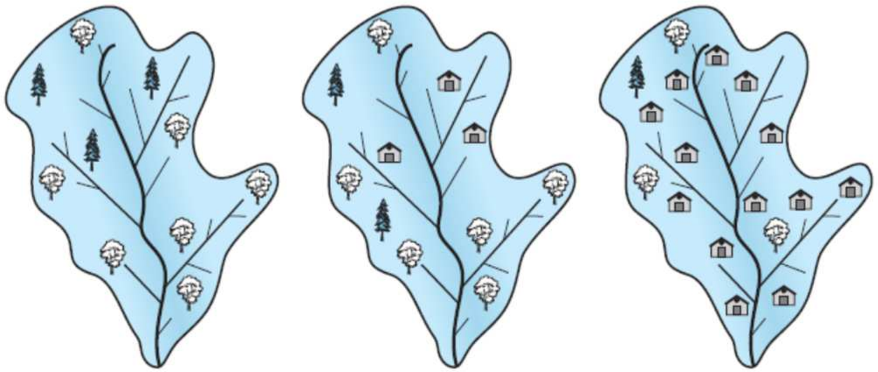
- Modeling the BOD
- N-BOD
- Modeling dissolved oxygen (DO) in rivers
- Groundwater quality

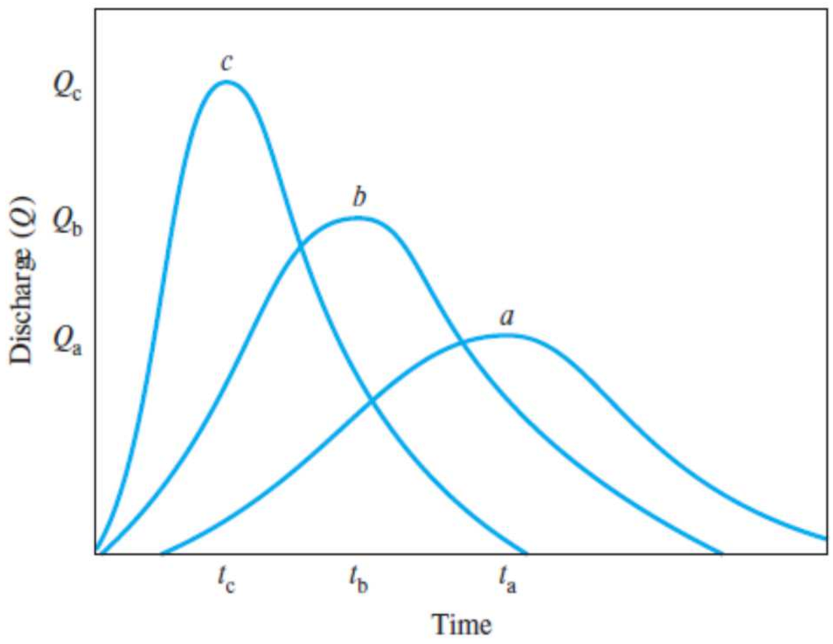
Hydrology II

Today's lecture

- Urban development impact on hydrology
- Low impact development
- Groundwater hydrology
  - Terminologies
  - Darcy's law and groundwater velocity

Urban development affects hydrology





- $Q_c > Q_b > Q_a$, $t_c < t_b < t_a$
- Urban & industrial development increases the impact of flood

The more developed, the greater the runoff coeff.

TABLE 7–1 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, 1969.

Low impact development (LID)

- A land planning and engineering design approach to minimize the hydrological impact of urban development

- Focused mainly on water quantity issues
(ex: flooding prevention)

- Some treatment of stormwater pollutants

LID example: Rain garden in Daejeon

Urban design concepts similar to LID

- Green infrastructure
- Sponge city (China)
- Water sensitive city (Australia)

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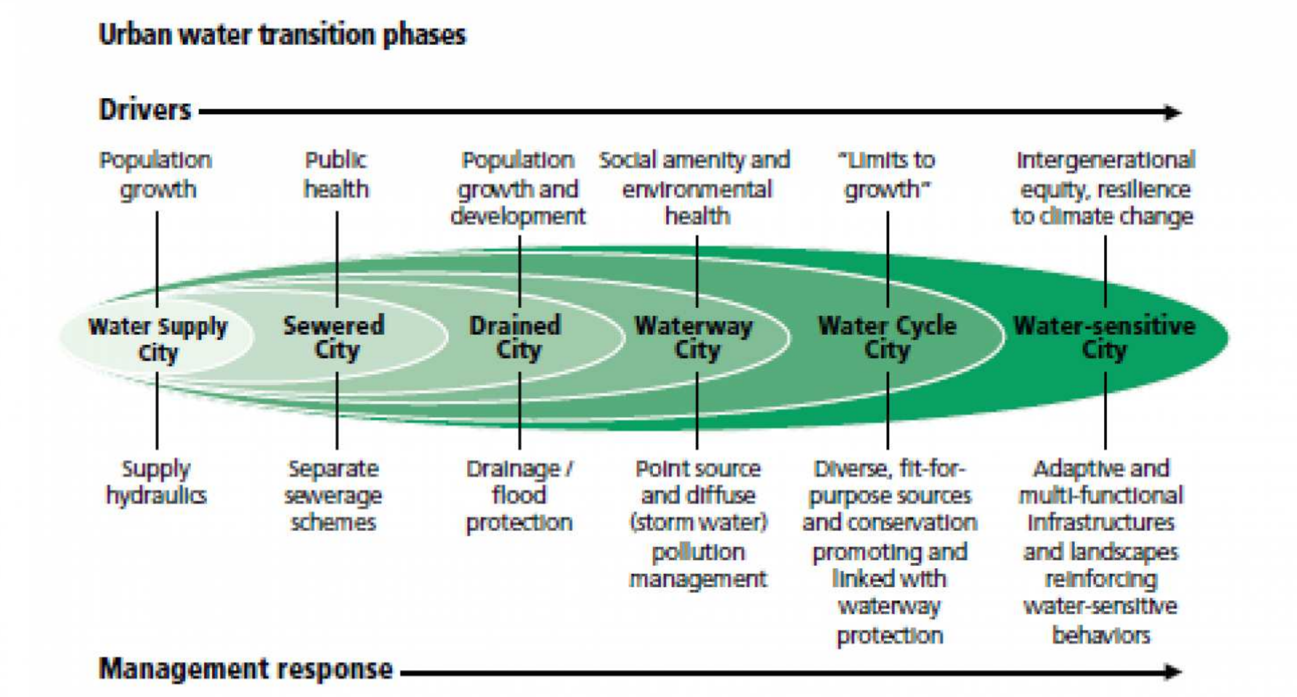
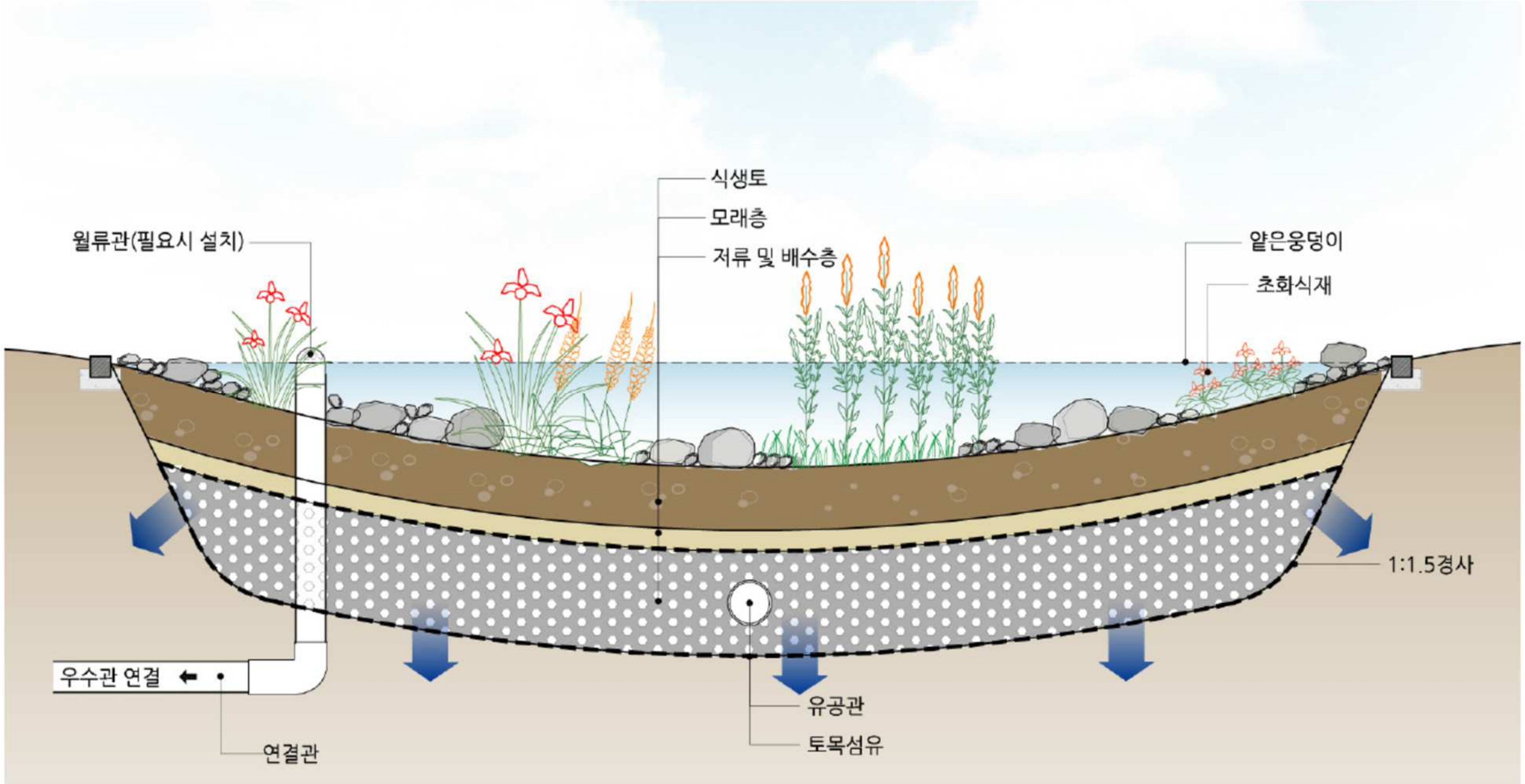


LID practices

- Bioretention zone (rain garden)



환경부(2016) 저영향개발 기법 설계 가이드라인

LID practices

- Green roof

LID practices

- Permeable pavements
  - sidewalks, bike roads, parking lots
- Grass swales and channels
  - Redirect runoff from stormwater drains
- Rain barrels, cisterns
  - Collection of stormwater and use for irrigation / toilet flushing

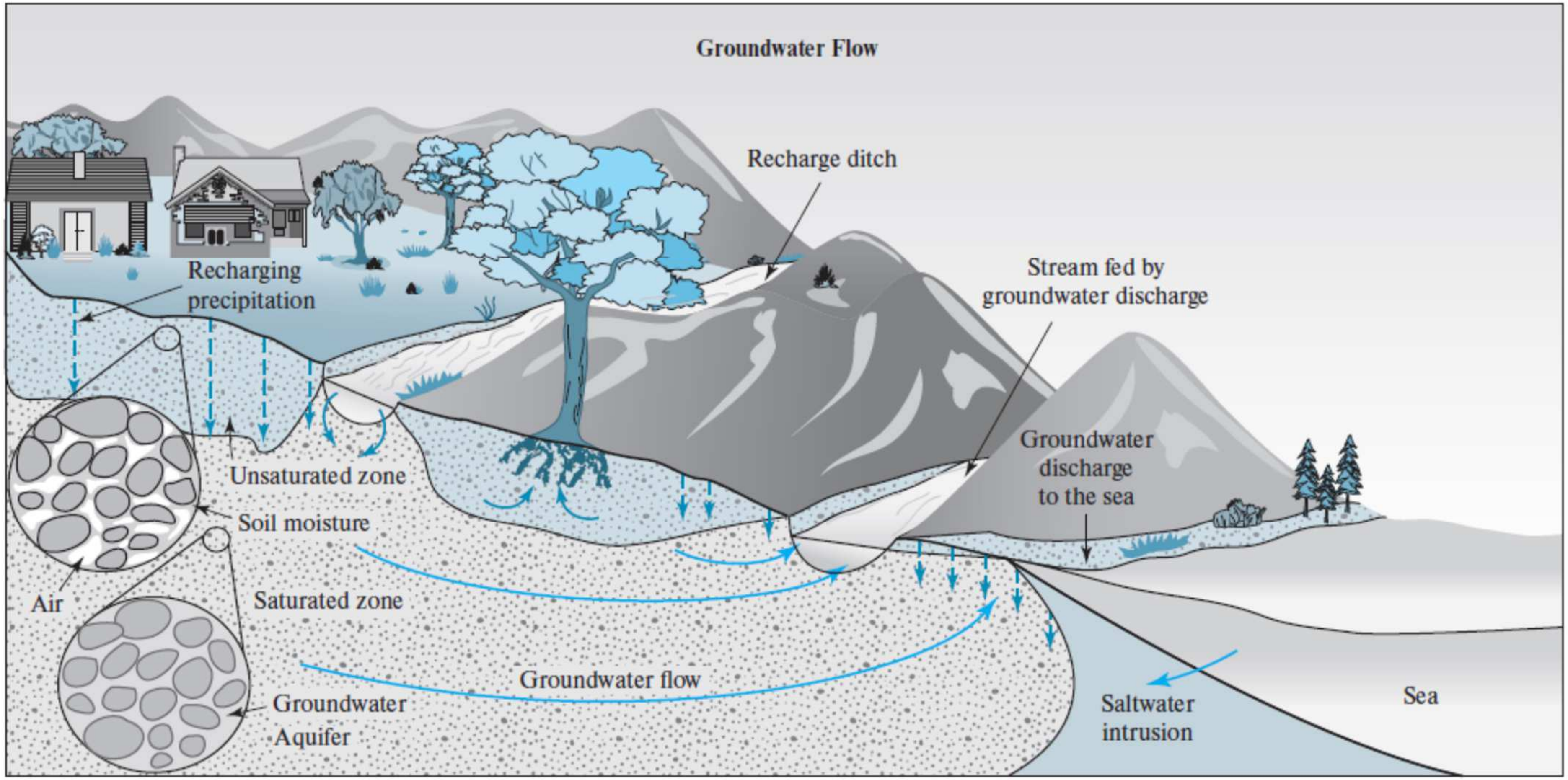
Grass swale in Ottawa, Canada

Rain barrel (SNU 35-dong)


❶ 나무여과상자
❷ 투수성포장
❺ 빗물정원
❻ 옥상녹화
❸ 식물재배화분
❹ 식생체류지
❼ 침투통
❽ 침투도랑


저영향개발(LID) 기법
설계 가이드라인

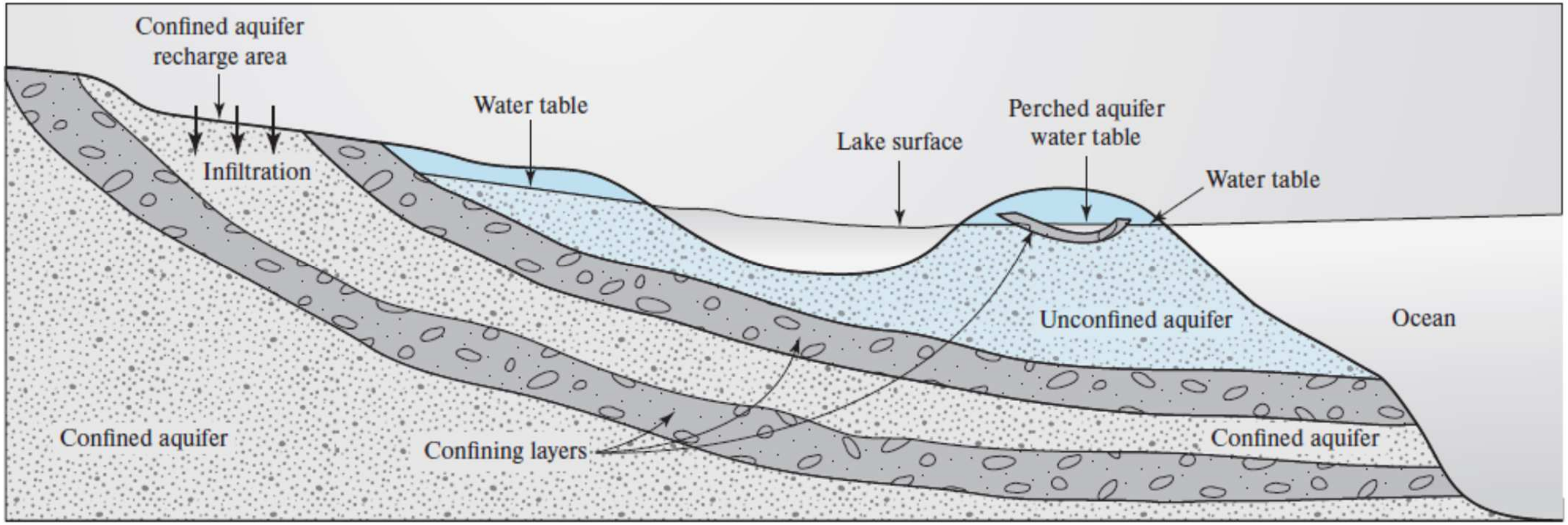
Groundwater hydrology



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.)

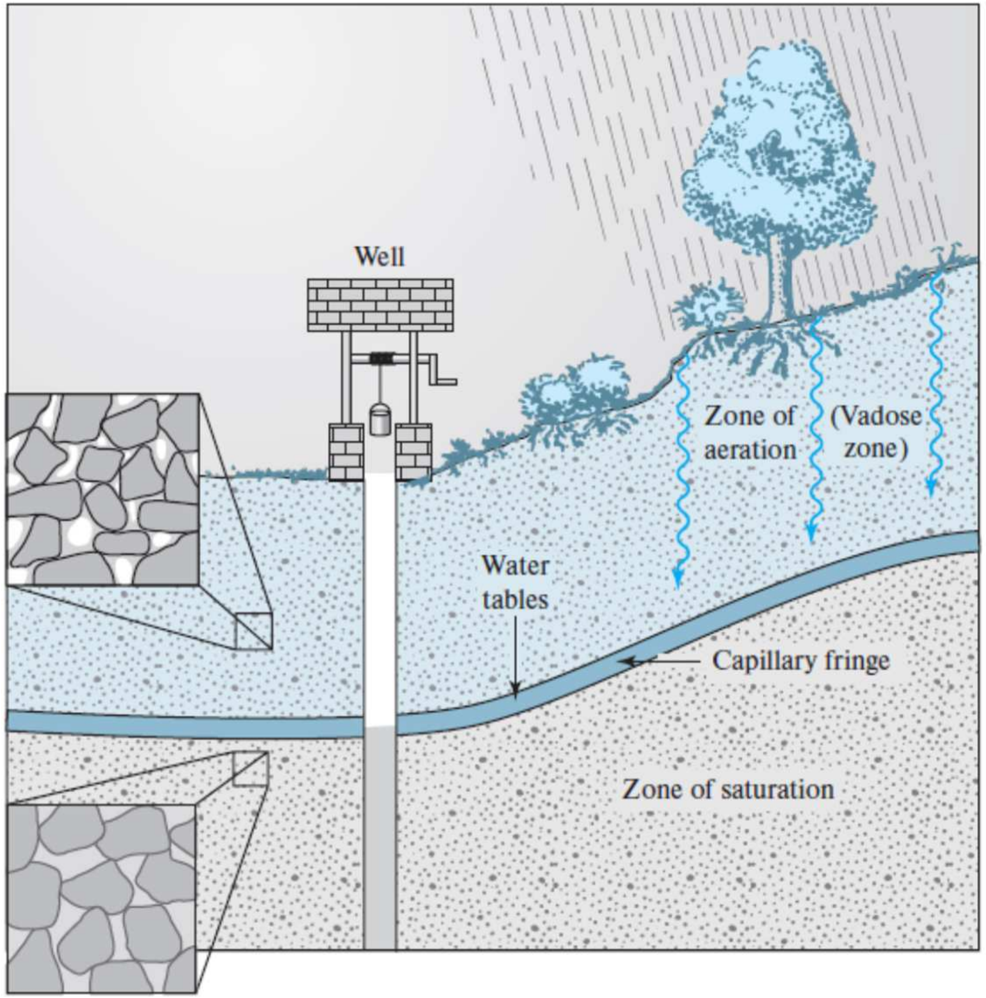
Unconfined vs. confined aquifer



- **Unconfined aquifer**: an aquifer of which upper surface of its saturated zone is not confined by an impermeable layer
- **Confined aquifer**: an aquifer bounded by impermeable layers (called as confining layers) both at the top and the bottom
- Confining layers: *aquicludes* or *aquitards*

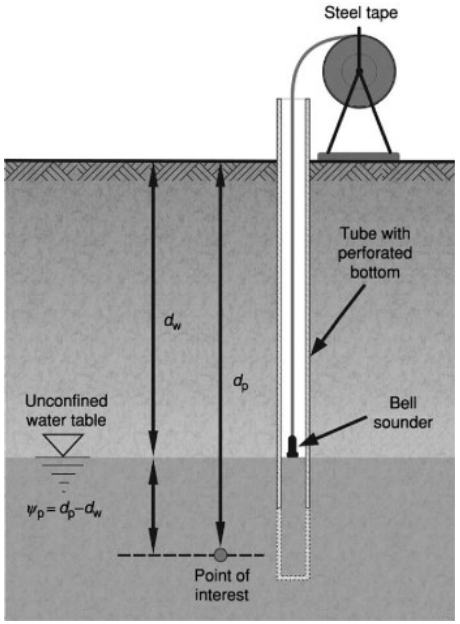
Unconfined aquifer

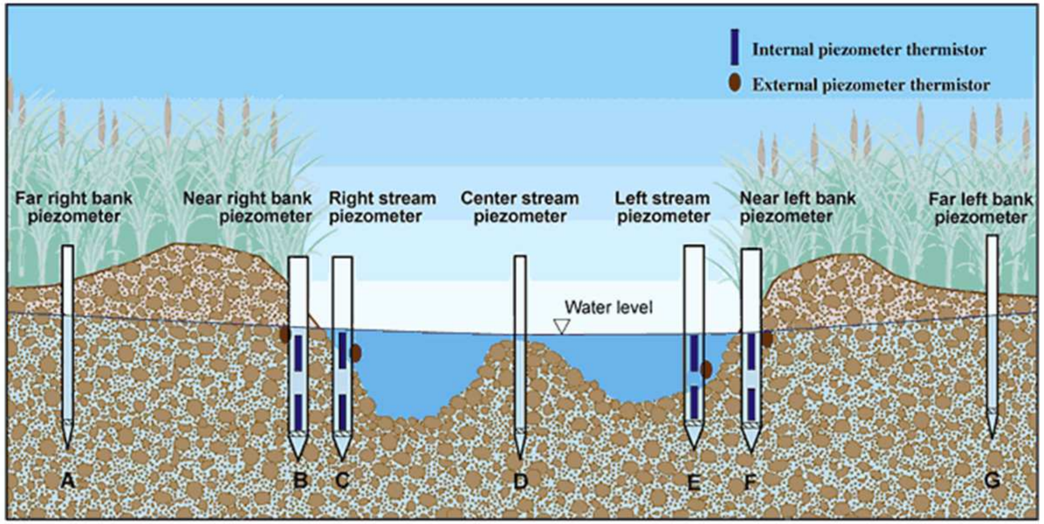
- **Water table**: The upper surface of the saturated zone in an unconfined aquifer
- **Capillary fringe**: the zone where capillary action occurs (the soil draws water above the water table)



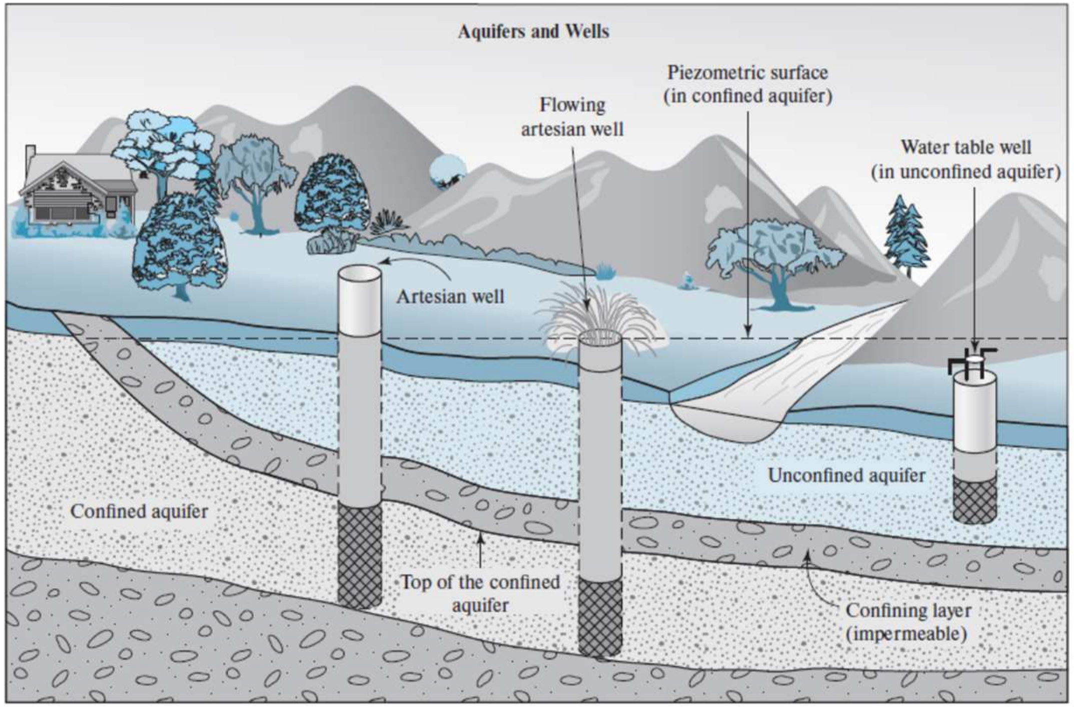
Piezometric head and surface

- **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 imaginary plane drawn through the piezometric head of several piezometers





Unconfined vs. confined aquifer: piezometric 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,

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

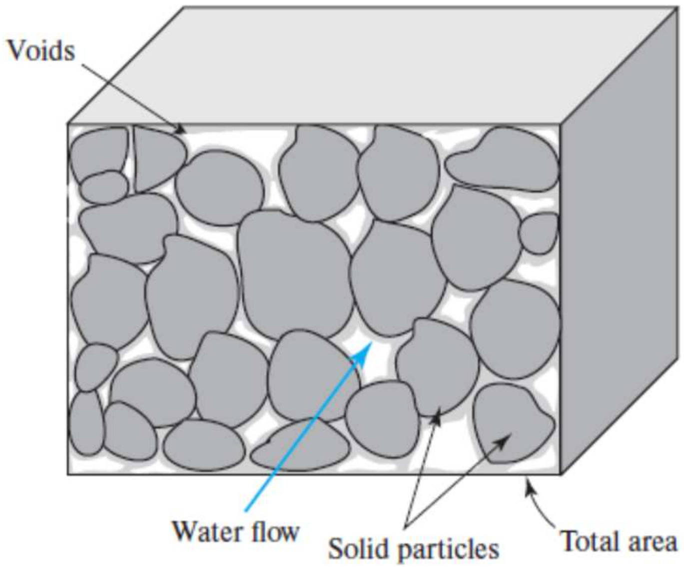
Q = flow rate [L^3/T]

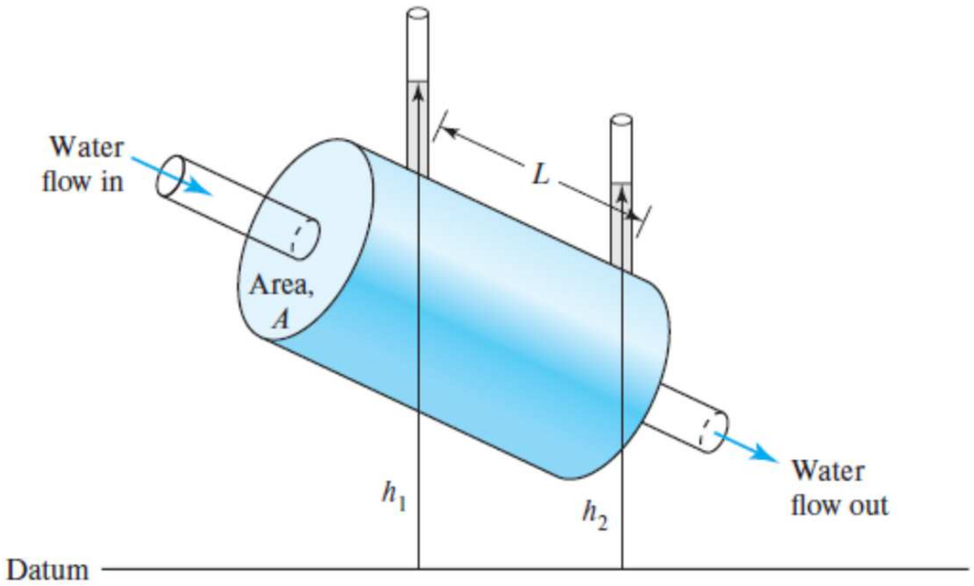
A = cross-sectional area [L^2]

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

Aquifer Material	Porosity (%)	Typical Values for Hydraulic Conductivi (m · 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	$1 \times 10^{-8}–1 \times 10^{-4}$

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

Q: While investigating the ground near your department building, 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.

Suggested readings

[ENG] pp. 280 – 289, 301 – 303

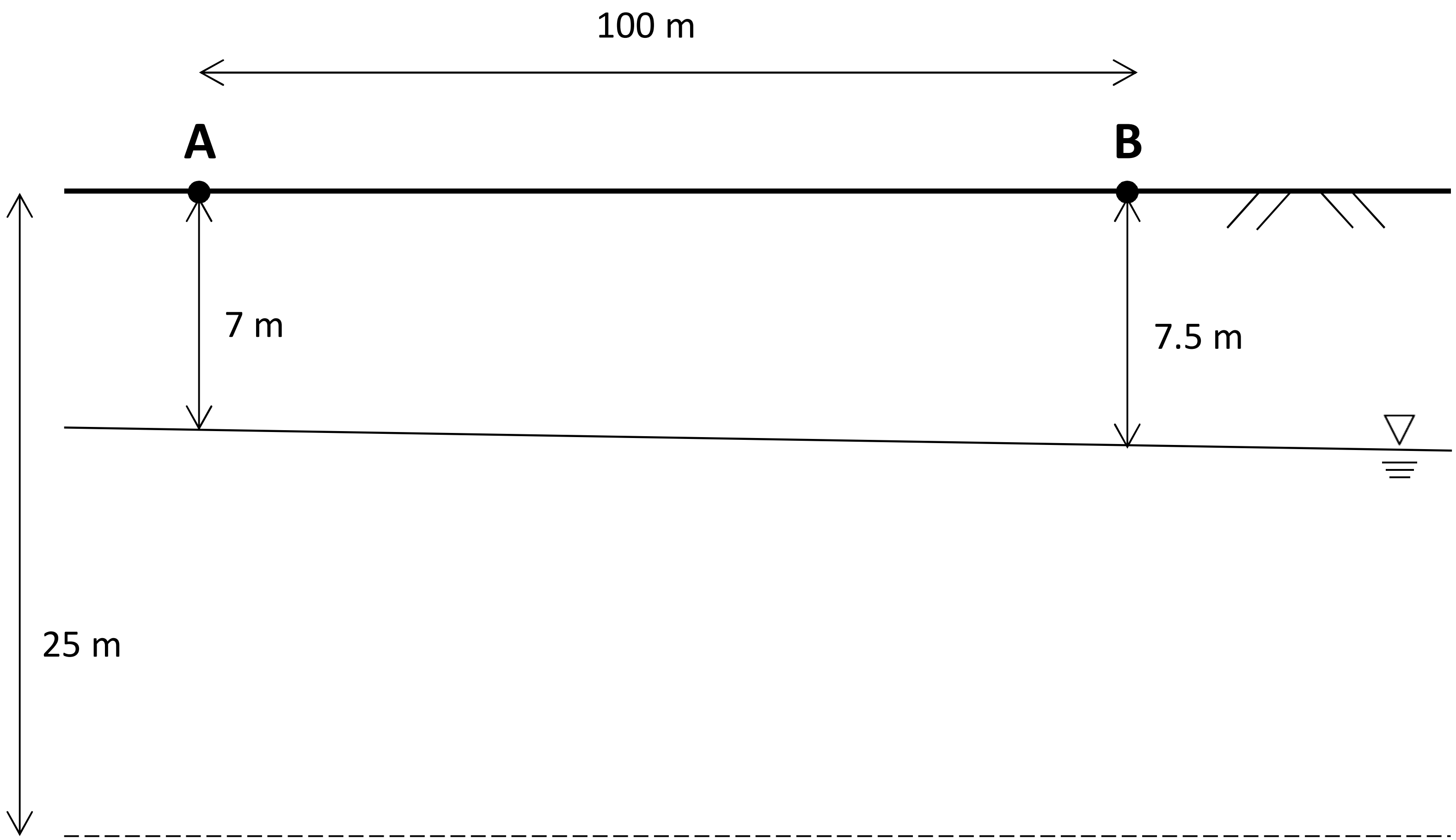
[KOR] pp. 287 – 296, 308 – 310

Next class

Water quality I

- Sources of water pollutants
- Types of water pollutants
- BOD & COD

Slide#20 solution



i) ***h_A = 18 m, h_B = 17.5 m***

ii) ***A to B***

iii) $i = \frac{\Delta h}{L} = \frac{0.5\ m}{100\ m} = \mathbf{0.005}$

iv) $v = K \cdot i = 5.2 \times 10^{-4}\ m/s\ \times 0.005 = 2.6 \times 10^{-6}\ m/s = \mathbf{0.225\ m/day}$

v) $Q = v \cdot A = 0.225\ m/day\ \times 925\ m^2 = \mathbf{208\ m^3/day}$

vi) $v' = \frac{v}{n} = \frac{0.225\ m/day}{0.3} = \mathbf{0.75\ m/day}$

Slide#28 solution

Reaction stoichiometry:

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

MW of glucose = 180 g/mole

ThOD of 108.75 mg/L glucose:

$$108.75\ mg\ glucose/L \times \frac{(6\times32)\ g\ O_2/mole\ glucose}{180\ g\ glucose/mole} = \mathbf{116\ mg\ O_2/L}$$