UNIT 4: GROUNDWATER

GEO 281: GEOLOGY FOR ENGINEERS

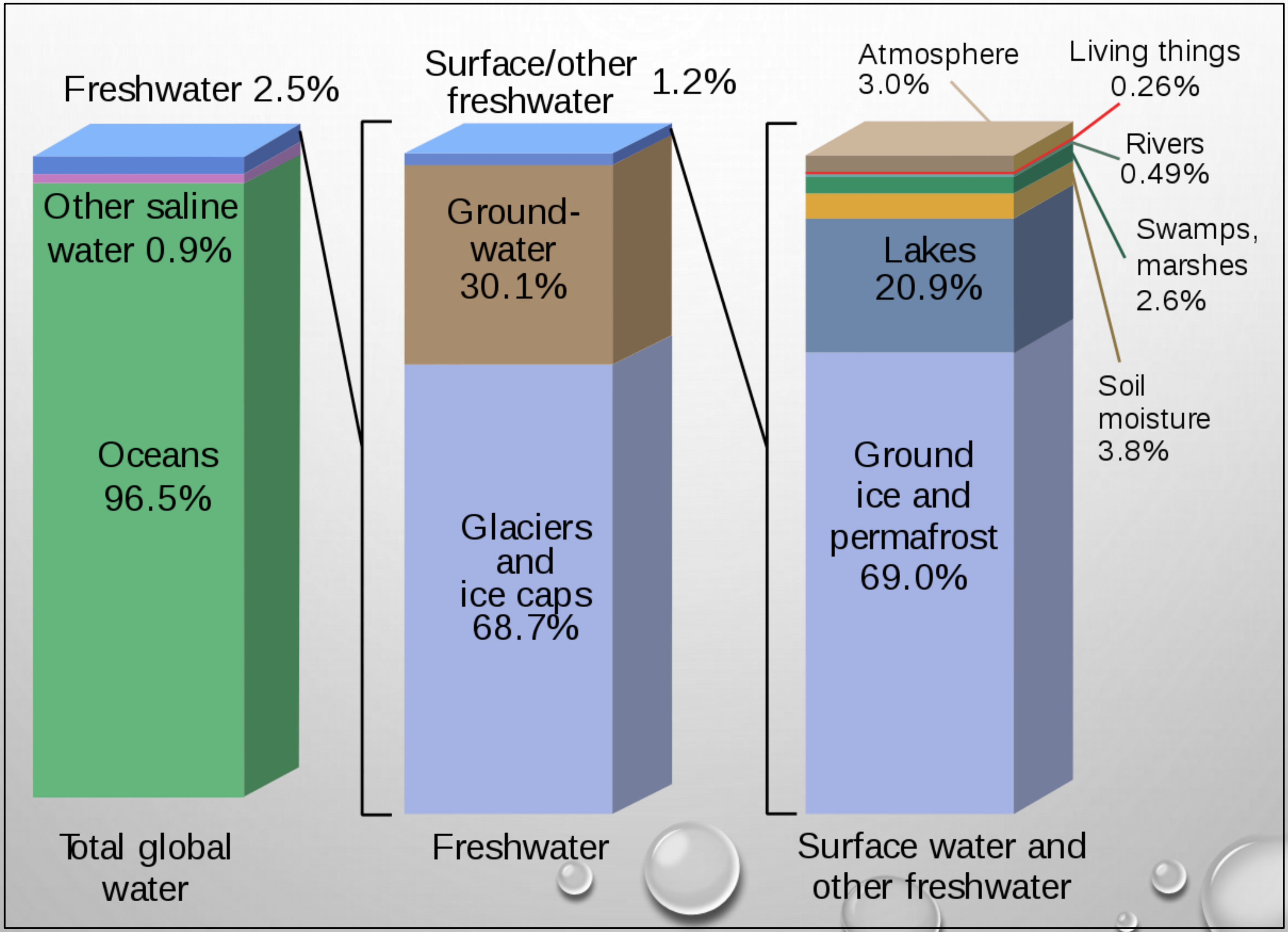
GEOLOGY AND GEOPHYSICS DEPARTMENT

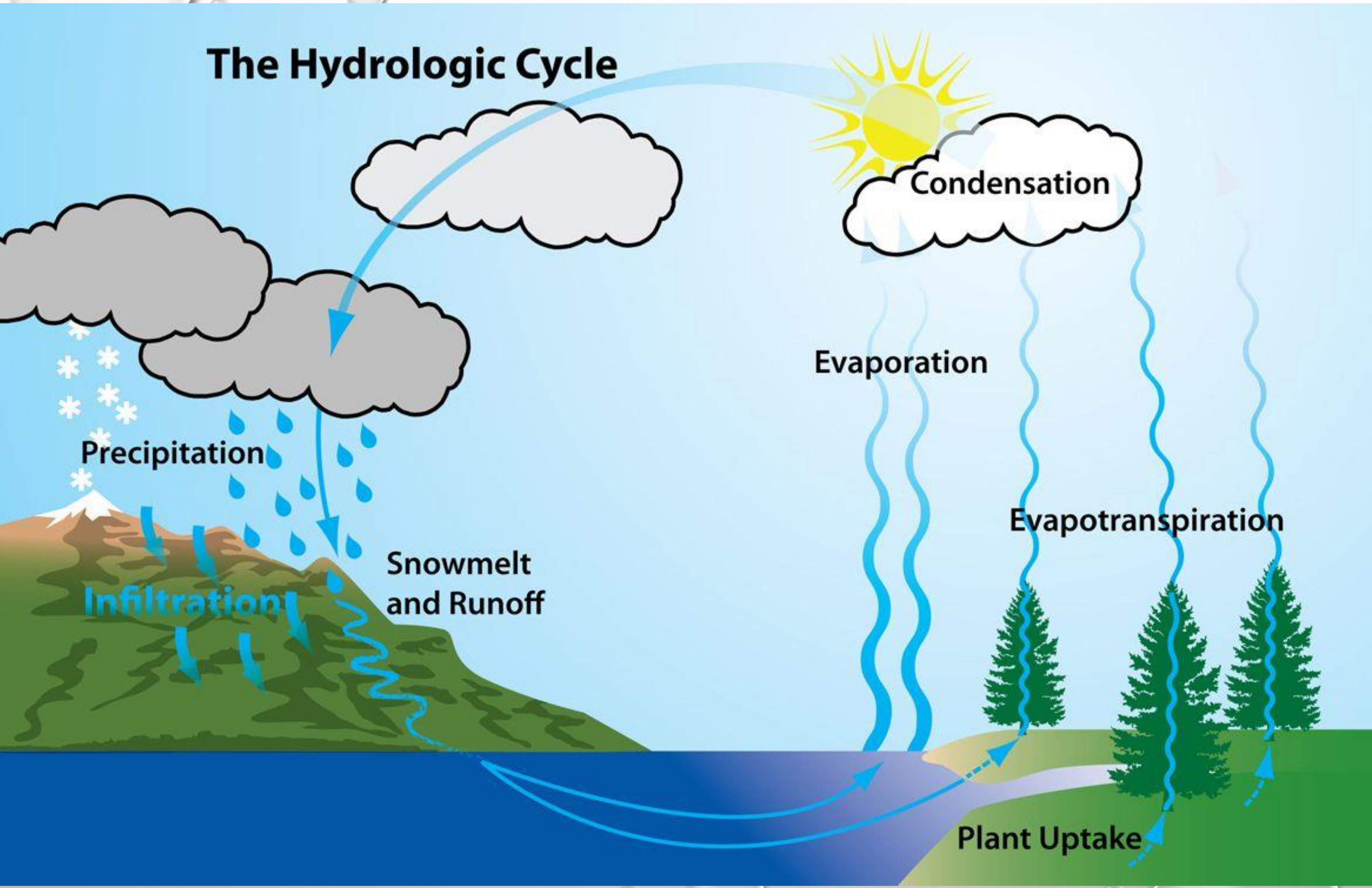
KING SAUD UNIVERSITY

GROUNDWATER

- Groundwater occurs almost everywhere beneath Earth's surface and is a major source of water worldwide.
- Groundwater is a valuable natural resource that provides about half of our drinking water and is essential for agriculture and industry
- In addition to human uses, groundwater plays a crucial role in sustaining streamflow, especially during protracted dry periods.
- ***Groundwater represents the largest reservoir of fresh water that is readily available to humans.***

WORLD WATER DISTRIBUTION




The Hydrologic Cycle
Condensation
Evaporation
Precipitation
Evapotranspiration
Snowmelt
and Runoff
Infiltration
Plant Uptake

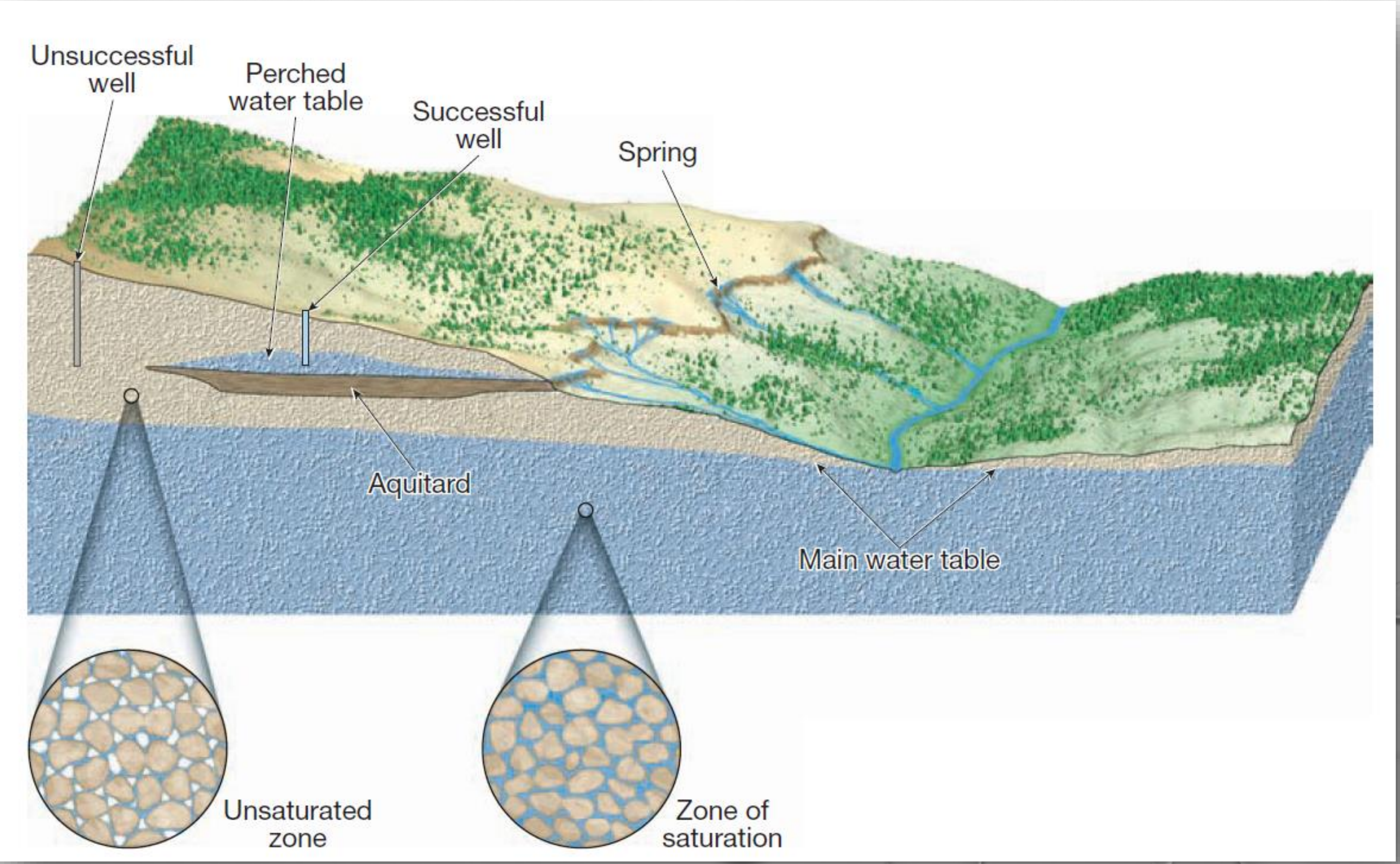
DISTRIBUTION OF GROUNDWATER

- When rain falls, some of the water runs off, some returns to the atmosphere by evaporation and transpiration, and the remainder enters the ground by a process known as **infiltration**.
- **Infiltration is the primary source of practically all subsurface water.**
- Some of the water that soaks in does not travel far, because it is held by molecular attraction as a surface film on soil particles. **This near-surface zone is called the zone of soil moisture.**
- **Soil water is used by plants in life functions and transpiration. Some water also evaporates directly back into the atmosphere.**

DISTRIBUTION OF GROUNDWATER

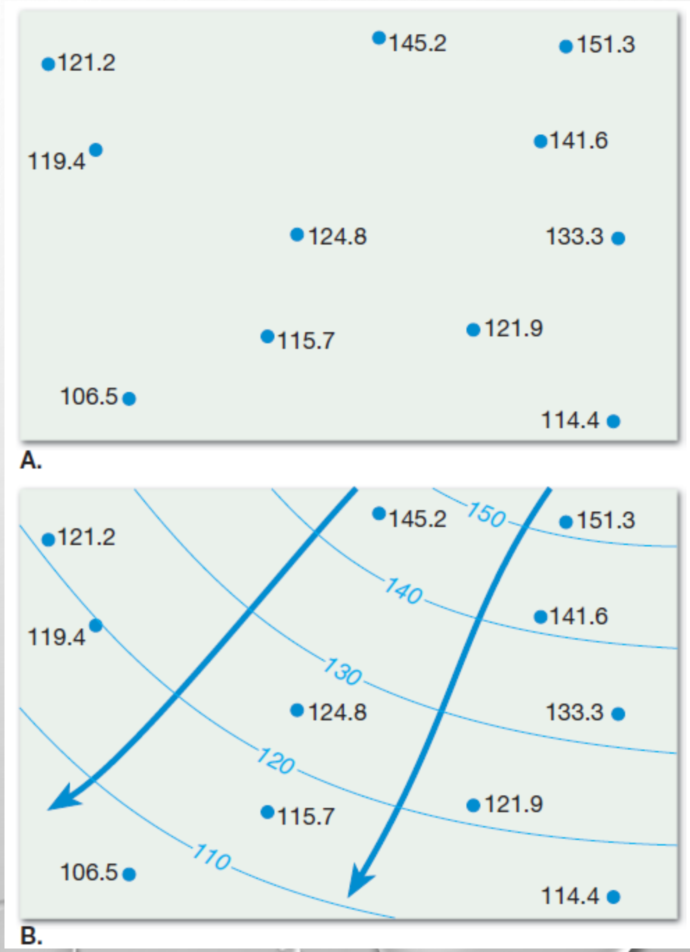
- Water that is not held as soil moisture will percolate downward until it reaches a zone where all of the **open spaces in sediment and rock are completely filled with water. This is the zone of saturation. Water within it is called groundwater.**
- ***The upper limit of the zone of saturation is known as the water table.***
- **The area above the water table where the soil, sediment, and rock are not saturated is called the unsaturated zone.**
- **The open spaces (pores) in between the soil and sediment particles are filled with both air and water in the unsaturated zone.**

DISTRIBUTION OF GROUNDWATER



THE WATER TABLE

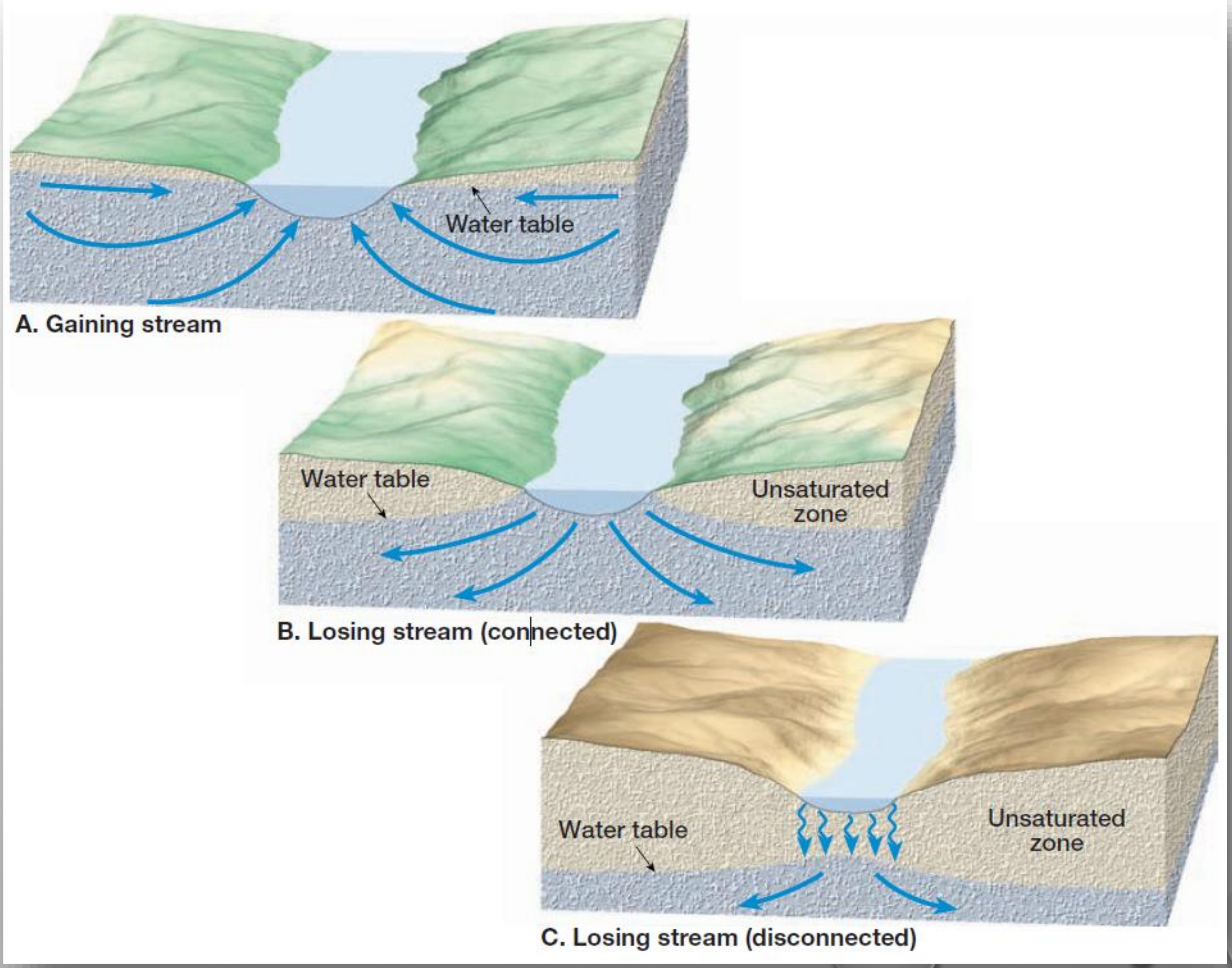
- Upper limit of the zone of saturation is known as the water table.
- ***The depth of the water table is highly variable and can range from zero, when it is at the surface, to hundreds of meters in some places.***
- An important characteristic of the water table is that its **configuration varies seasonally and from year to year** because the addition of water to the groundwater system is closely related to the quantity, distribution, and timing of precipitation.
- Except where the water table is at the surface, we cannot observe it directly.
- Nevertheless, **its elevation can be mapped and studied in detail where wells are numerous, because the water level in wells coincides with the water table.**



INTERACTION BETWEEN GROUNDWATER AND STREAMS

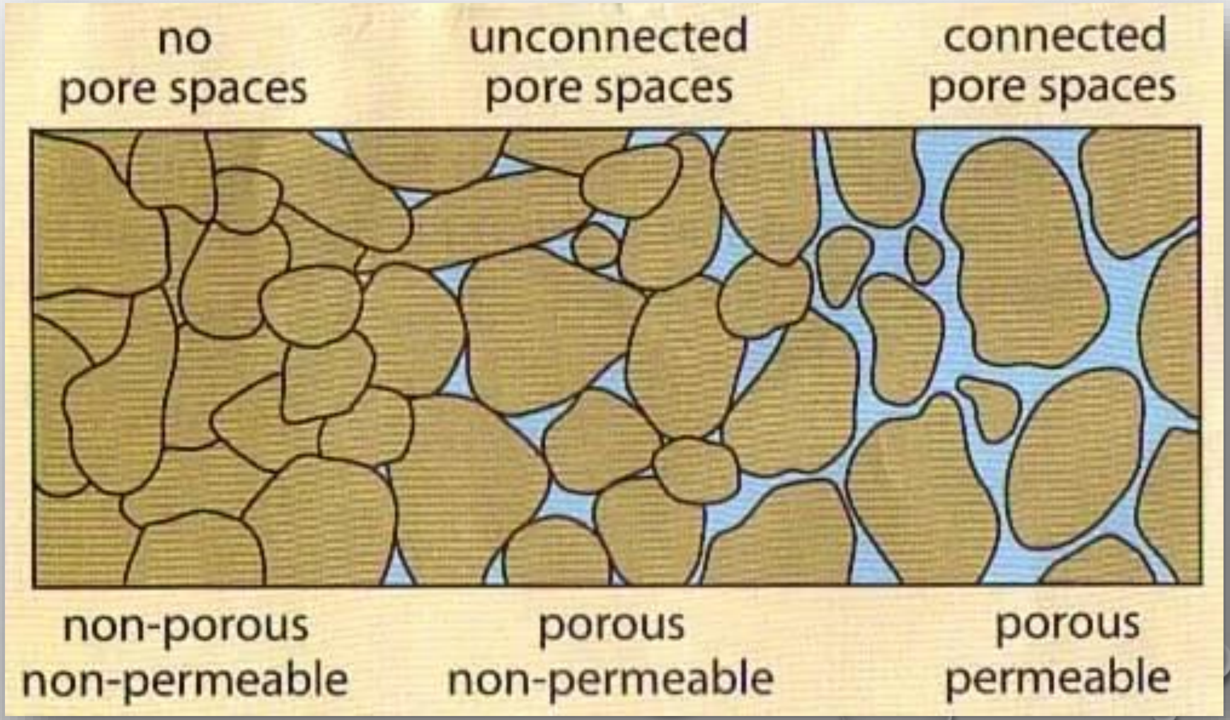
- The interaction between the groundwater system and streams is a basic link in the hydrologic cycle.
- It can take place in one of three ways. **Streams may gain water from the inflow of groundwater through the streambed. Such streams are called gaining streams.**
- For this to occur, the elevation of the water table must be higher than the level of the surface of the stream.
- **Streams may lose water to the groundwater system by outflow through the streambed. The term losing stream is applied to this situation.** When this happens, the elevation of the water table is lower than the surface of the stream.
- **Losing streams can be connected to the groundwater system by a continuous saturated zone, or they can be disconnected from the groundwater system by an unsaturated.**

INTERACTION BETWEEN GROUNDWATER AND STREAMS



FACTORS INFLUENCING THE STORAGE AND MOVEMENT OF GROUNDWATER

- The nature of subsurface materials strongly influences the rate of groundwater movement and the amount of groundwater that can be stored.
- Two factors are especially important—**porosity** and **permeability**.



POROSITY

- Water soaks into the ground because bedrock, sediment, and soil contain countless voids, or openings.
- **These openings are similar to those of a sponge and are often called pore spaces.**
- The quantity of groundwater that can be stored depends on the porosity of the material, **which is the percentage of the total volume of rock or sediment that consists of pore spaces.**
- Voids most often are spaces between sedimentary particles, but also common are joints, faults, cavities formed by the dissolving of soluble rocks such as limestone, and vesicles (voids left by gases escaping from lava).
- Variations in porosity can be great.
- Sediment is commonly quite porous, and open spaces may occupy 10 to 50 percent of the sediment's total volume.
- **Pore space depends on the size and shape of the grains, how they are packed together, the degree of sorting, and in sedimentary rocks, the amount of cementing material.**

PERMEABILITY, AQUITARDS, AND AQUIFERS

- Porosity alone cannot measure a material's capacity to yield groundwater.
- **Rock or sediment might be very porous yet still not allow water to move through it.**
- The pores must be connected to allow water flow, and they must be large enough to allow flow.
- **Thus, the permeability of a material, its ability to transmit a fluid, is also very important.**
- For example, clay's ability to store water can be great, owing to its high porosity, but its pore spaces are so small that water is unable to move through it.
- Thus, clay's porosity is high but its permeability is poor.

PERMEABILITY, AQUITARDS, AND AQUIFERS

- **Impermeable layers that hinder or prevent water movement are termed aquitards. Clay is a good example.**
- In contrast, larger particles, such as sand or gravel, have larger pore spaces and the water moves easily.
- **Permeable rock strata or sediments that transmit groundwater freely are called aquifers. Sands and gravels are common examples.**
- **Porosity is not always a reliable guide to the amount of groundwater that can be produced**, and **permeability is significant in determining the rate of groundwater movement** and the quantity of water that might be pumped from a well.

MEASURING GROUNDWATER MOVEMENT

- The foundations of our modern understanding of groundwater movement began in the mid-19th century with the work of the **French scientist-engineer Henri Darcy**.
- Among the experiments carried out by Darcy was one that showed that the velocity of groundwater flow is proportional to the slope of the water table—the steeper the slope, the faster the water moves
- **The water-table slope is known as the hydraulic gradient** and can be expressed as follows:

$$\text{hydraulic gradient} = \frac{h_1 - h_2}{d}$$

- where h_1 is the elevation of one point on the water table, h_2 is the elevation of a second point, and d is the horizontal distance between the two points

MEASURING GROUNDWATER MOVEMENT

- **Darcy also discovered that the flow velocity varied with the permeability of the sediment** — groundwater flows more rapidly through sediments having greater permeability than through materials having lower permeability.
- This factor is known as **hydraulic conductivity and is a coefficient that takes into account the permeability of the aquifer and the viscosity of the fluid.**

MEASURING GROUNDWATER MOVEMENT

- To determine **discharge (Q)**—that is, the actual volume of water that flows through an aquifer in a specified time — the following equation is used:

$$Q = \frac{KA(h_1 - h_2)}{d}$$

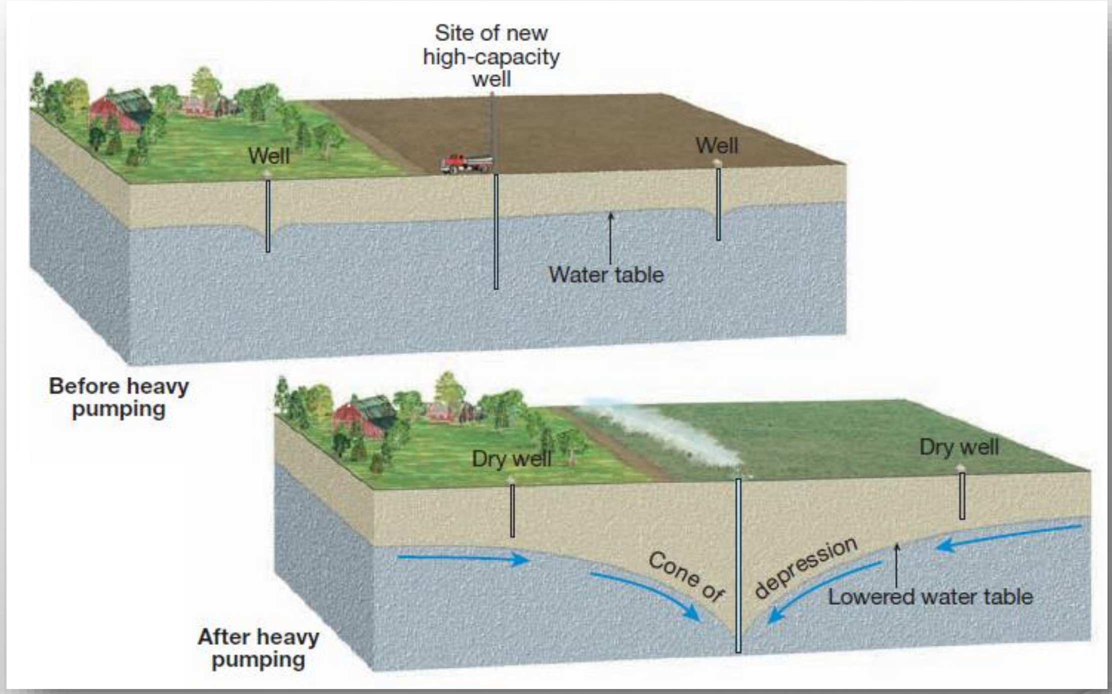
- Where $\frac{h_1 - h_2}{d}$ is the hydraulic gradient,

K is the coefficient that represents hydraulic conductivity, and **A is the cross-sectional area of the aquifer.**

- **This expression has come to be called Darcy's law.**

GROUNDWATER WELLS

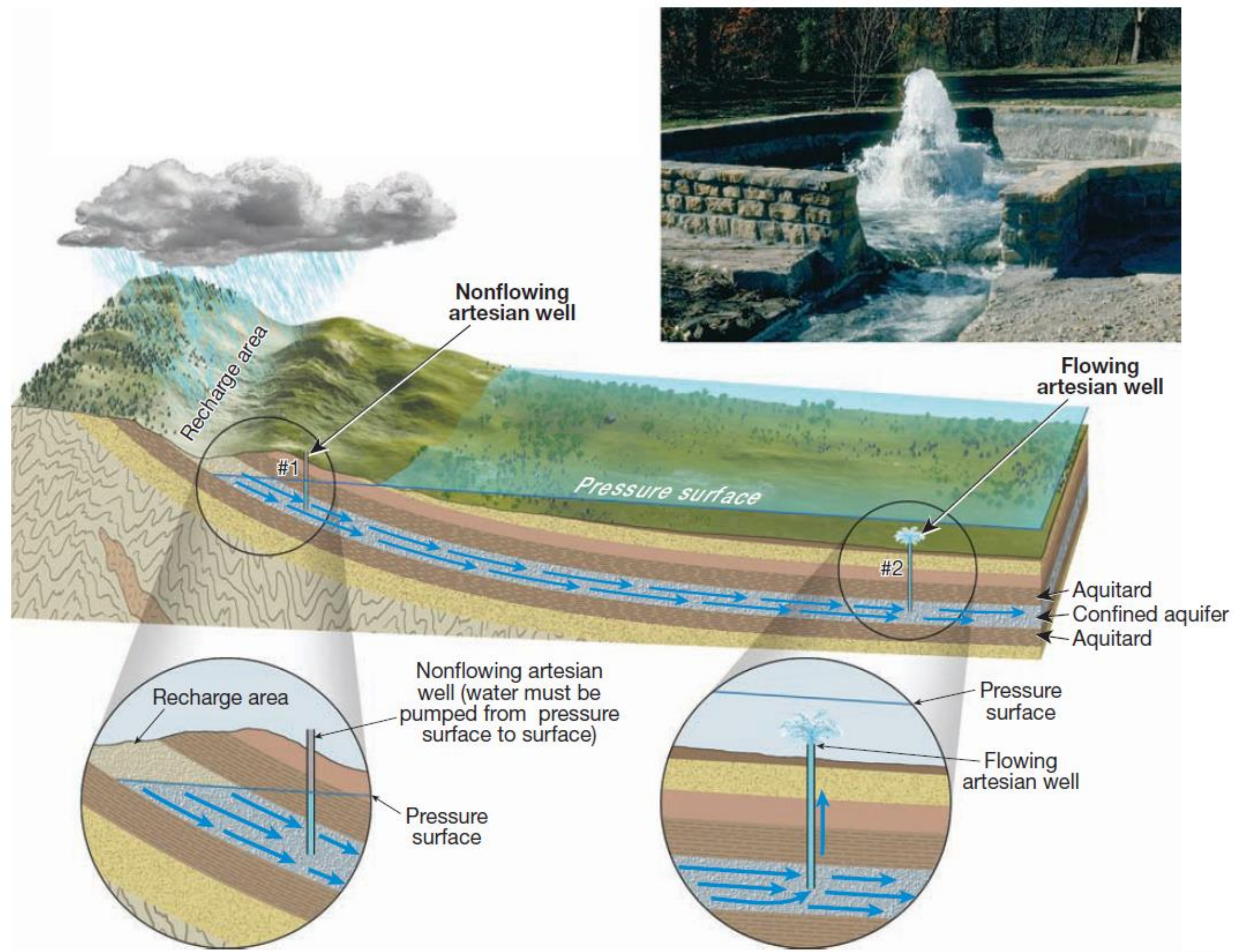
- The most common device used by people for removing groundwater is the **well**, a *hole bored into the zone of saturation.*
- Often when water is withdrawn from a well, the water table around the well is lowered. **This effect, termed drawdown** decreases with increasing distance from the well.
- **The result is a depression in the water table, roughly conical in shape, known as a cone of depression**



ARTESIAN WELL

- In most wells, water cannot rise on its own.
- If water is first encountered at 30 meters depth, it remains at that level, fluctuating perhaps a meter or two with seasonal wet and dry periods.
- However, in some wells, water rises, sometimes overflowing at the surface.
- Such wells are abundant in the Artois region of northern France, and so we call these self-rising wells **artesian**.
- **The term artesian is applied to any situation in which groundwater rises in a well above the level where it was initially encountered.**
- For such a situation to occur, two conditions usually exist:
- ***(1) Water is confined to an aquifer that is inclined so that one end is exposed at the surface, where it can receive water; and***
- ***(2) aquitards, both above and below the aquifer, must be present to prevent the water from escaping. Such an aquifer is called a confined aquifer.***

ARTESIAN WELL



ENVIRONMENTAL PROBLEMS ASSOCIATED WITH GROUNDWATER

Treating Groundwater as a Nonrenewable Resource

- The water table's height reflects a balance between the rate of water added by precipitation and the rate of water removed by discharge and withdrawal.
- **Any imbalance will either raise or lower the water table.**
- **A long-term drop in the water table can occur if there is either a decrease in recharge due to a prolonged drought or an increase in groundwater discharge or withdrawal.**
- For many, groundwater appears to be an endlessly renewable resource because it is continually replenished by rainfall and melting snow.
- **But in some regions groundwater has been and continues to be treated as a nonrenewable resource.**
- Where this occurs, the water available to recharge the aquifer falls significantly short of the amount being withdrawn.

ENVIRONMENTAL PROBLEMS ASSOCIATED WITH GROUNDWATER

Land Subsidence Caused by Groundwater Withdrawal

- **The ground may sink when water is pumped from wells faster than natural recharge processes can replace it.**
- This effect is particularly pronounced in areas underlain by thick layers of loose sediment.
- As water is withdrawn, the weight of the overburden packs the sediment grains more tightly together and the ground subsides.
- *Examples of land subsidence due to over pumping of groundwater are San Joaquin Valley of California and Mexico City.*

ENVIRONMENTAL PROBLEMS ASSOCIATED WITH GROUNDWATER

Groundwater Contamination

- The pollution of groundwater is a serious matter, particularly in areas where aquifers provide a large part of the water supply.
- One common source of groundwater pollution is **sewage**.
- Other sources and types of contamination also threaten groundwater supplies. These include widely used substances such as highway salt, **fertilizers that are spread across the land surface, and pesticides**.
- In addition, a wide array of **chemicals and industrial materials** may leak from pipelines, storage tanks, landfills, and holding ponds.

GROUNDWATER POLLUTION/CONTAMINATION