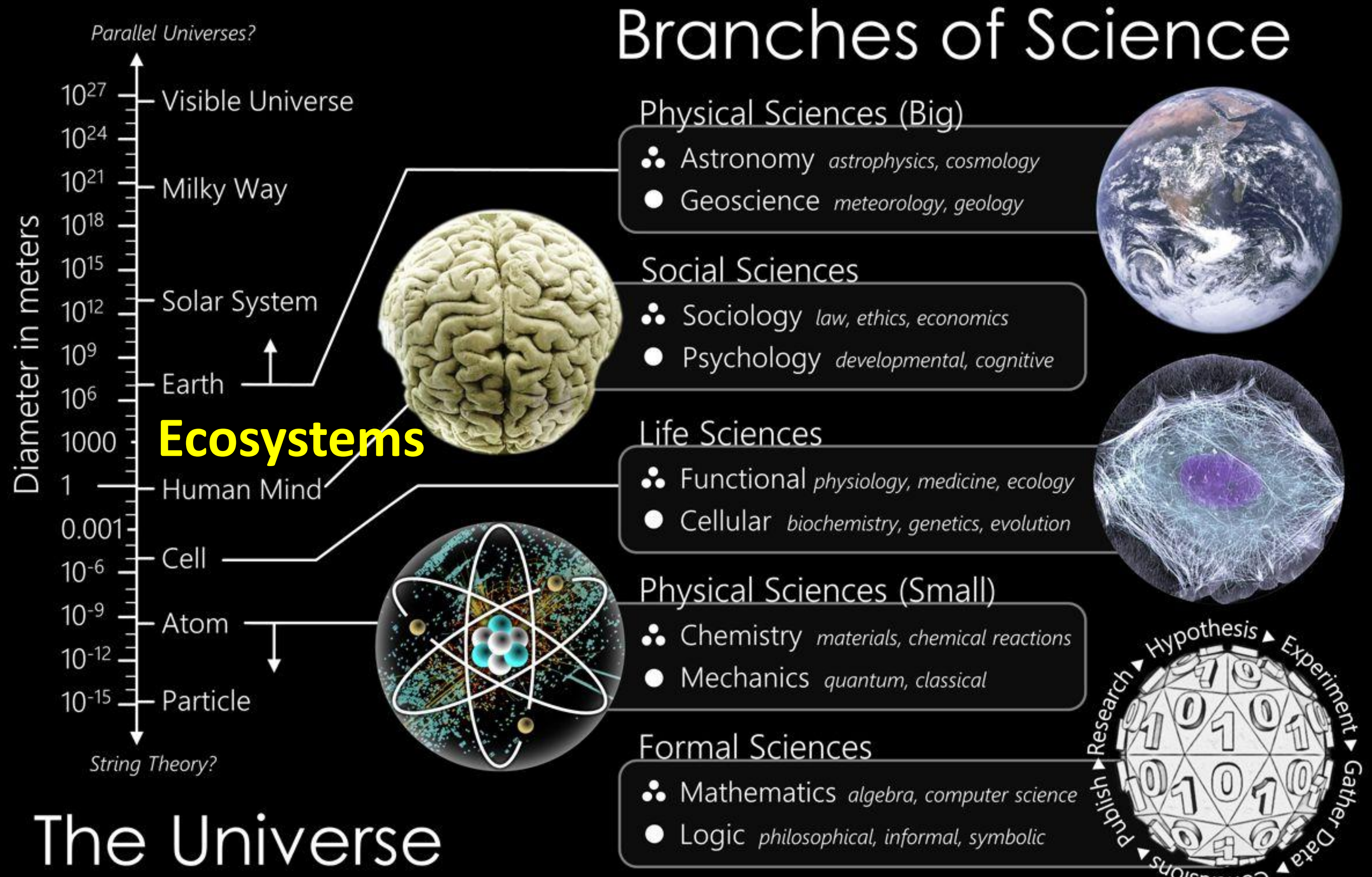
Water

Why it matters…water shapes life from the molecular to the planetary level.

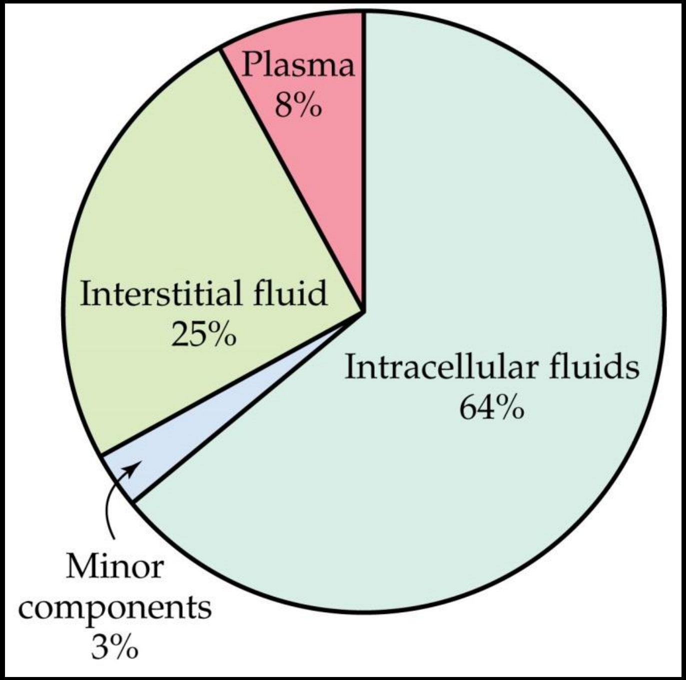


Where is Water?

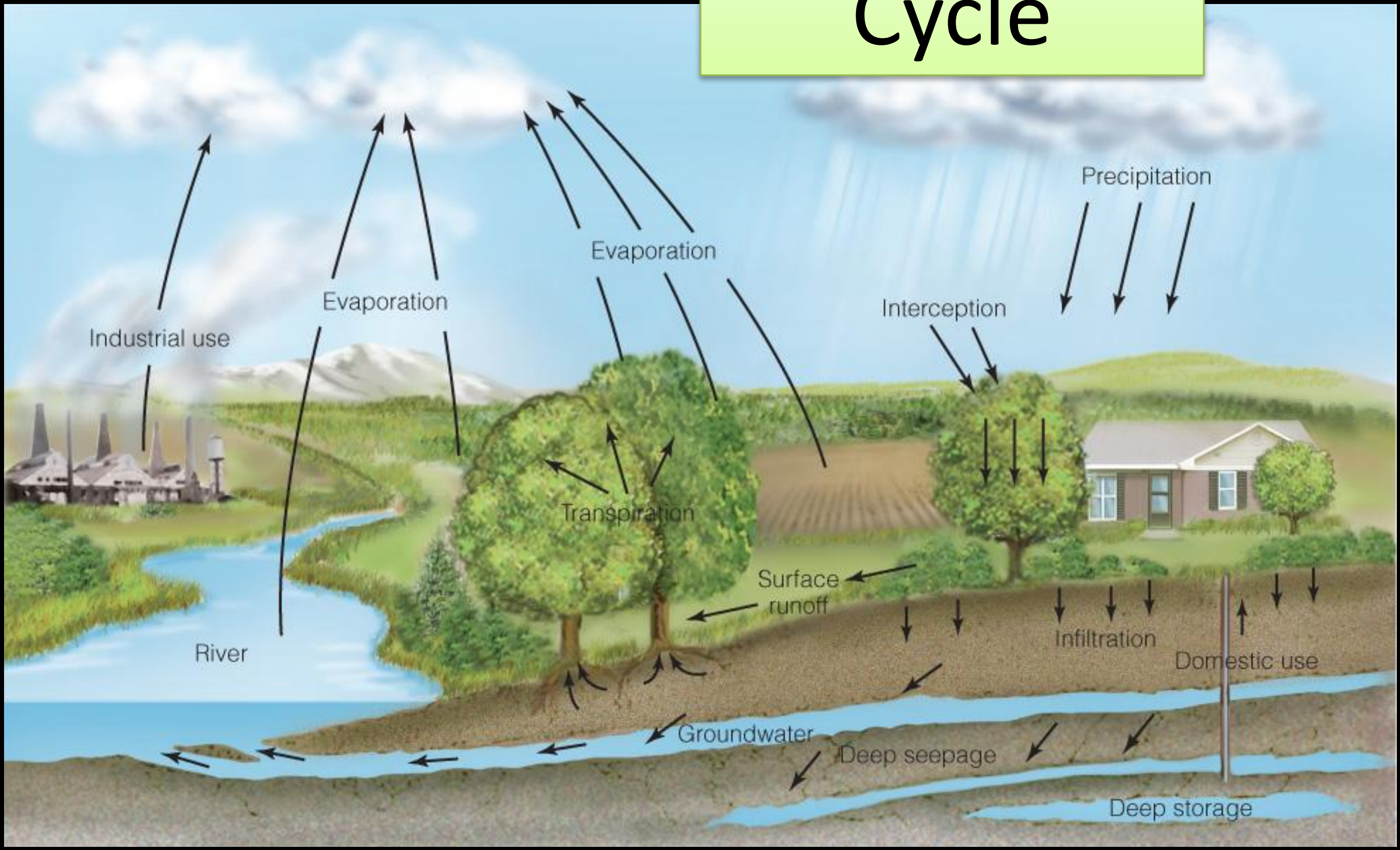
70% of earth's surface

We are bags of mostly water

60% of an adult human

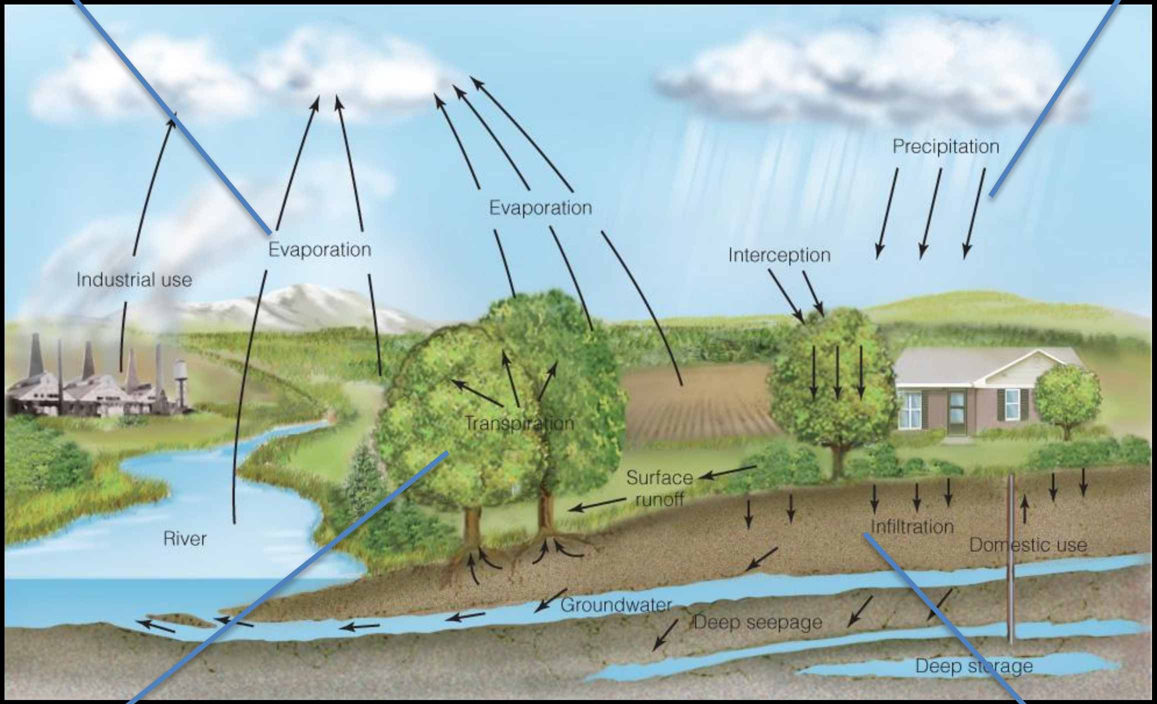


Water Cycle


Precipitation
Evaporation
Evaporation
Industrial use
Interception
Transpiration
Surface runoff
River
Infiltration
Domestic use
Groundwater
Deep seepage
Deep storage

Solar radiation provides the energy required to drive **evaporation**

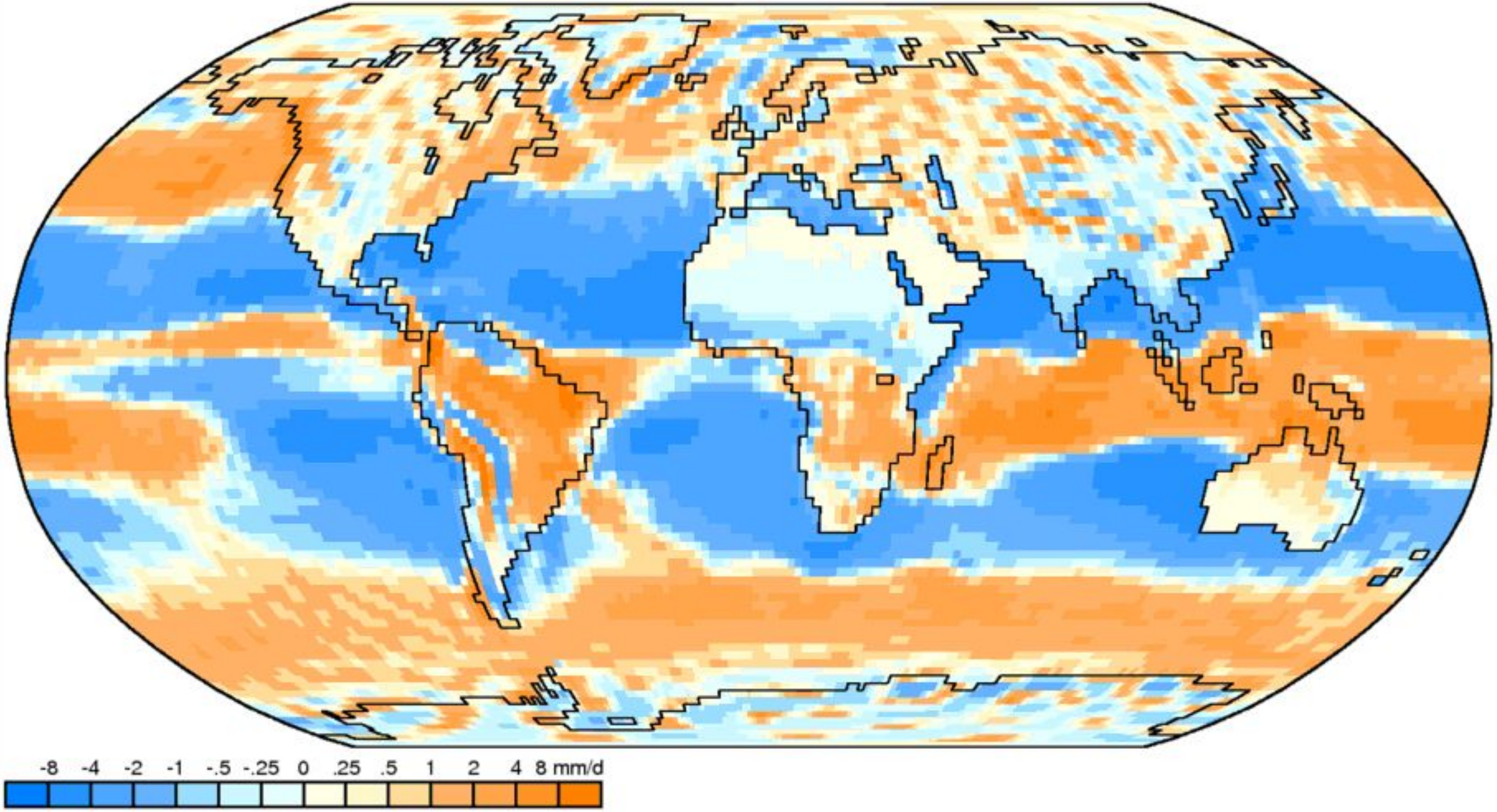
Water vapor circulates eventually forming **precipitation**



A considerable portion of precipitation is **intercepted** by plants, dead organic matter and other structures

Precipitation that reaches the soil enters the ground by **infiltration**

Precipitation minus Evaporation (P-E) Jan

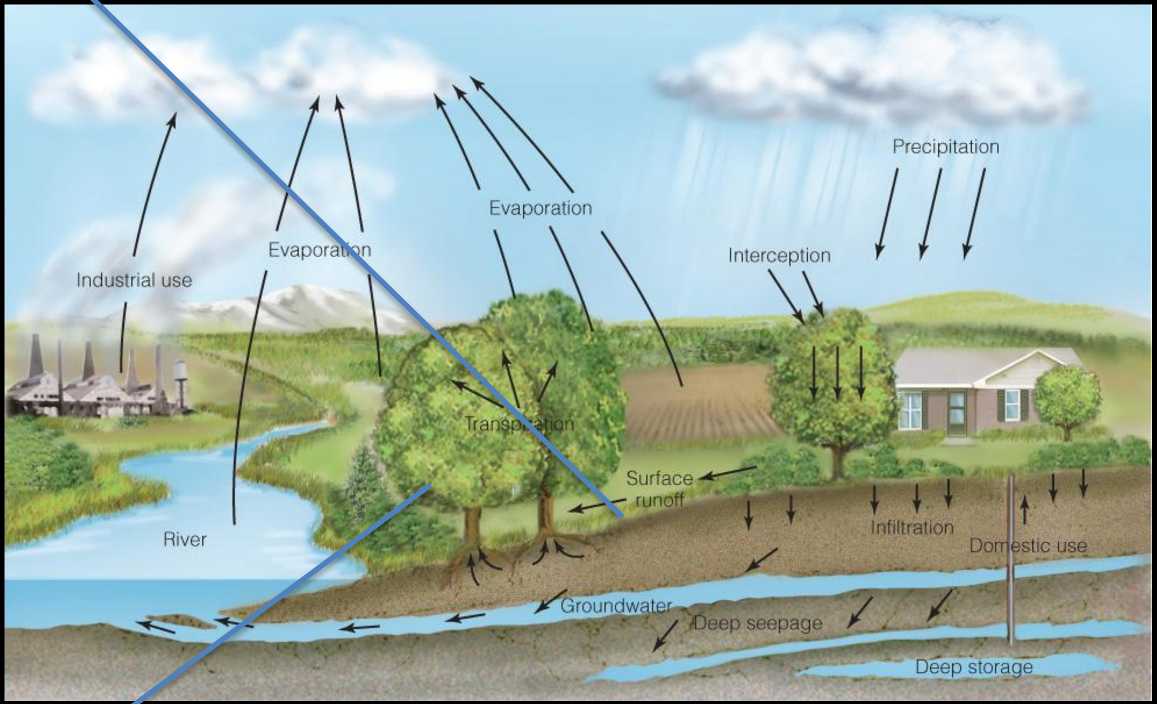


Climate Data: NCEP/NCAR Reanalysis at CDC [http://www.cdc.noaa.gov/cdc/reanalysis/]

Images: http://climvis.org

(1971-2000 base period)

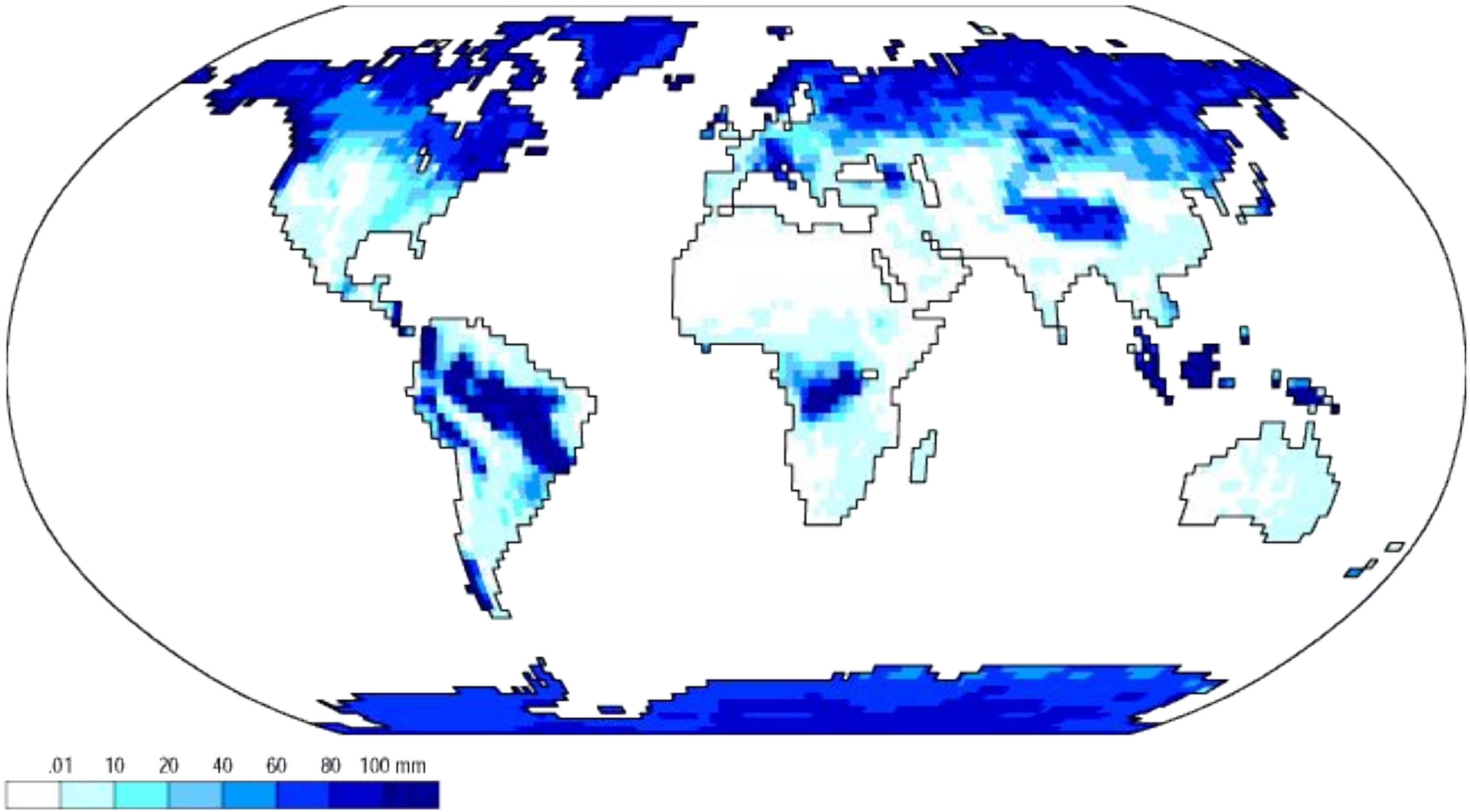
During heavy rains, excess water moves across the ground as **surface runoff**



Plants absorb water through their roots and release it via **transpiration**

Low infiltration of urban areas can result in runoff of as much as 85%

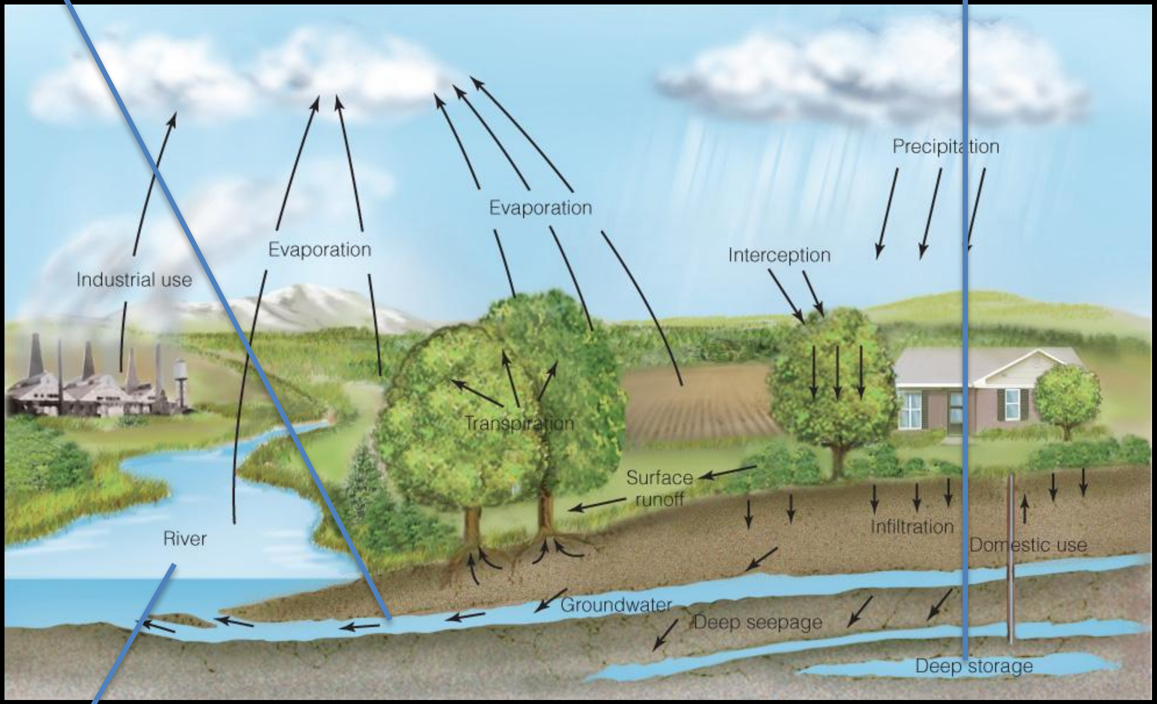
Run Off/Water Surplus Dec



Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000

Once it reaches impervious layers of clay or rock it collected as **groundwater**

Portion of groundwater can seep into deep-storage areas called **aquifers**



Eventually all groundwater finds its way into springs and streams which coalesce into rivers

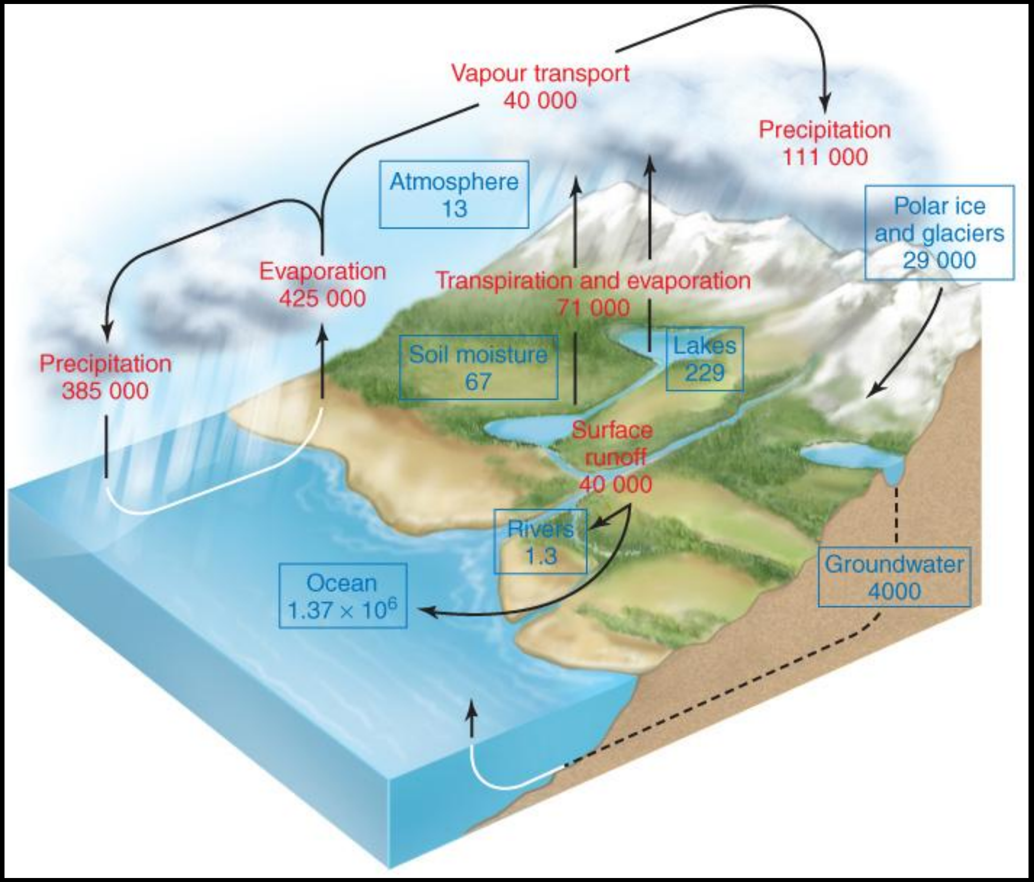
Water turnover time:

- **Atmosphere**

  Entire water content is replaced every 9 days!

- **Ocean**

  Entire water content replacement takes more than 3 000 years



Aquatic Ecosystems

Lakes and Ponds

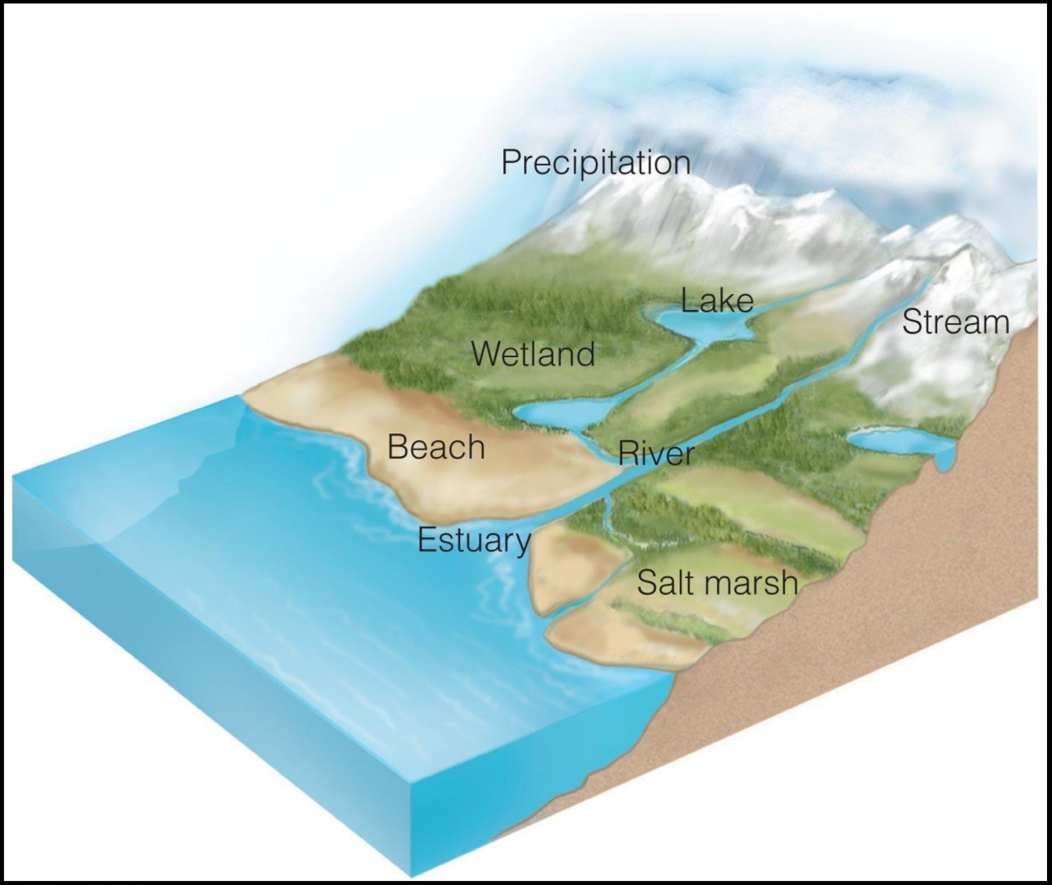
Wetlands

Streams and Rivers

Estuaries

Coastal Zones

Oceans and Seas

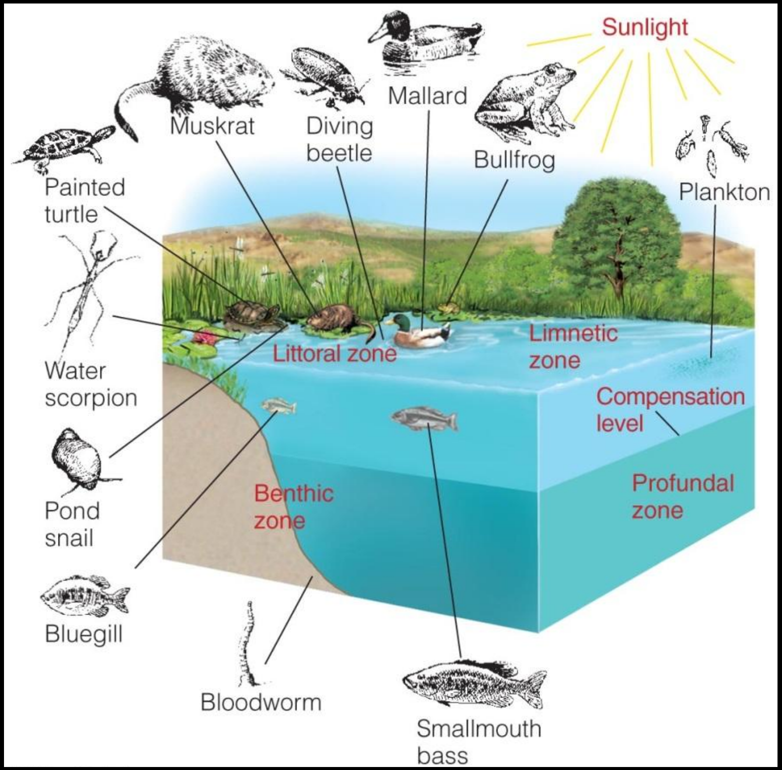


Lake and ponds origins:

- Glacial erosion and deposition (kettle lakes and potholes)
- Formed when sediment and debris dam up water behind them (oxbow lakes)
- Shifts in the Earth's crust
- Beaver dam, human-created dams, quarries and surface mines

(a) (b) (c) (d)

Shallow water zone: emergent vegetation, floating plants, insects, fish, birds, etc.



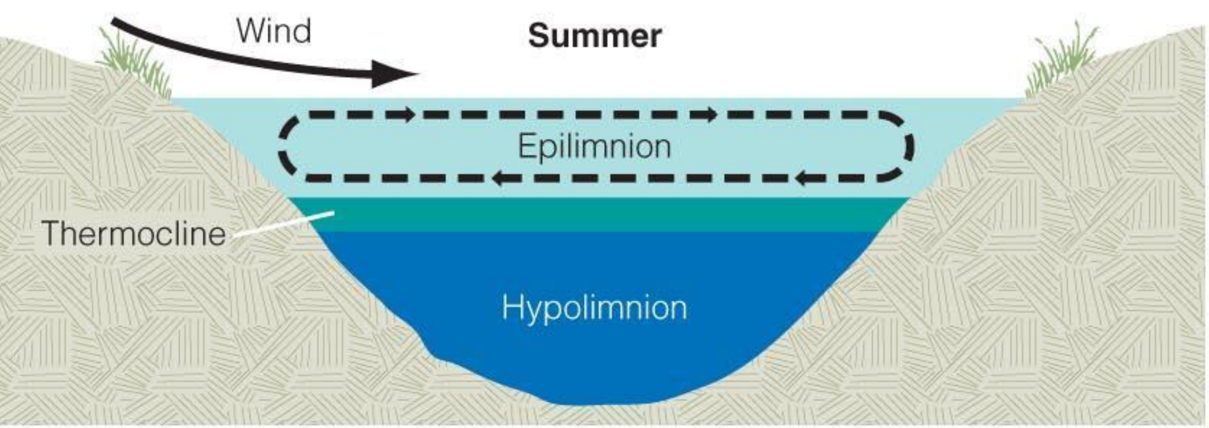
Light open water zoneplankton and free-swimming organisms, such as fish

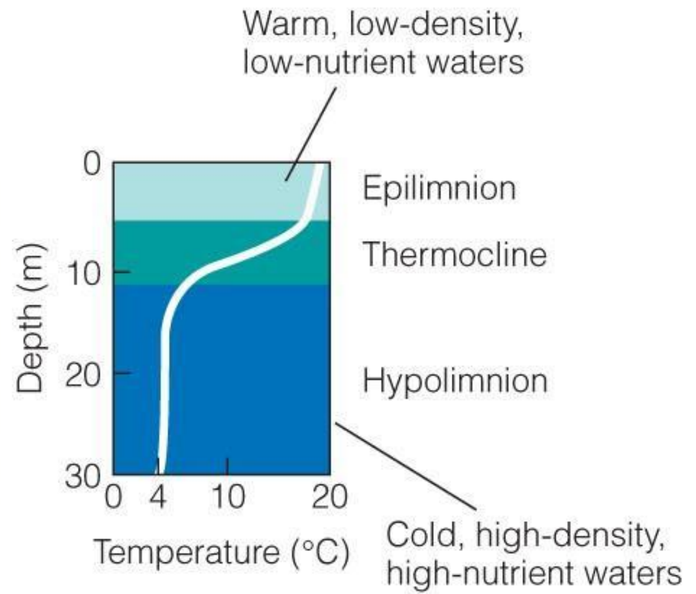
Dark open water zone: limited light and oxygen

Bottom (Benthic) zone: the primary place of decomposition

As solar radiation is absorbed in the surface waters, it heats up. Heat is distributed vertically as winds and surface waves mix. Layers form:

- The upper layer has warm, low-density, low-nutrient water.
- The **thermocline** is the region of the vertical depth profile where water temperature declines most rapidly
- The lower layer has cold, high-density, high nutrient water

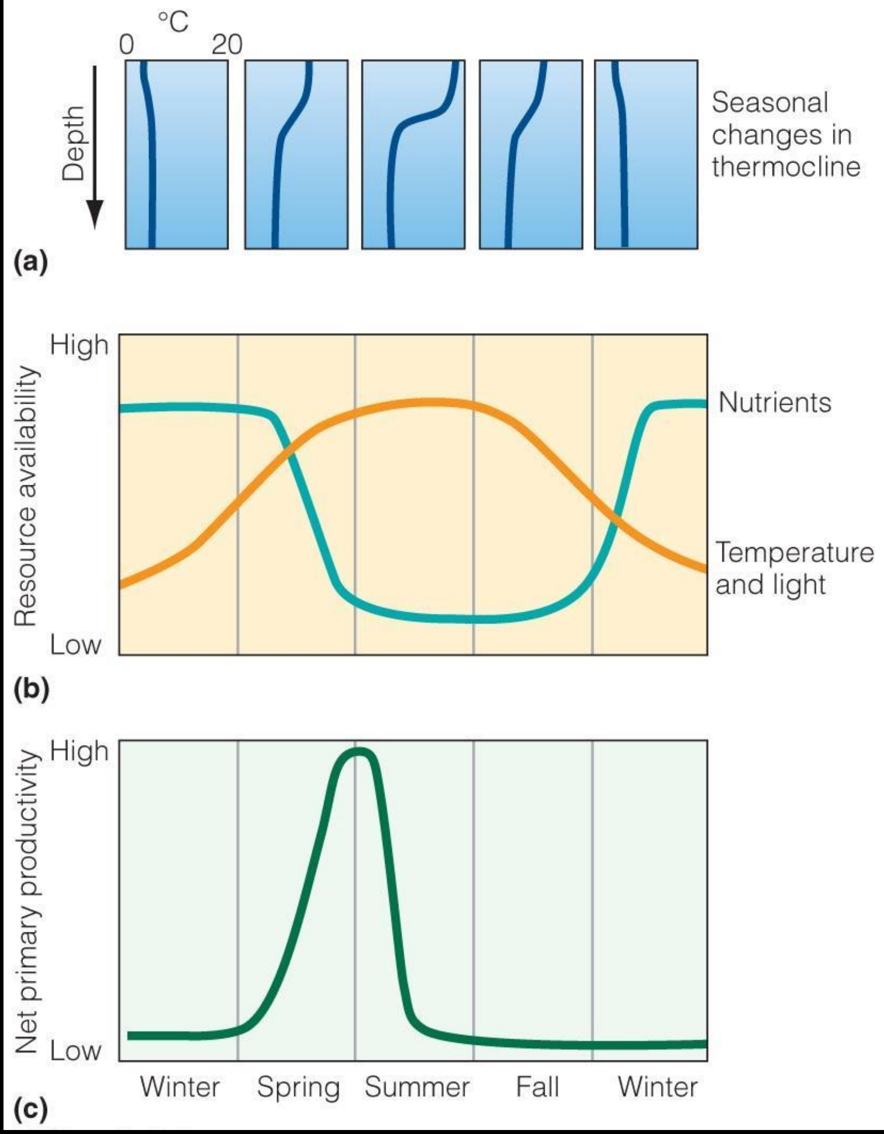




Seasonal Changes

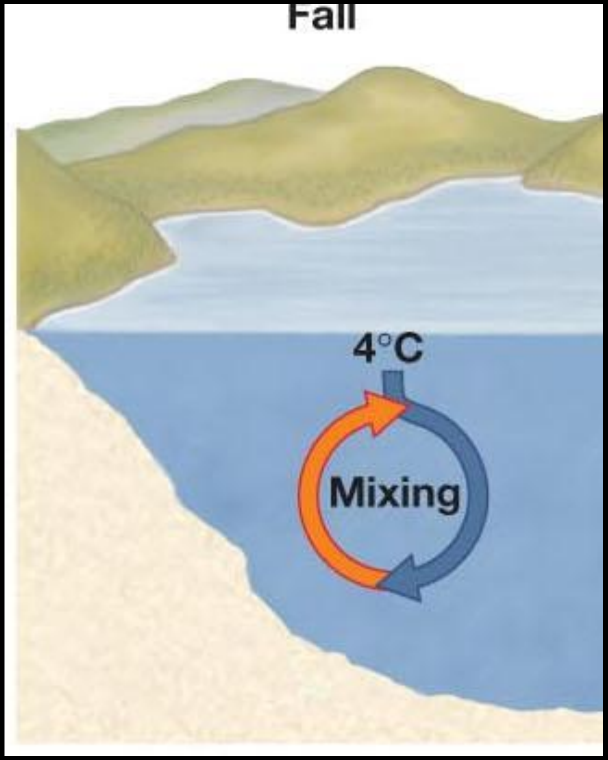
In **tropical zones**, the position of the thermocline is permanent.

In **temperate zones**, many larger bodies of water experience a seasonal mixing of the layers in the fall and spring.



Fall turnover – a circulation cell is formed

1. Surface waters cool, become dense and sink
2. Cool dense water displaces warmer water to the surface where it cools in turn.
3. As the density difference between the layers decrease, winds mix the profile to greater depths
4. Mixing continues until water temperatures are uniform
5. Vertical mixing continues until ice forms at the surface



Winter:

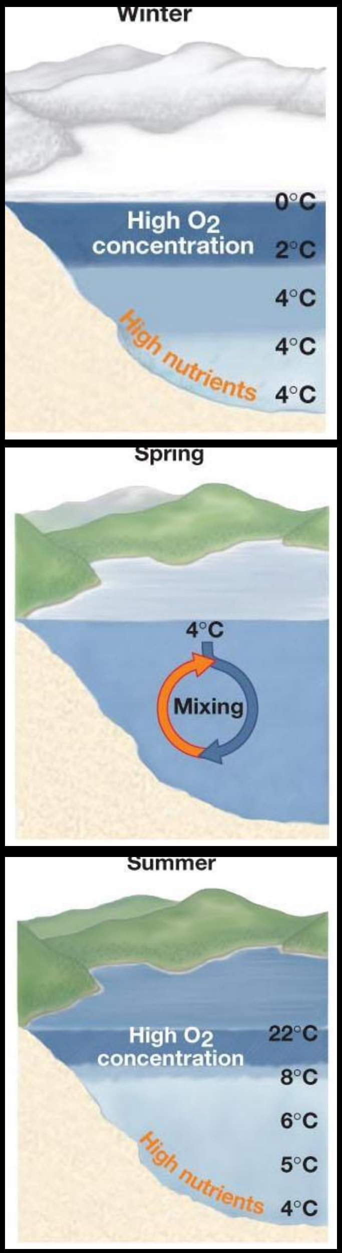
- When surface water temperatures are < 4°C, surface water densities decrease
- Temperature of the water column is stratified (layered)
- The warmest waters are now at lower depths

Spring:

Increased solar radiation warms the surface water creating a circulation cell

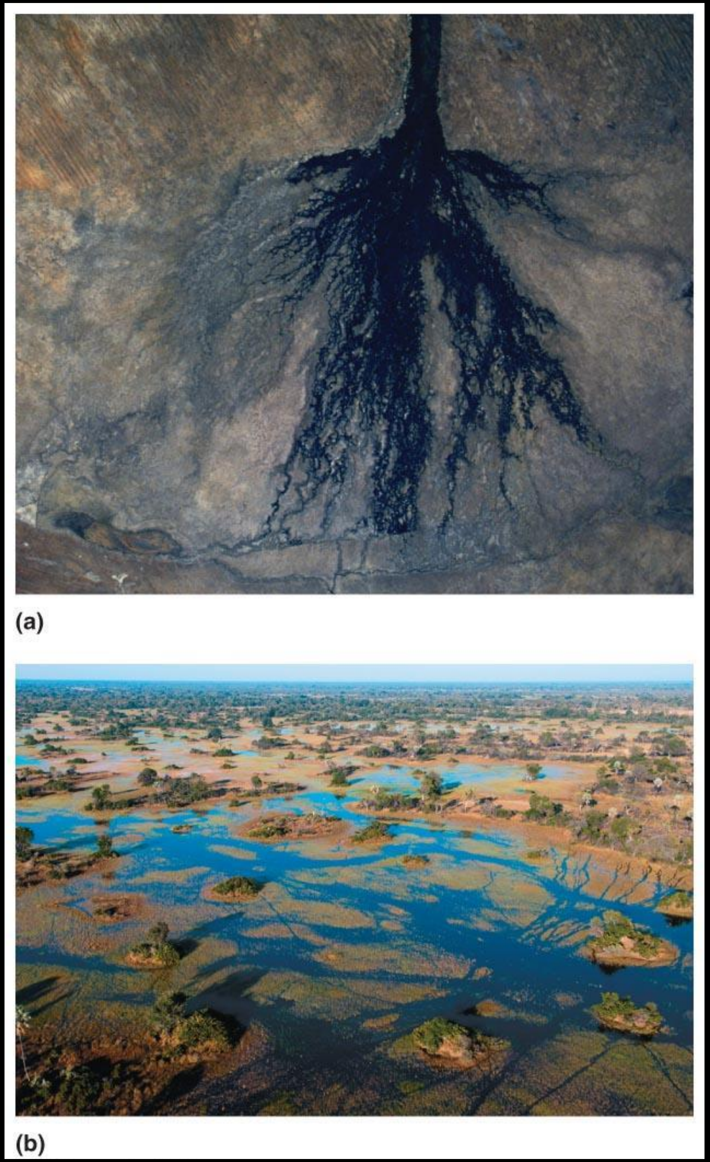
Summer:

The separation of the layers is re-established



Wetlands cover 6% of the Earth’s surface and are found in every climatic zone

- **Basin wetlands**
  - develop in shallow basins, from upland depressions to filled-in lakes and ponds
  - water flow is vertical
- **Riverine wetlands**
  - develop along shallow and periodically flooded banks of rivers
  - water flow is unidirectional
- **Fringe wetlands**
  - occur along the coasts of large lakes
  - water flow is in two directions



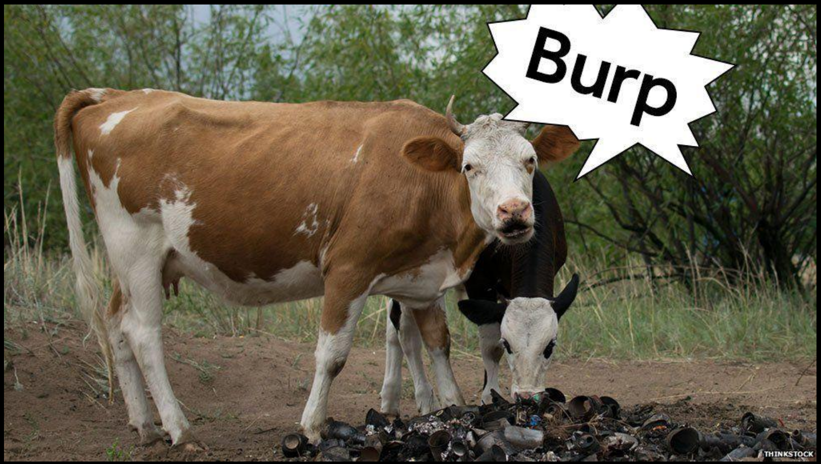
Words for different types of wetlands:

- **Marshes** : wetlands dominated by emergent vegetation
- **Swamps :** forested wetlands
- **Bottomland** or **riparian woodlands:** occasionally or seasonally flooded by river waters
- **Peatlands** or **mires:** characterized by an accumulation of organic matter
  - **Fens:** Mires fed by groundwater (the source of nutrients) and dominated by sedges
  - **Bogs**: Mires dependent on precipitation and are dominated by *Sphagnum*



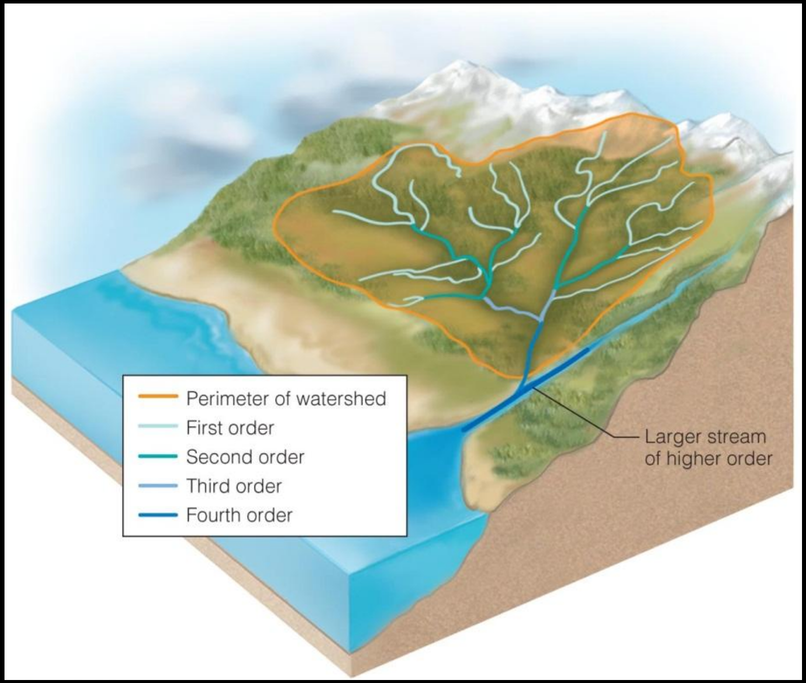


Methane is produced in anaerobic conditions, organic decay: wetlands, rice fields, grazing animals intestines, termites, landfills, coal mining, oil and gas extraction



Streams are classified according to order and increase in order when a stream of the same order joins it

- **First-order stream**: a small headwater stream with no tributaries
- **Second-order stream**: formed when two first-order streams unite

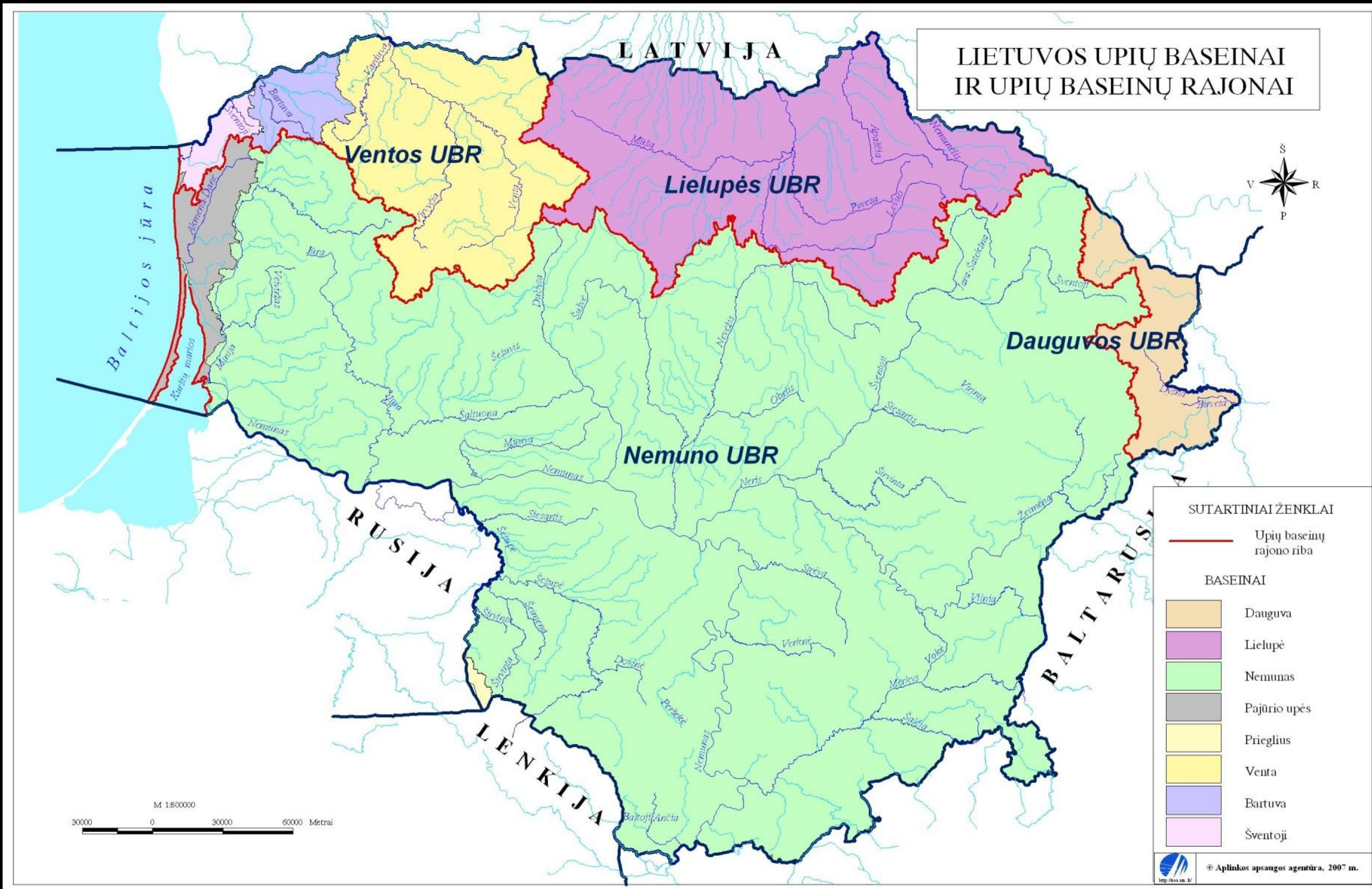


Headwater streams are orders 1 to 3

Medium-sized streams are orders 4 to 6

Rivers are orders greater than 6

Lithuanian River Basins



Estuaries: semi-enclosed parts of the coastal ocean where freshwater joins saltwater

- Mixing waters of different salinities and temperatures
- Complex currents
- Nutrients are carried into the estuary by the tides

- Mostly marine species
  - Oyster bed and oyster reef
  - Sea grasses
- Fish that live most of their lives in saltwater and return to freshwater to spawn

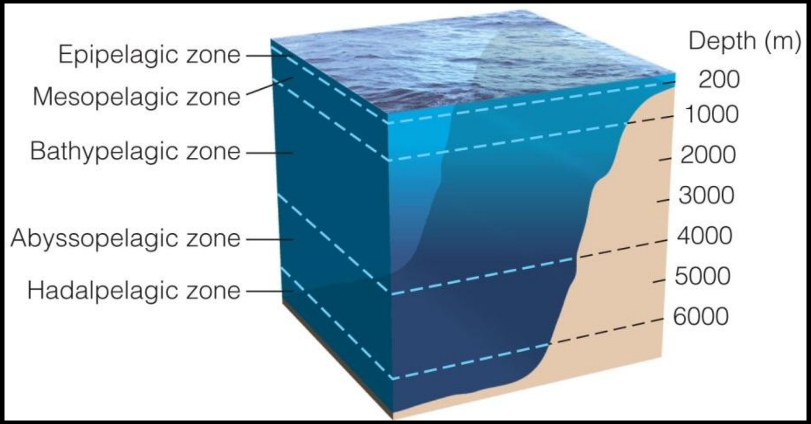
Wherever land and water meet, there is a transitional zone that gives rise to a diverse array of unique ecosystems:

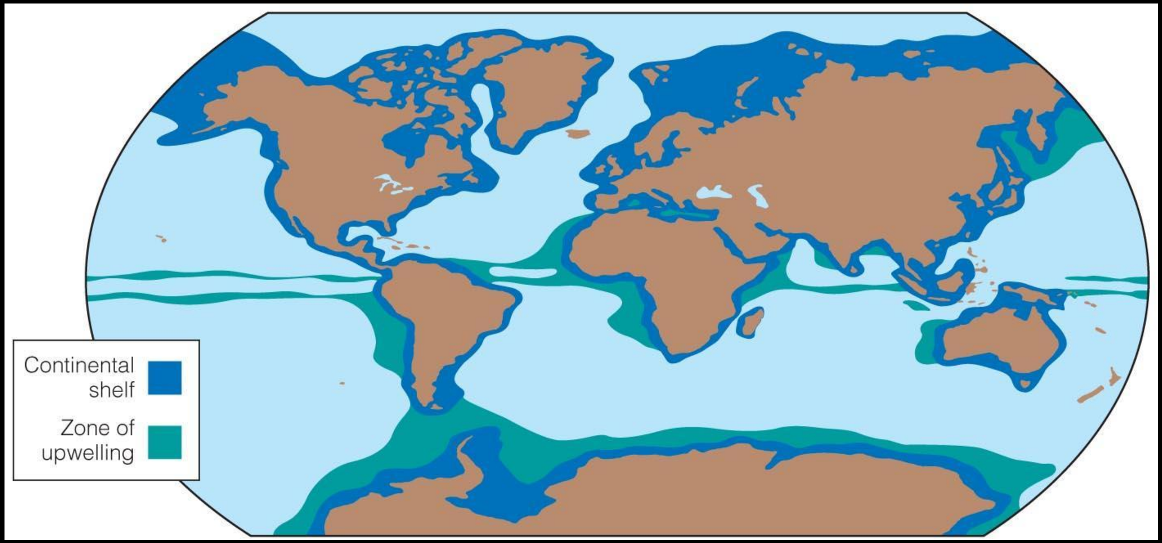
- Rocky shore
- Tide pools
- Sandy beach
- Coastal dunes
- Salt marshes
- Mangroves

Flora and fauna that are resistance to disturbance

The **marine** (ocean) environment exhibits stratification and zonation based on depth, light, and temperature

- **Benthic zone:** bottom region
- **Pelagic zone:**
  - Continental Shelf
  - Zone of upwelling
  - Open ocean





- Ocean depth varies from a few hundred meters to 10,000 m.
- Water pressure increases with increasing depth (1 atm per 10 meters in depth)
- Thus sea floor pressure can vary from 20 atm to ≥ 1,000 atm

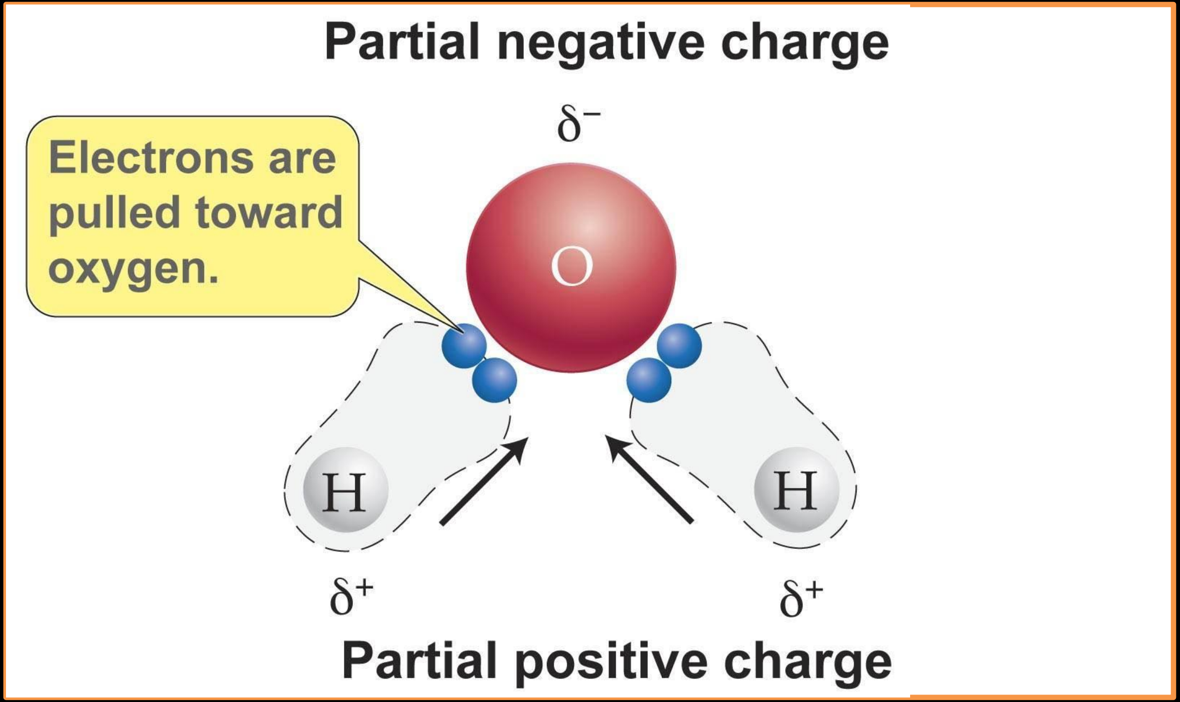
- Proteins and membranes are pressure sensitive so deep-sea organisms have to have adaptations to survive in high pressure.

Why is water so amazing?

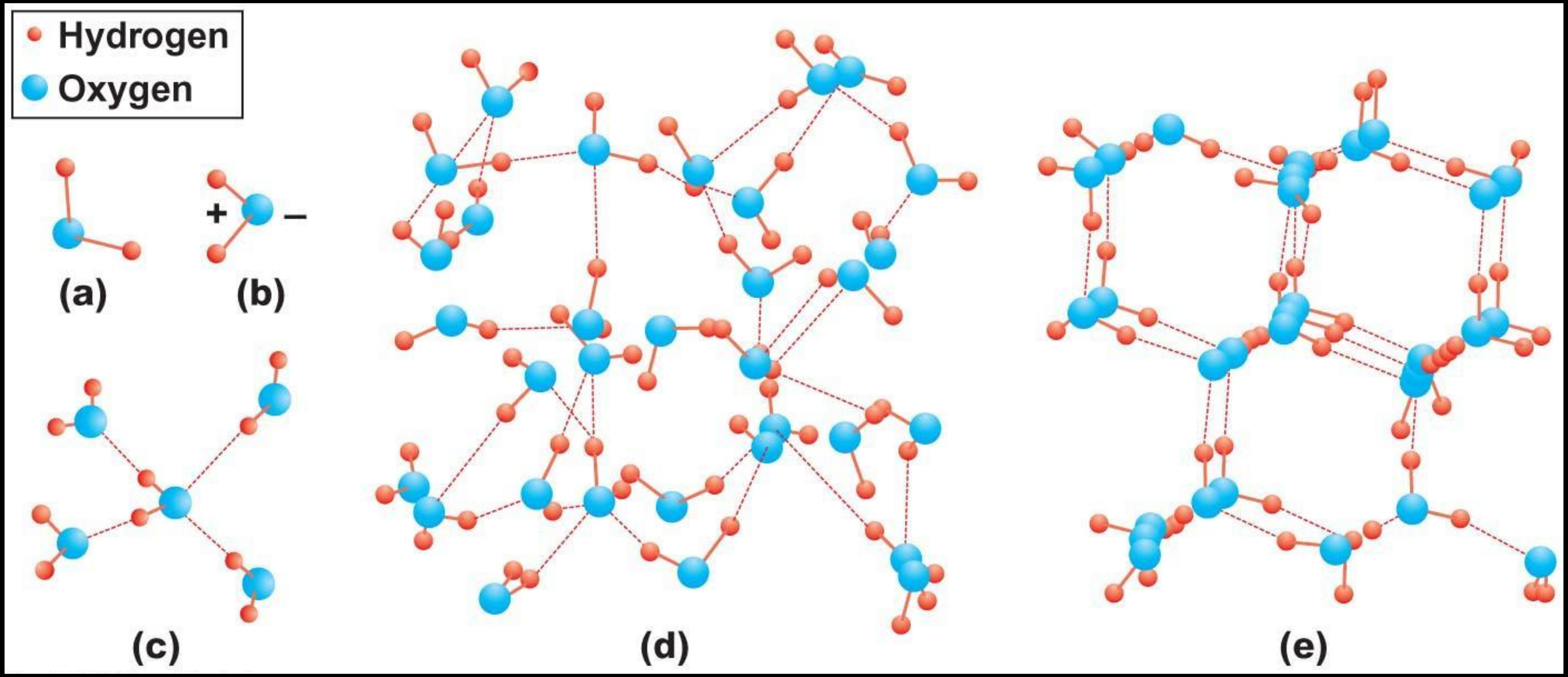
- Water exists in gas, liquid, and solid form on Earth
- Ice floats!
- Water sticks to itself!
- Water sticks to other things
- Water dissolves more substances than any other liquid

Because of its **Structure**

- The hydrogen atoms share an electron with the oxygen atom through a **covalent bond**
- Because electrons are unequally shared and spend more time around oxygen, water is considered a **polar** molecule



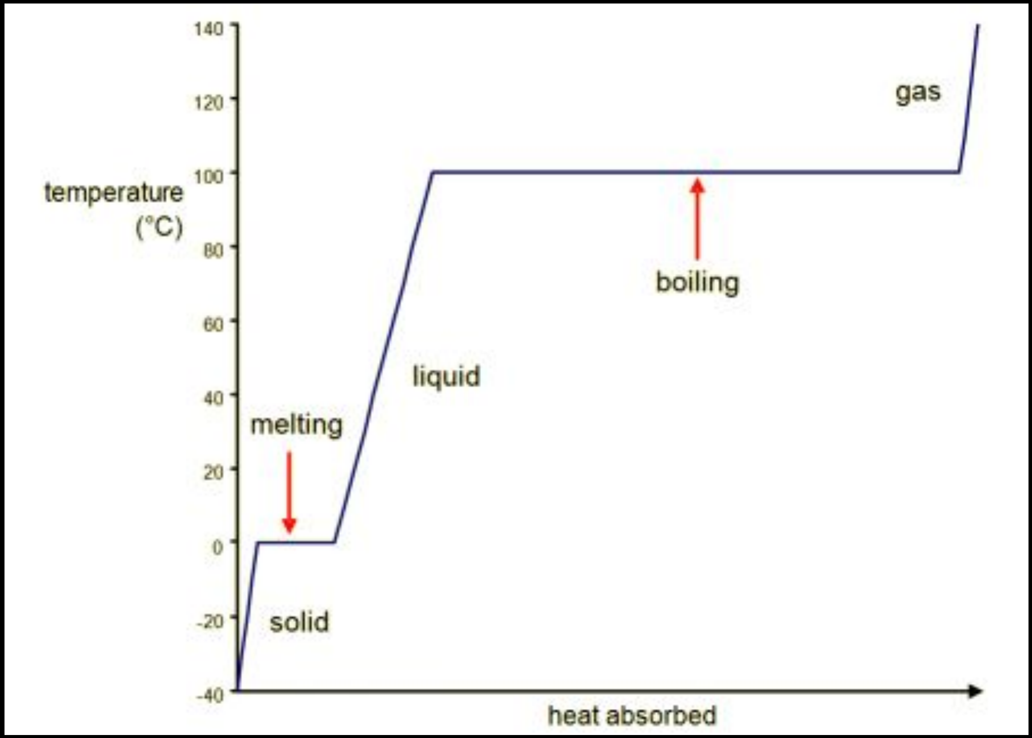
Because of their polarity, water molecules bond with one another (hydrogen bonding)



…water is stable

Water must absorb (or lose) great quantities of heat to change its temperature

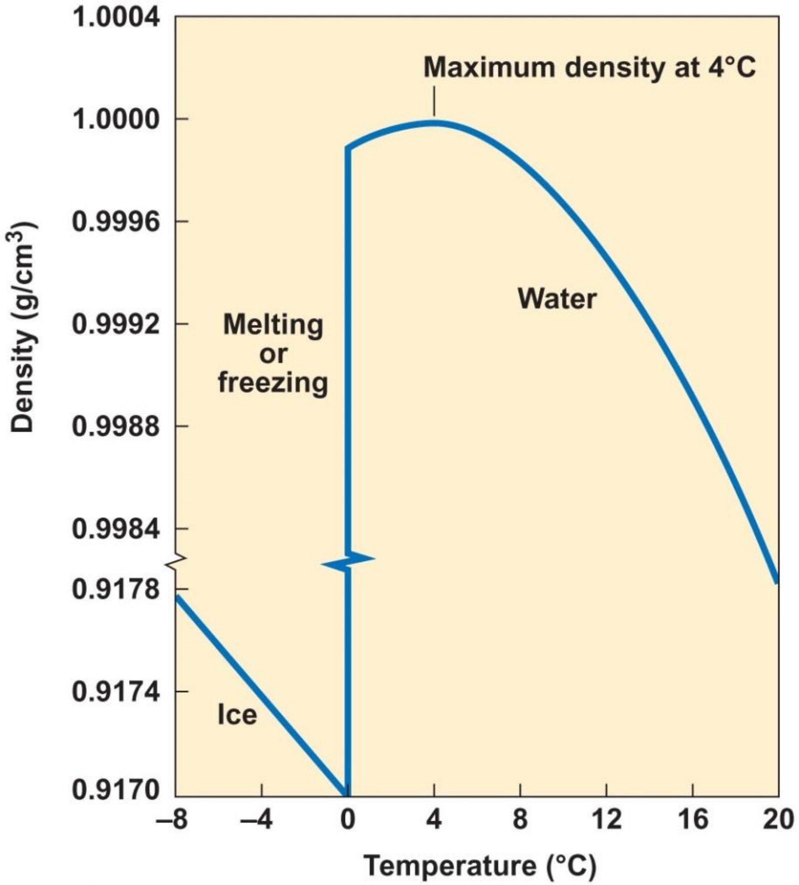
- This helps protect aquatic habitats from huge temperature fluctuations
- It also helps organisms control their body temperature



…ice floats!

Water becomes less dense as it converts from liquid to solid because in crystal form the molecules are spaced farther apart

- Ice helps protect water ecosystems by providing a layer of insulation on the water's surface.



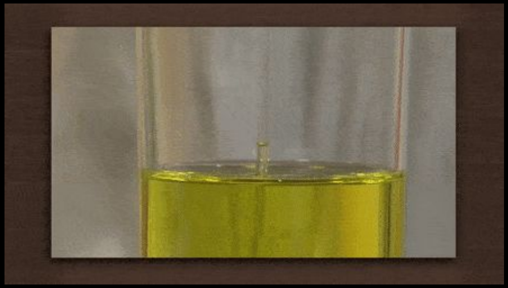
…water has:

- **Cohesion** is the tendency for water molecules to stick together, resisting external forces

- **Surface tension** of water is the result of differences in attraction among water molecules between the surface of the water and air

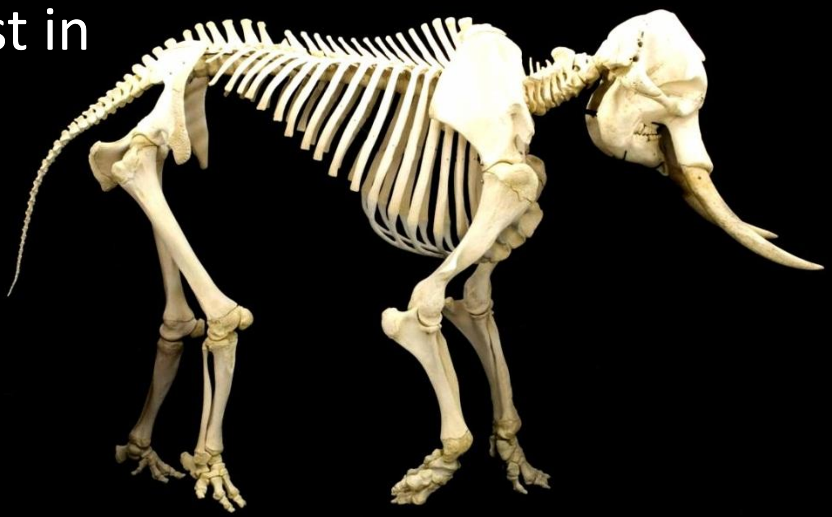
- **Adhesion** is the tendency for water molecules to stick to surfaces

- **Viscosity** is the ability to resist a force necessary to separate the molecules (860 x air)



Why it matters: Support

- Terrestrial organisms have to invest in structural materials to overcome gravitational forces
  - Skeletons for animals
  - Cellulose for plants

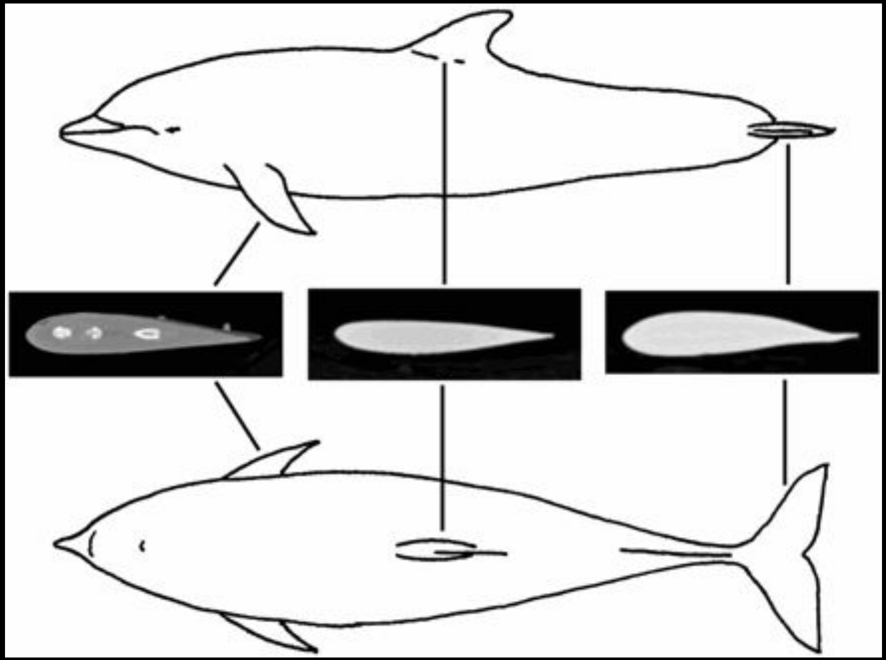


- The density of most aquatic organisms is similar to water, resulting in **neutral buoyancy**

- Most aquatic organisms would be unable to support their bodies if brought onto land

Why it matters: Mobility

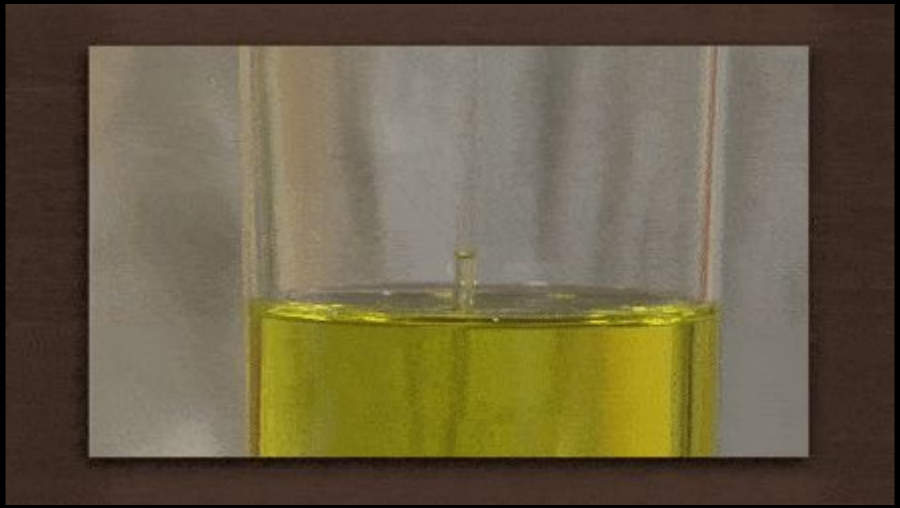
High viscosity can limiting mobility and create a barrier to movement at the air-water interface.



Adaptations:

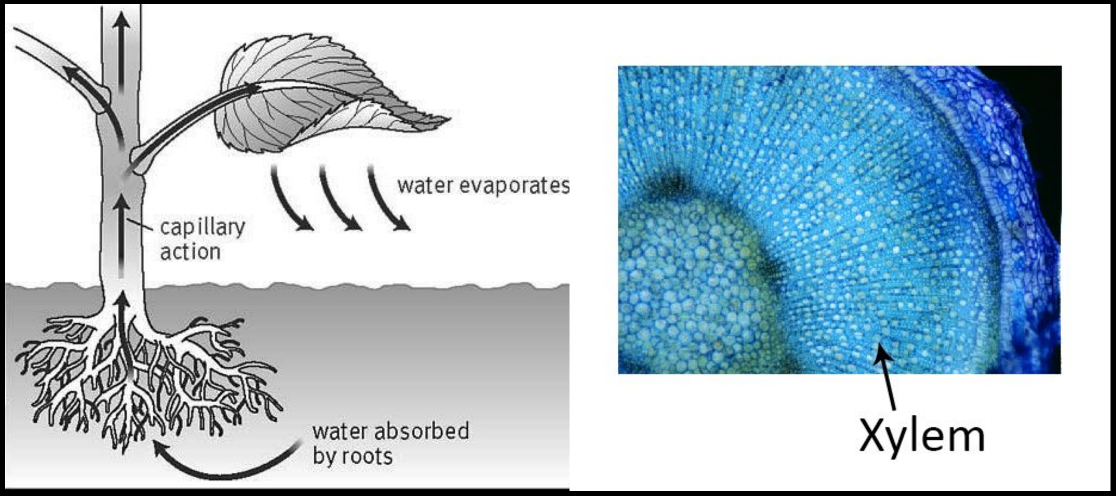
- Streamlined body shape (round front and tapered body) reduces resistance or drag.
- Swimming requires less energy

Why it Matters: Transportation in Plants



Capillary action: When adhesion is stronger than cohesion, water will move up the surface

- This allows plants to transport water through the xylem from roots to leaves

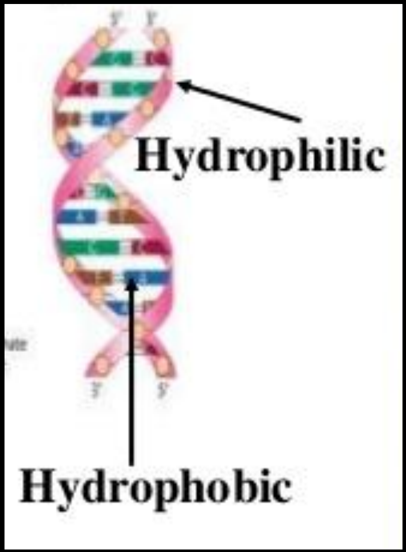


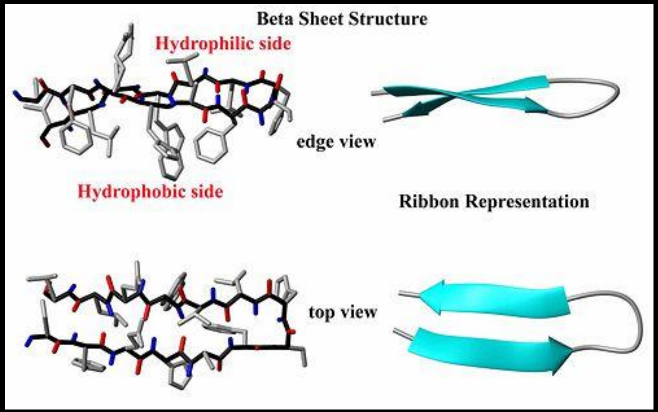
…water is polar

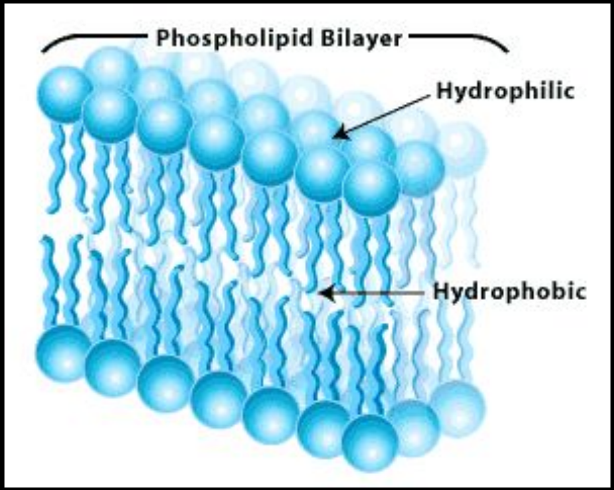
Hydrophilic: materials that are attracted to water

Hydrophobic: materials that are repelled by water

Why it matters: Complex biological molecules such as DNA, proteins, and cell membranes have hydrophilic and hydrophobic sections that allow them to form biologically functional shapes



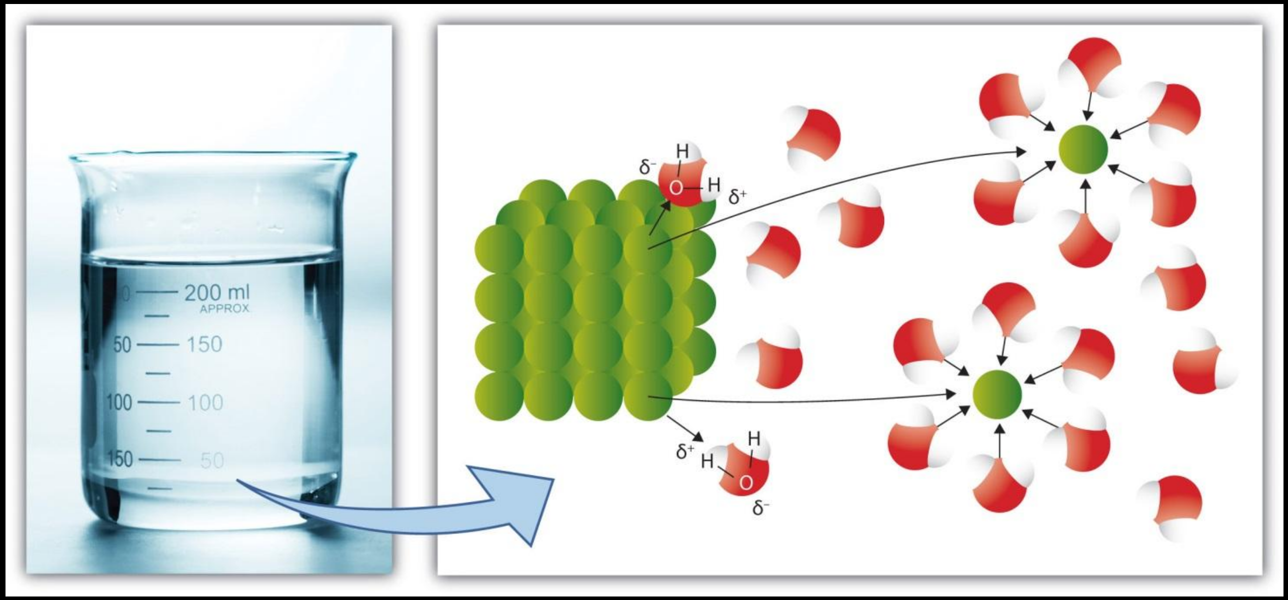




…water is the universal solvent

- Water can dissolve more substances than any other liquid
  - Ionic and polar molecules easily dissolve in water
  - Acids, salts, sugars, alcohols
  - Low concentrations of O_2

- Why it matters: Water carries the valuable nutrients and mineral necessary for sustaining life



…water varies in salinity

- Rivers and lakes contain **0.01** to **0.02%** dissolved minerals
- Relative concentration of solutes reflect differences in substrates

  For example, water that flows over limestone (primarily calcium carbonate) will contain a high concentration of calcium (Ca^{+}) and bicarbonate (HCO_3^-)

Table 3.1 Composition of Seawater of 35 Practical Salinity Units (psu)

Element	g/kg	Millimoles/kg	Element	g/kg	Millimoles/kg
Cations			*Anions*		
Sodium	10.75	467.56	Chlorine	19.35	545.59
Magnesium	1.30	53.25	Sulphate	2.70	28.12
Calcium	0.42	10.38	Bicarbonate	0.15	2.38
Potassium	0.40	10.10	Bromine	0.07	0.83
Strontium	0.008	0.09	Boric acid	0.03	0.44
			Fluorine	0.001	0.07

…water varies in pH

Water reacts even with itself!

$$H_2O \leftrightarrows OH^- + H_3O^+$$

Pure water has an equal number of hydroxide (OH^-) and hydronium ions (H_3O^+).

Water reacts with substances that it dissolves, altering pH.

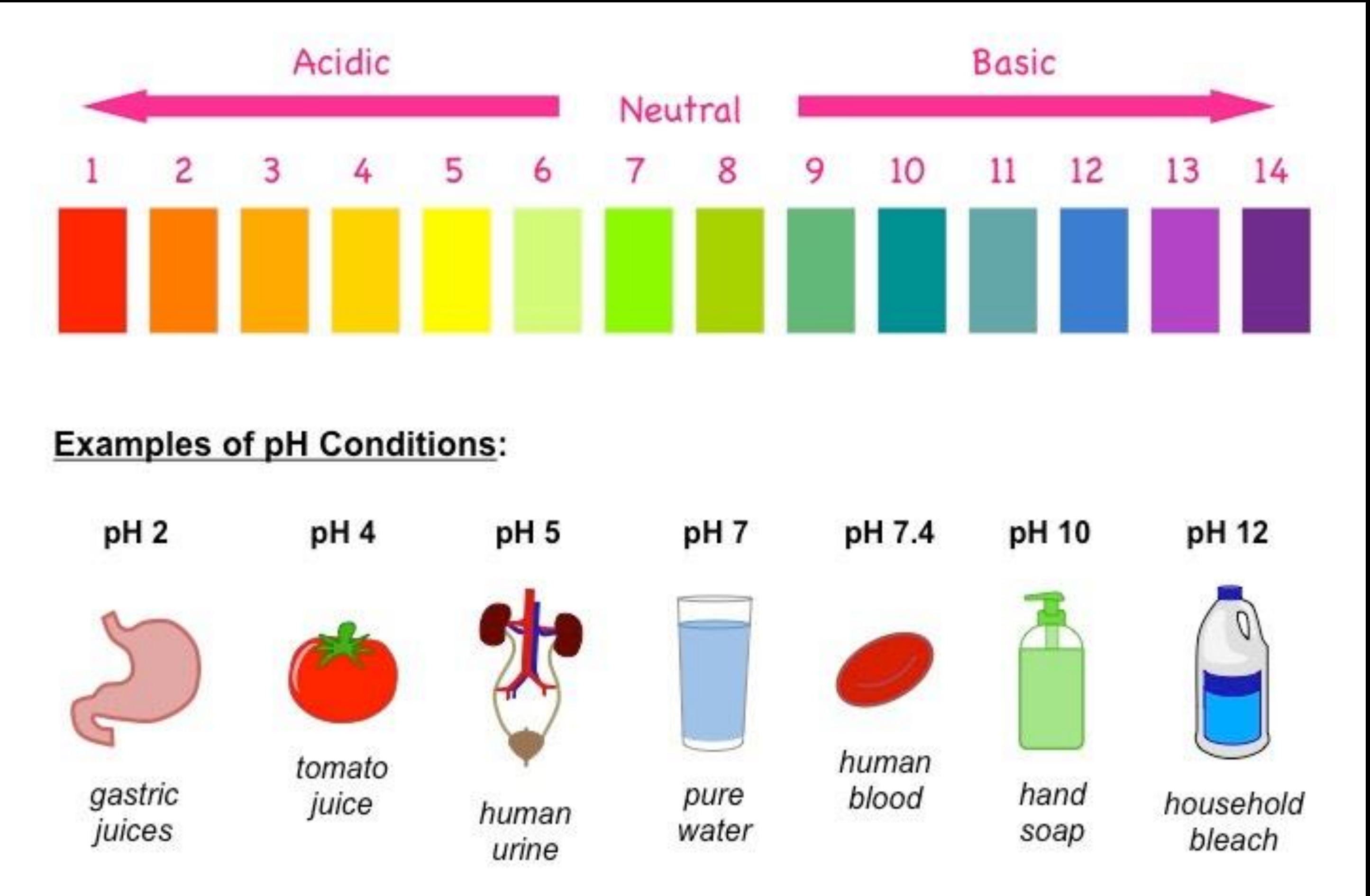
Ammonia + water ⇆ hydroxide + Ammonium

$$NH_3 + H_2O \leftrightarrows OH^- + NH_4^+$$

Acidic solutions have a high number of hydrogen ions (H^+)

A neutral pH (7) results when $[H^+] = [OH^-]$

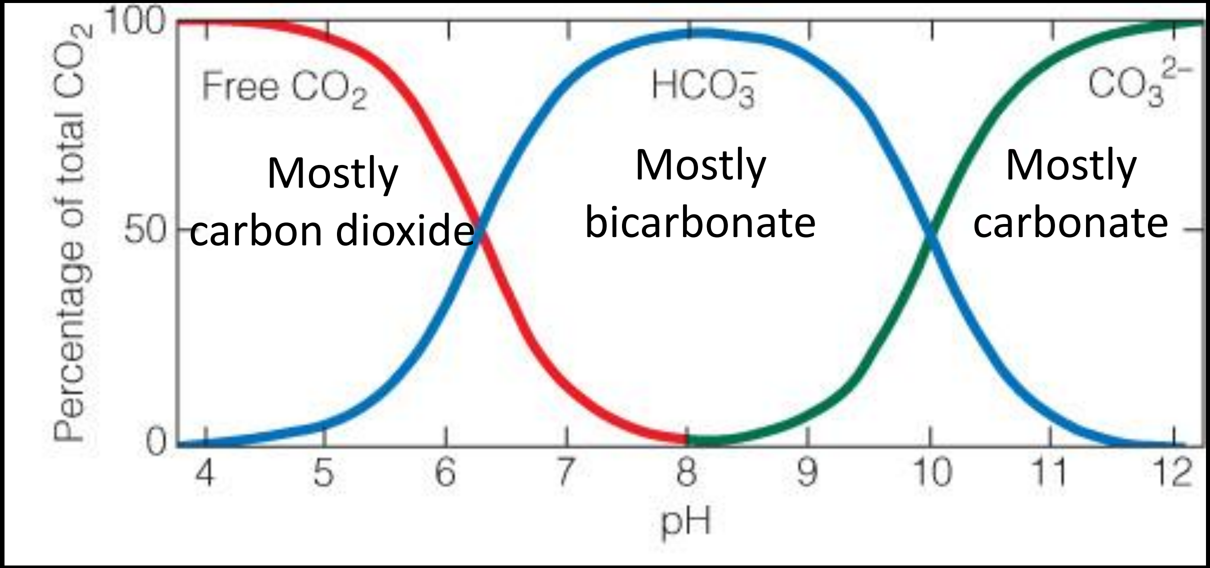
Alkaline solutions have a high concentration of hydroxyl ions (OH^-)



…water acts as a CO_2 sink

- Water has a considerable capacity to absorb **carbon dioxide**
- The carbon dioxide–carbonic acid–bicarbonate system tends to stay in **equilibrium**

$$\mathbf{CO_2 + H_2O \leftrightarrows H_2CO_3}\ (\textit{carbonic acid})$$
$$\mathbf{H_2CO_3 \leftrightarrows HCO_3^-}\ (\textit{bicarbonate}) \mathbf{+ H^+}$$
$$\mathbf{HCO_3^- \leftrightarrows + H^+ + CO_3^{2-}}\ (\textit{carbonate})$$



Why it matters:

The carbon system directly affects the pH of aquatic ecosystems, generally keeping the pH of water within a narrow range

The pH of aquatic environments influences distribution and abundance of organisms

- Physiological processes
- Concentration of toxic metals

As CO_2 levels increase in the atmosphere, they also increase in the ocean making the ocean more acidic

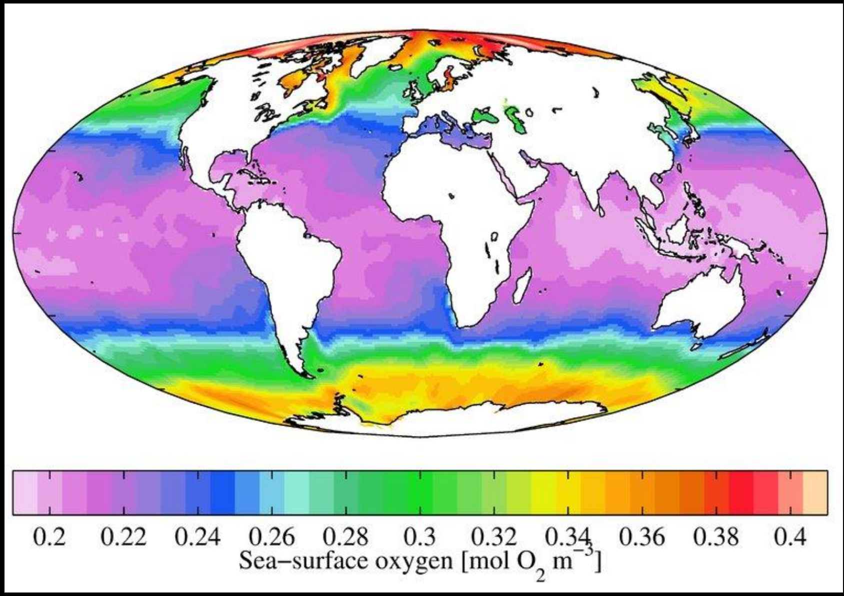
- e.g. Aluminum dissolves as pH decreases and becomes more concentrated in aquatic environments

…water contains Oxygen

From air to water:

O_2 (and CO_2) diffuse from the atmosphere into the surface waters

- Greater when water is moving (increased contact)
- Greater in cold water

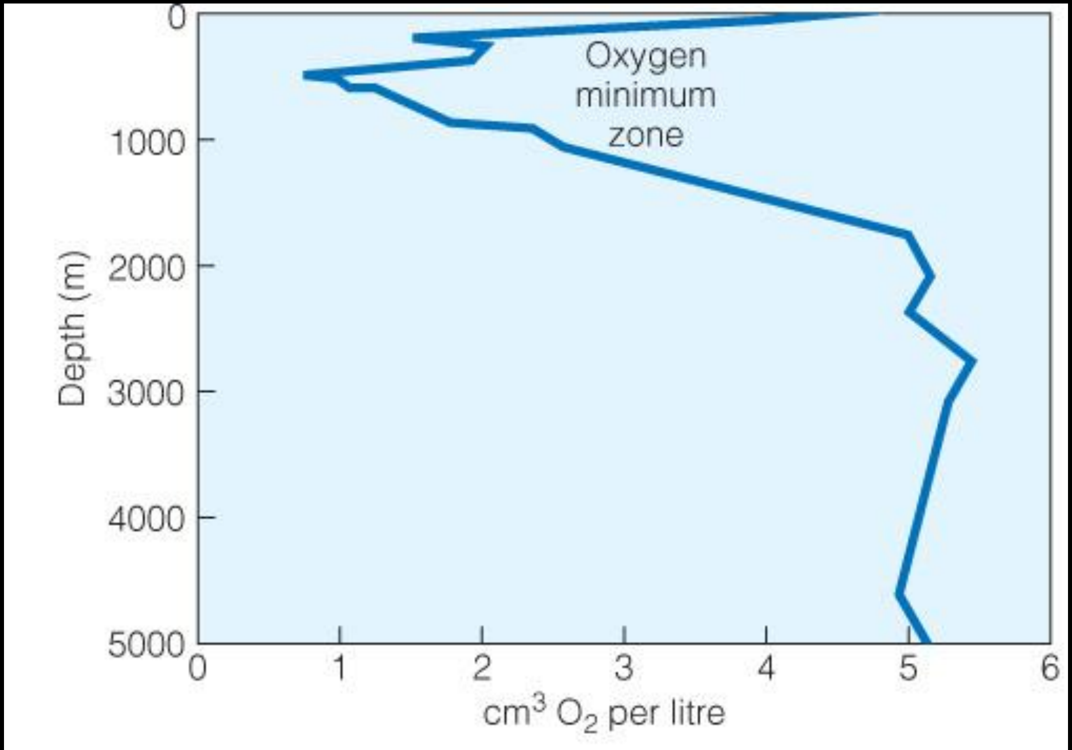


From the surface to the deep. Rate of diffusion:

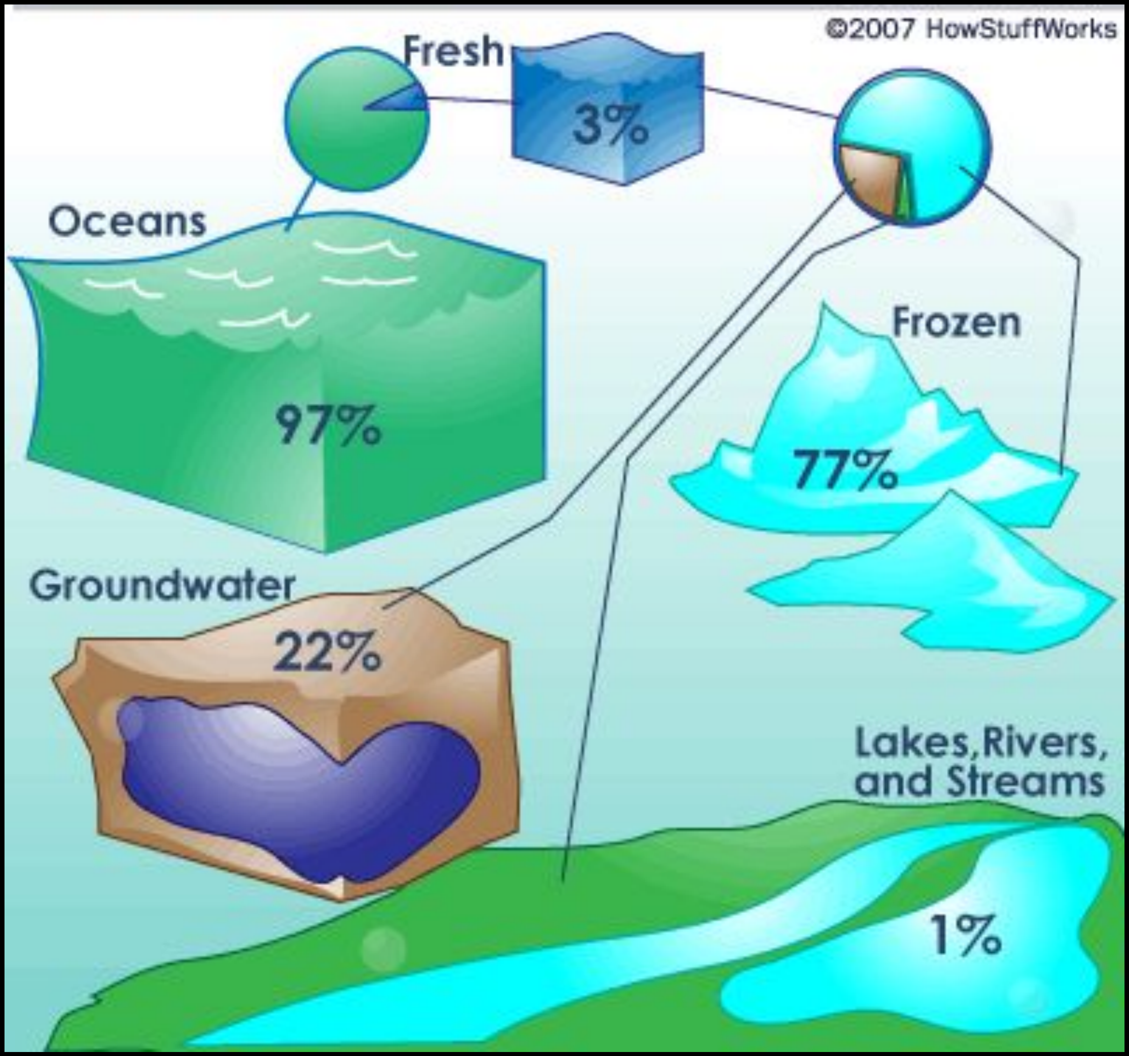
- Is limited by the density and viscosity of water.

In oceans, O_2 is not distributed uniformly

- Maximum O_2 levels are found in the upper 10 to 20 m
- In open waters, O_2 levels reach a minimum between 500 to 1 000 m, called the **oxygen minimum zone**



Only 0.3% of the world's water is usable by humans



Why it matters…necessary for life

Dessication, or the loss of water, is probably the greatest constraint imposed by terrestrial environments

Water evaporates from cell and body surfaces

- Waxy cuticle of plants prevent water loss
- Terrestrial animals acquire water by drinking and eating

Why it matters…water shapes societies.

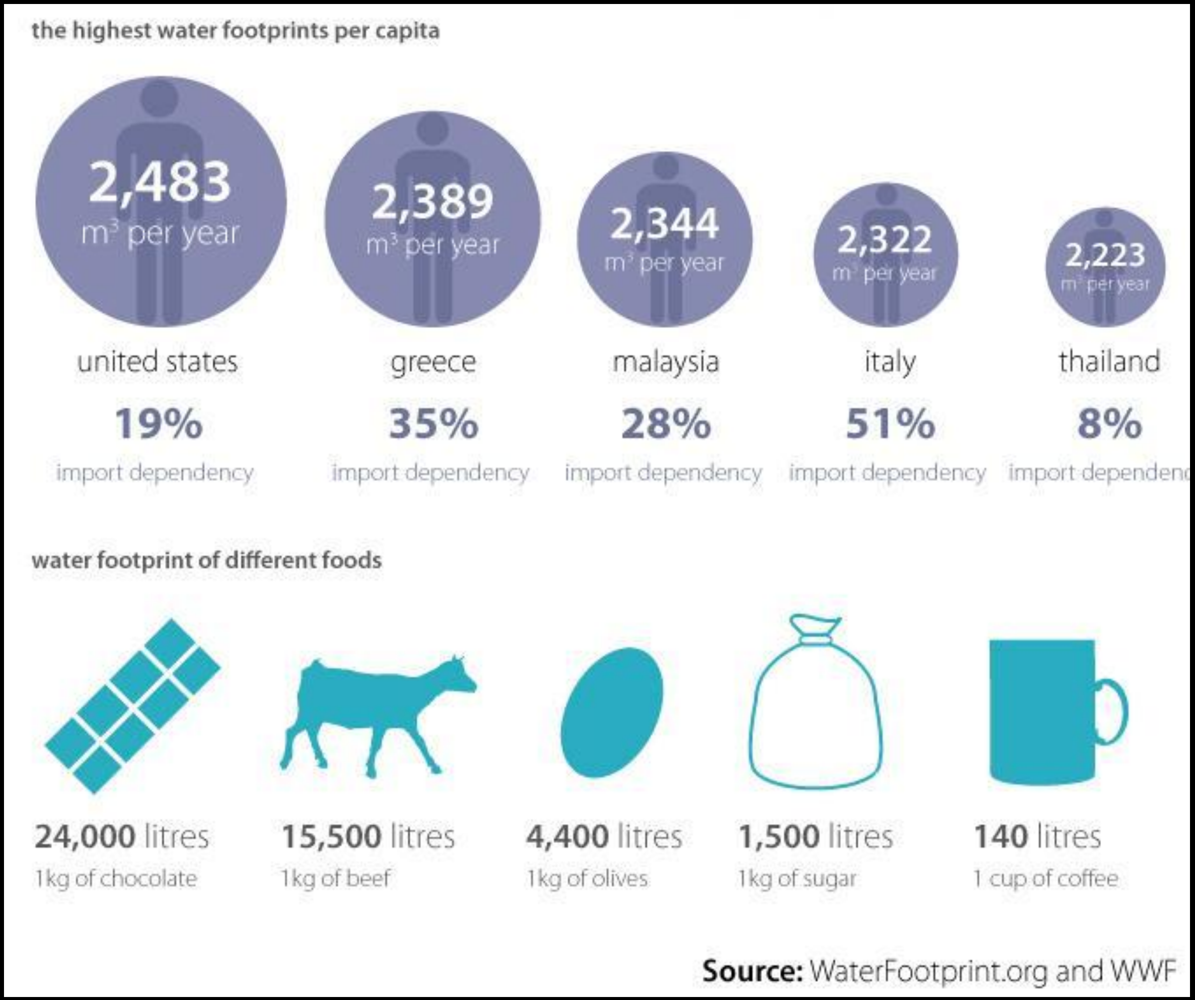
- The first known treaty in human history was between two Sumerian city-states over water rights to the Tigris river

- River basins shape empires…whoever controls the river has the power. Europe may be a politically divided continent because of the lack of major rivers to control.

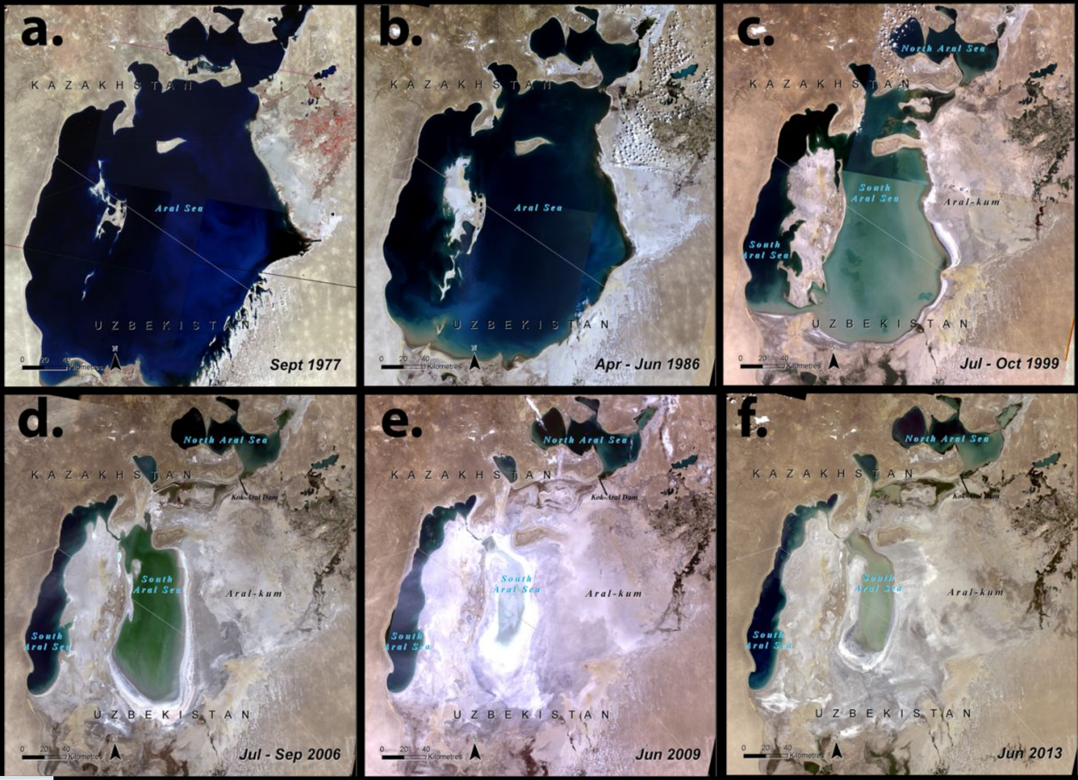
Why it matters…water shapes economics.

Paradox of Value:
Diamonds vs water

Water footprint

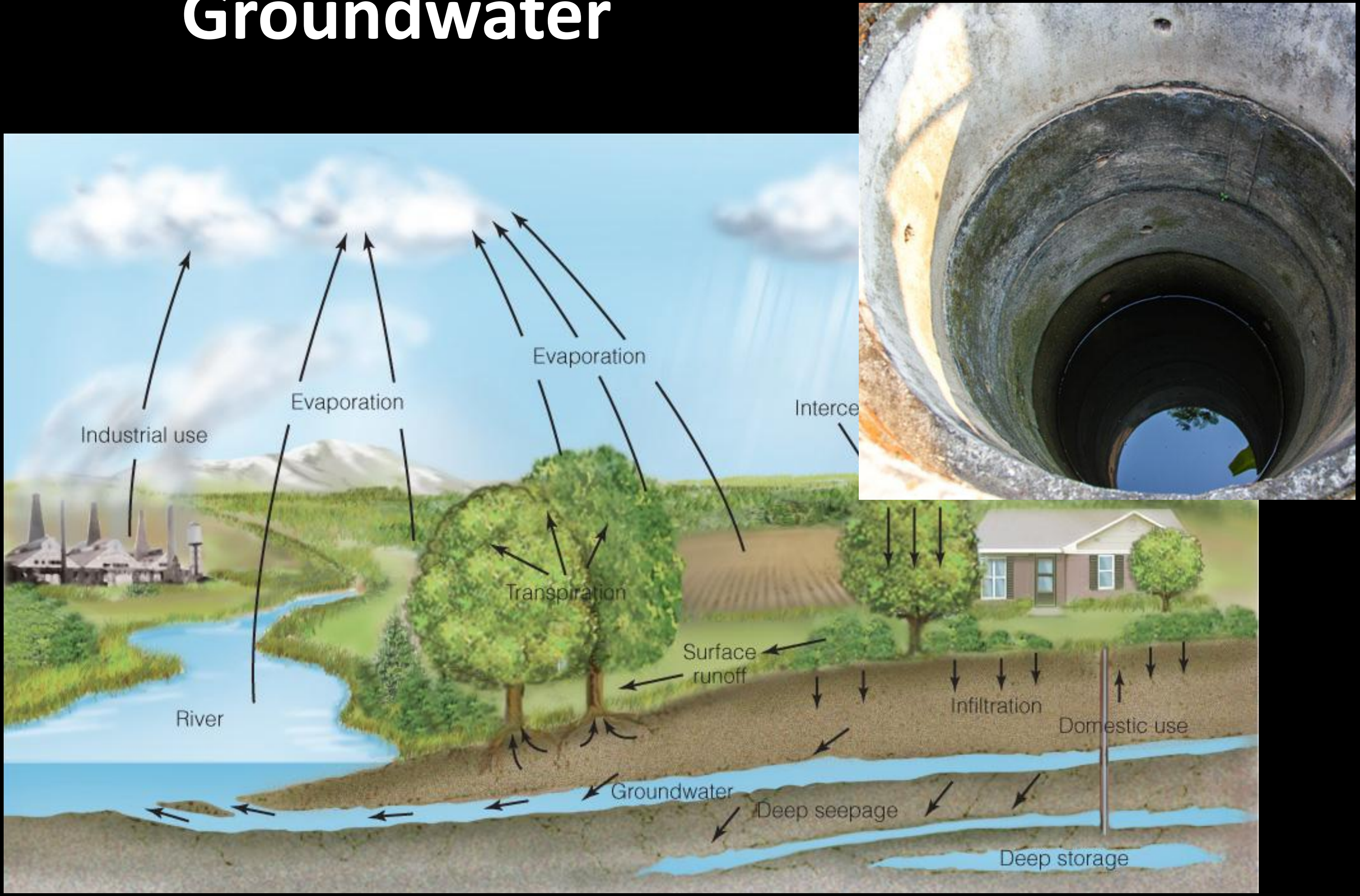


Aral Sea



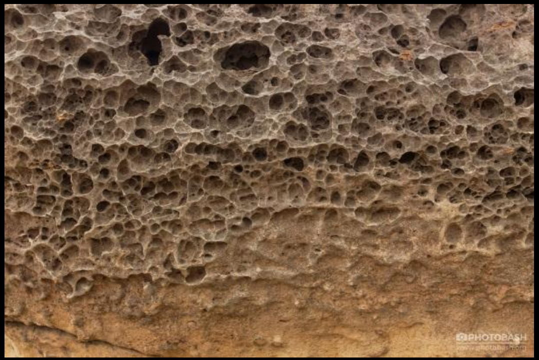
Colorado River

Groundwater



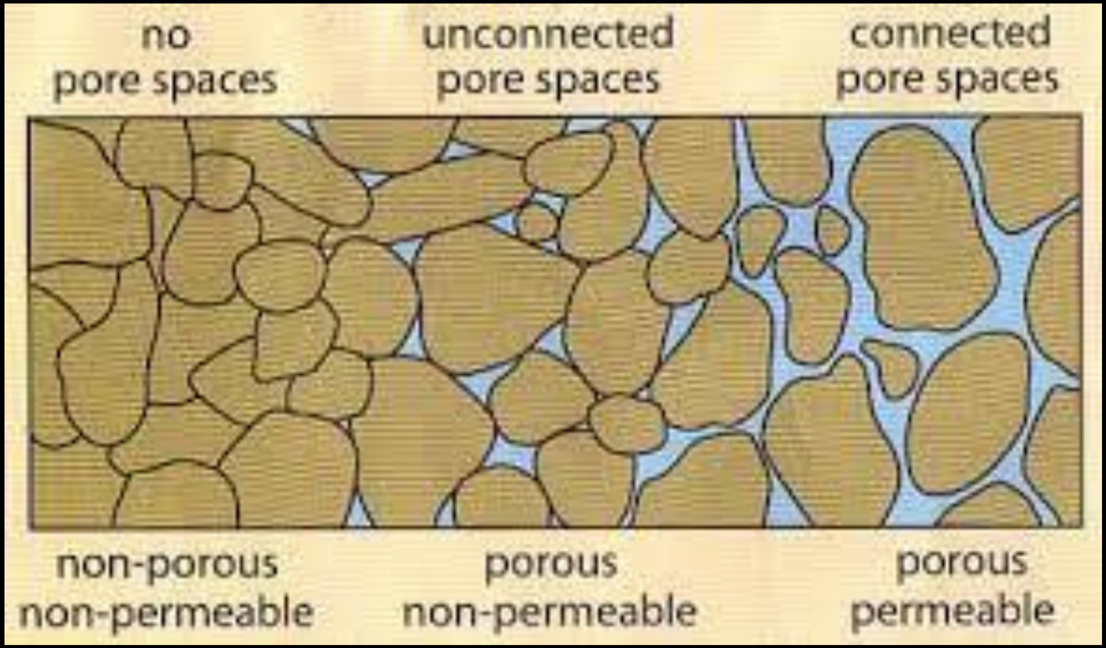
Porosity – the percentage of open space within sediment or rock

- Primary: space between grains
- Secondary: space between fractures

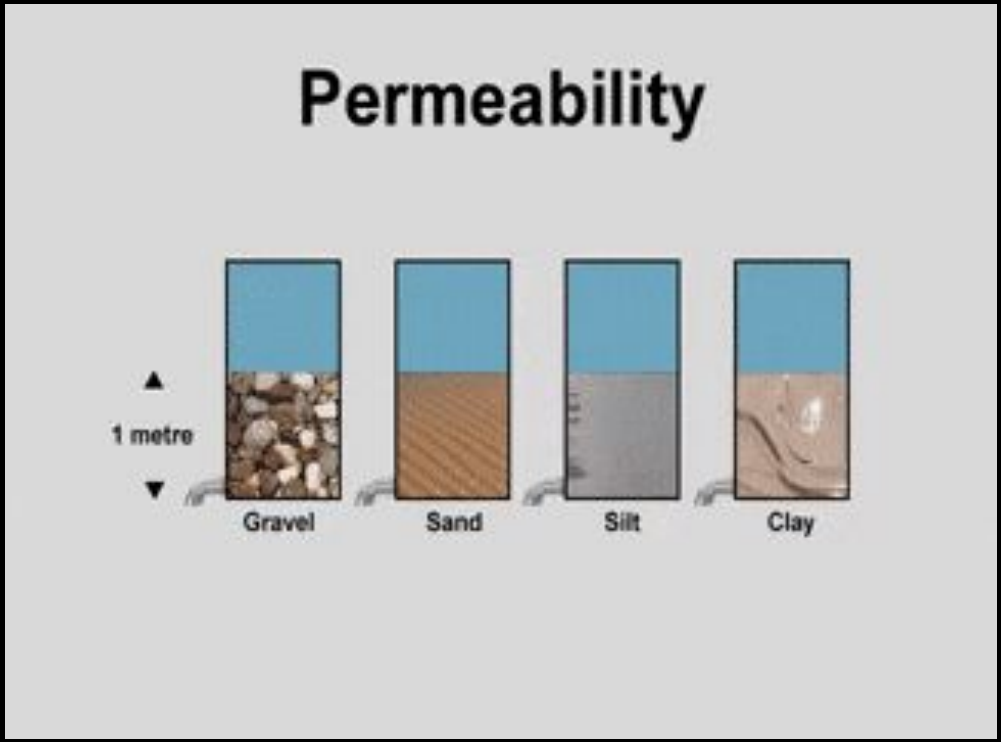


Permeability – ability of water to flow from one pore to the next

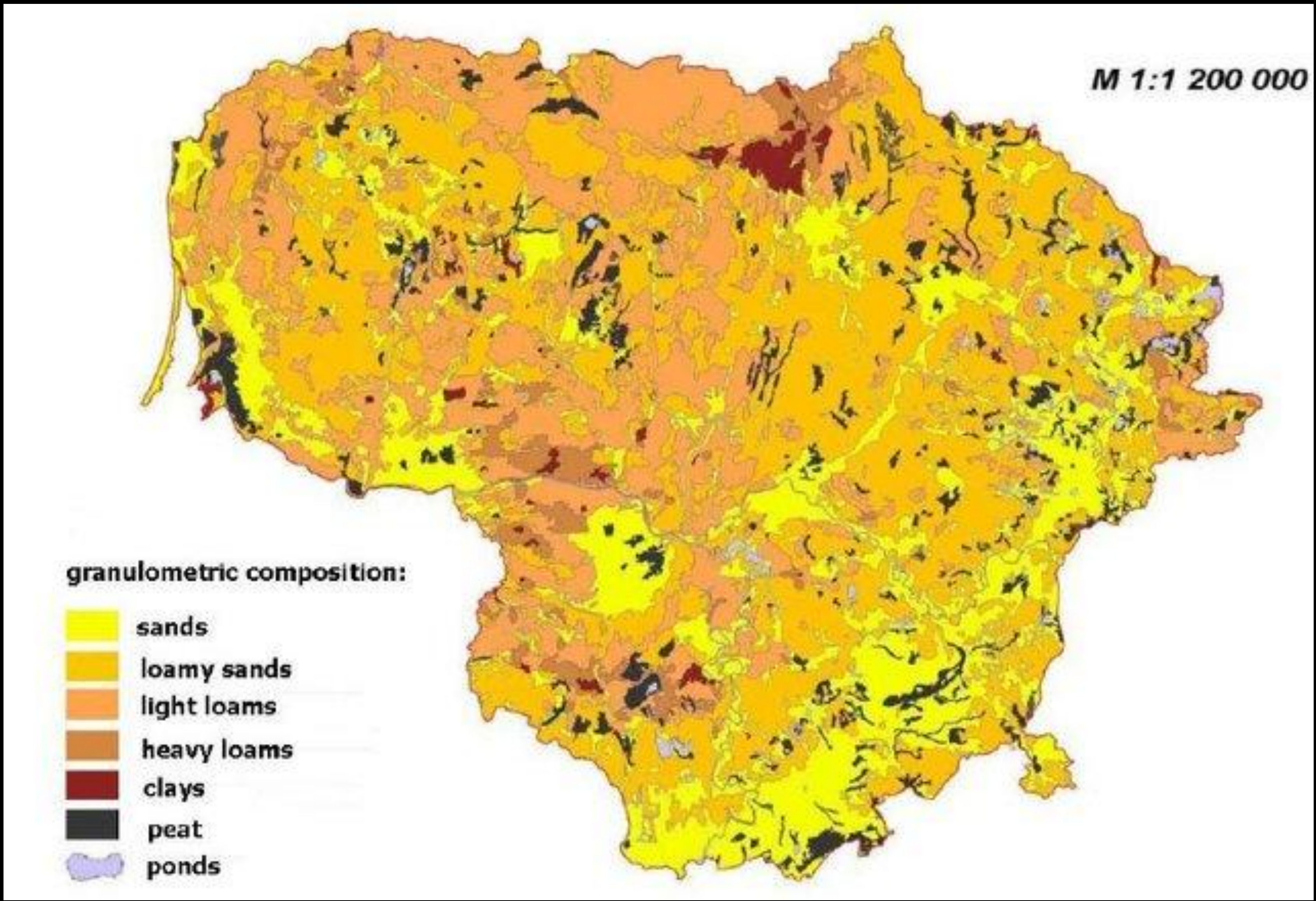
- Size and shape of pores
- Connectivity between pores



Hydraulic conductivity (*K*): – measure of how easily liquid passes through porous materials.

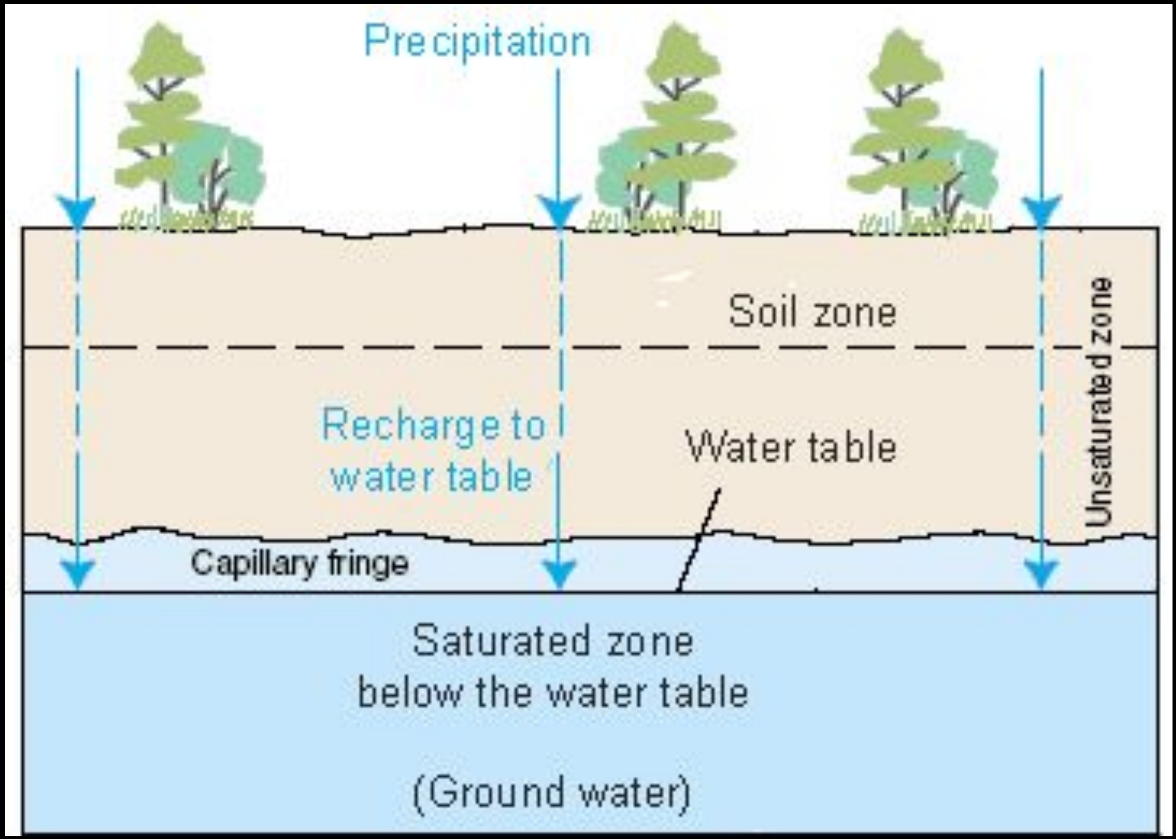


Lithuanian soil by particle size

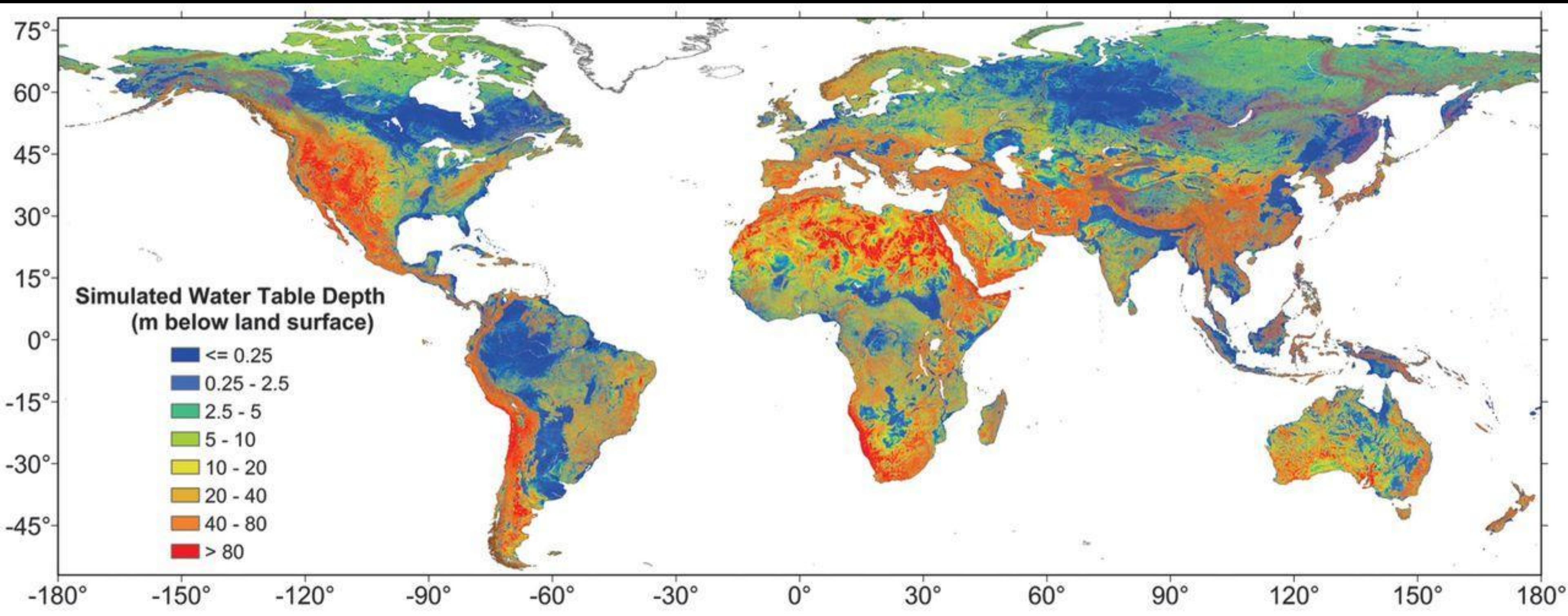


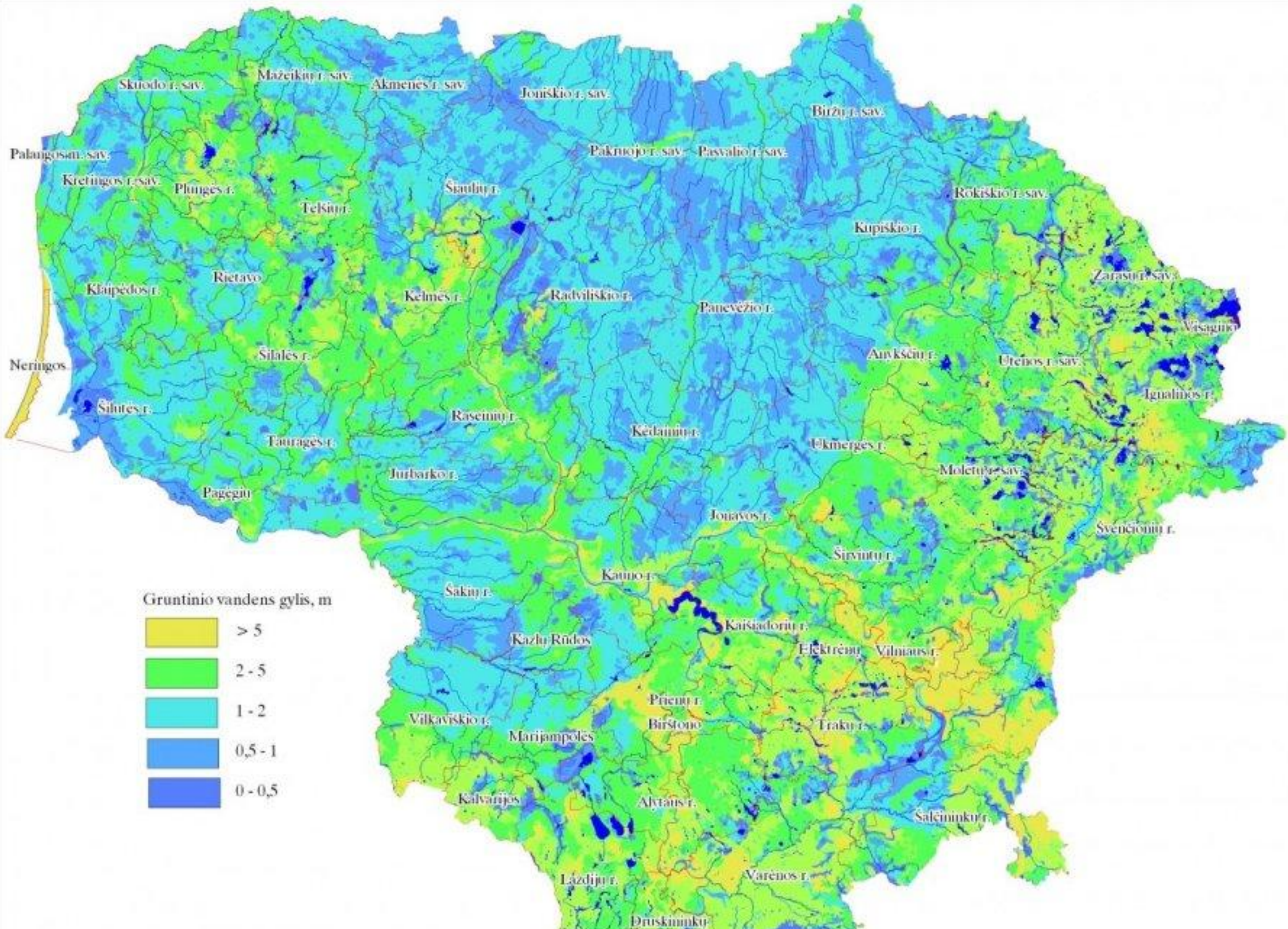
Water Table

- Recharge area: areas in which some water from precipitation **infiltrates** the soil
- Unsaturated zone – pore spaces filled with water and air
- Saturated zone – pore spaces filled with water



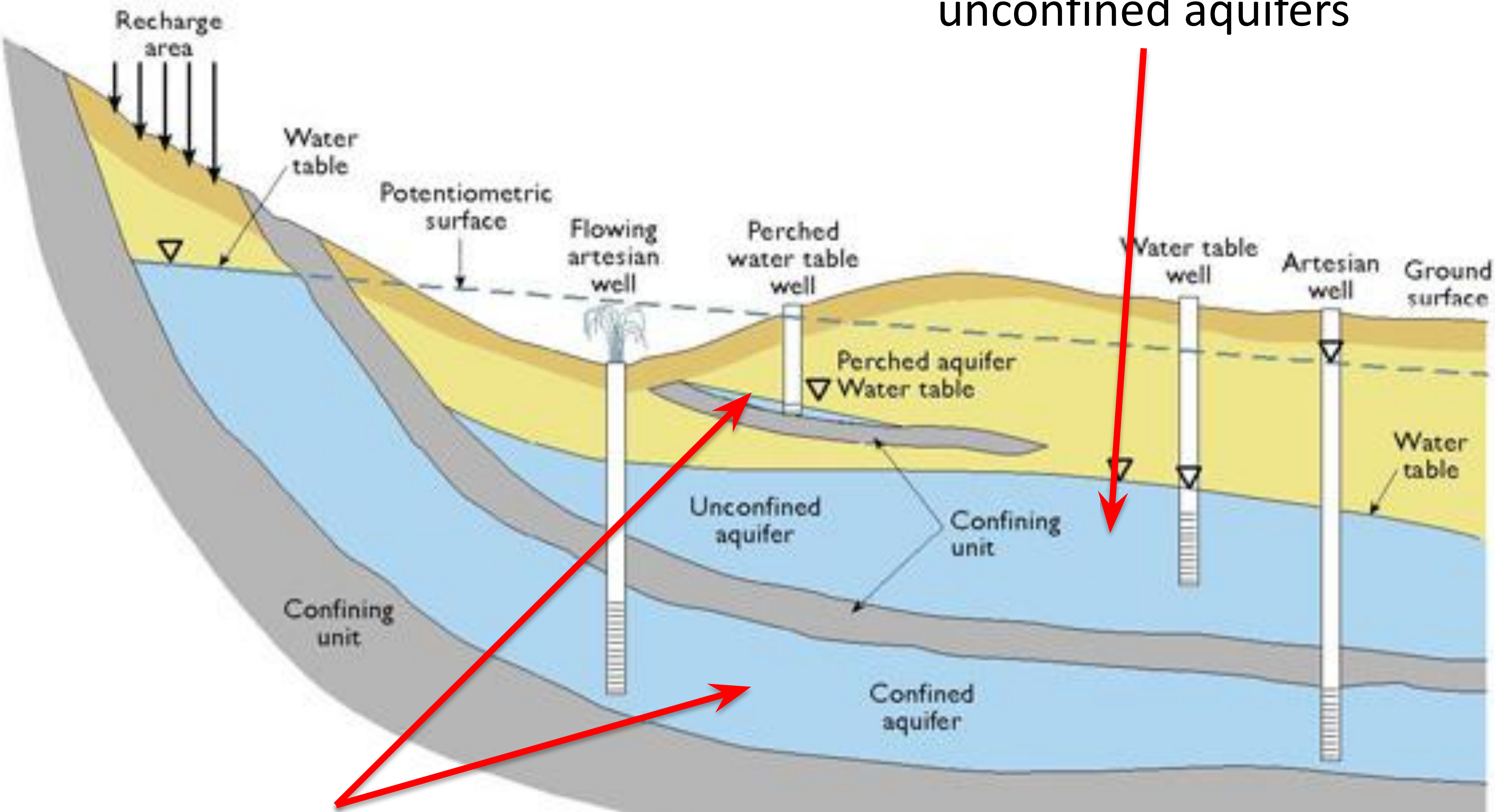
Water Table


Simulated Water Table Depth
(m below land surface)
<= 0.25
0.25 - 2.5
2.5 - 5
5 - 10
10 - 20
20 - 40
40 - 80
> 80
75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-180°
-150°
-120°
-90°
-60°
-30°
0°
30°
60°
90°
120°
150°
180°



Skuodo r. sav.
Mažeikių r. sav.
Akmenės r. sav.
Joniškio r. sav.
Biržų r. sav.
Palangos m. sav.
Pakruojo r. sav.
Pasvalio r. sav.
Kretingos r. sav.
Plungės r.
Šiaulių r.
Telšių r.
Rokiškio r. sav.
Kupiškio r.
Rietavo
Klaipėdos r.
Kelmės r.
Radviliškio r.
Panevėžio r.
Zarasų r. sav.
Visagino
Neringos
Šilalės r.
Anykščių r.
Utenos r. sav.
Ignalinos r.
Šilutės r.
Raseinių r.
Kėdainių r.
Tauragės r.
Ukmergės r.
Molėtų r. sav.
Jurbarko r.
Pagėgių
Jonavos r.
Švenčionių r.
Širvintų r.
Kauno r.
Šakių r.
Kaišiadorių r.
Kazlų Rūdos
Elektrėnų
Vilniaus r.
Prienų r.
Birštono
Trakų r.
Vilkaviškio r.
Marijampolės
Kalvarijos
Alytaus r.
Šalčininkų r.
Lazdijų r.
Varėnos r.
Druskininkų
Gruntinio vandens gylis, m
> 5
2 - 5
1 - 2
0,5 - 1
0 - 0,5

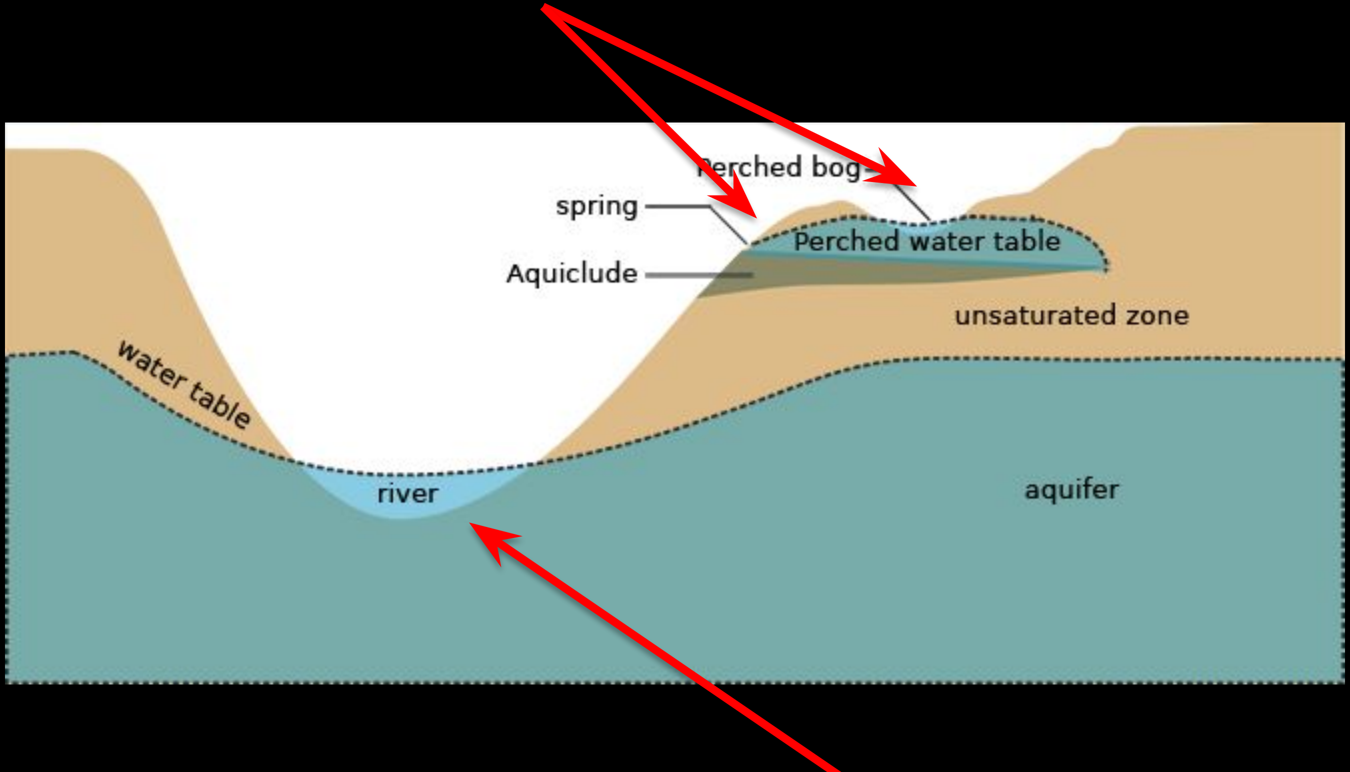
Water infiltrates freely into unconfined aquifers



Modified after Harlan and others, 1989

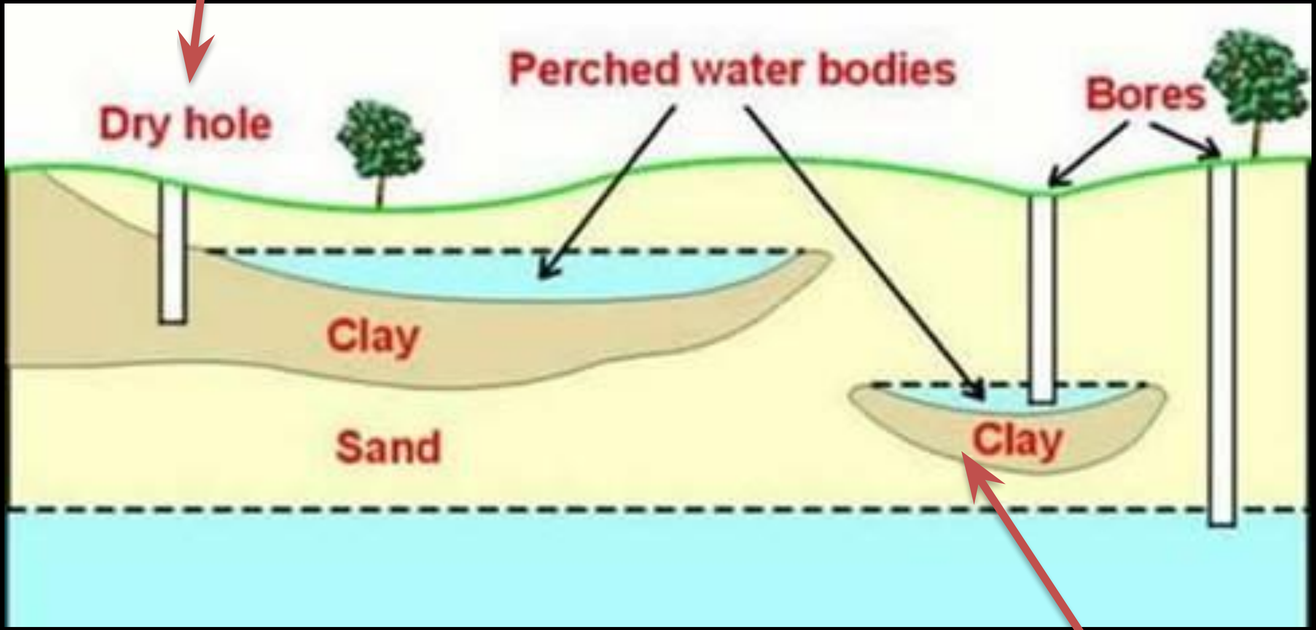
Clay or intrusive rock form aquicludes, leading to perched or confined aquifers.

When the water table intersects with the surface it can form a bog or spring.



Water leaving the aquifer is called discharge

Wells must be dug so that the bottom of the well is below the water table.



Perched aquifers can easily be sucked dry.

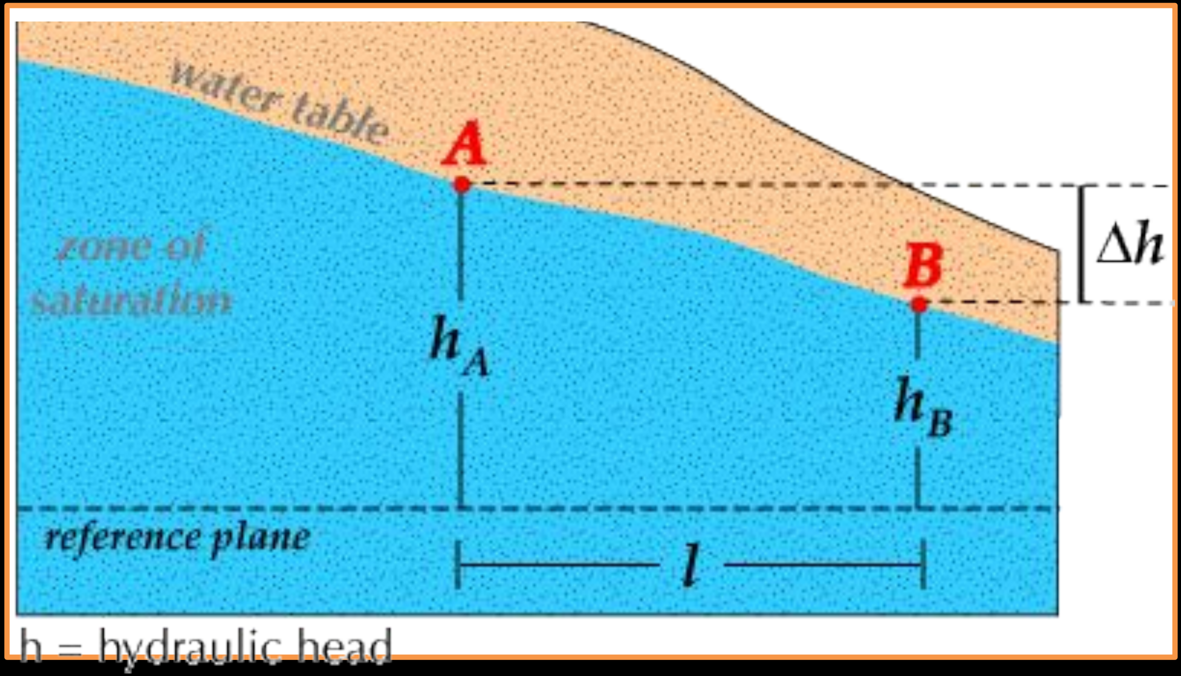
A well for the Hospital of Hope in Togo, West Africa


Photo Credit: Ethan Molsee

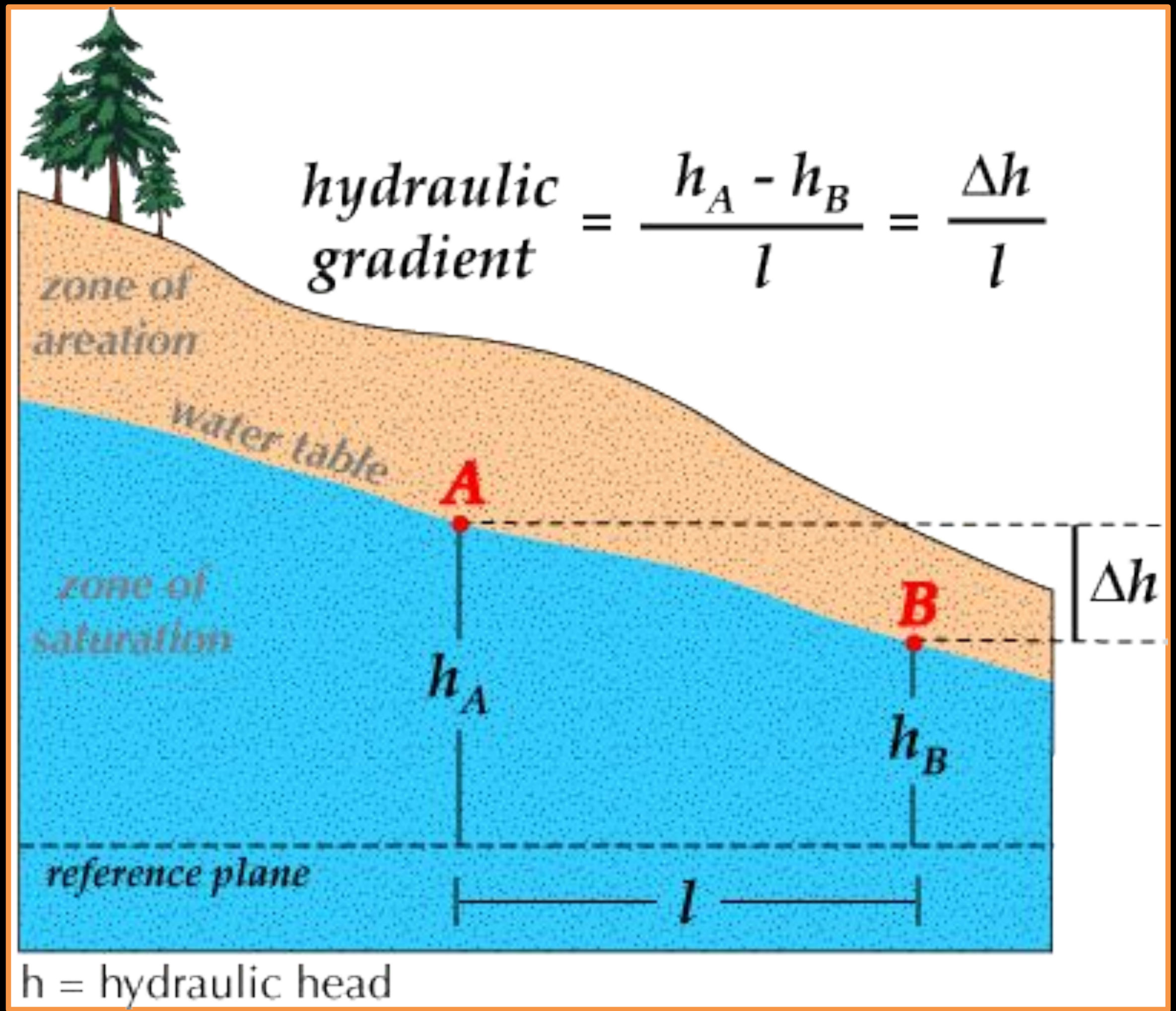
At 240 meters, they had to give up, with only a small water output.

Hydraulic head – hydraulic potential at a specific point of the aquafer, measured in terms of elevation (e.g. 50 m above sea level)

- In an unconfined aquifer the head = water table
- Water moves from high to low head potential



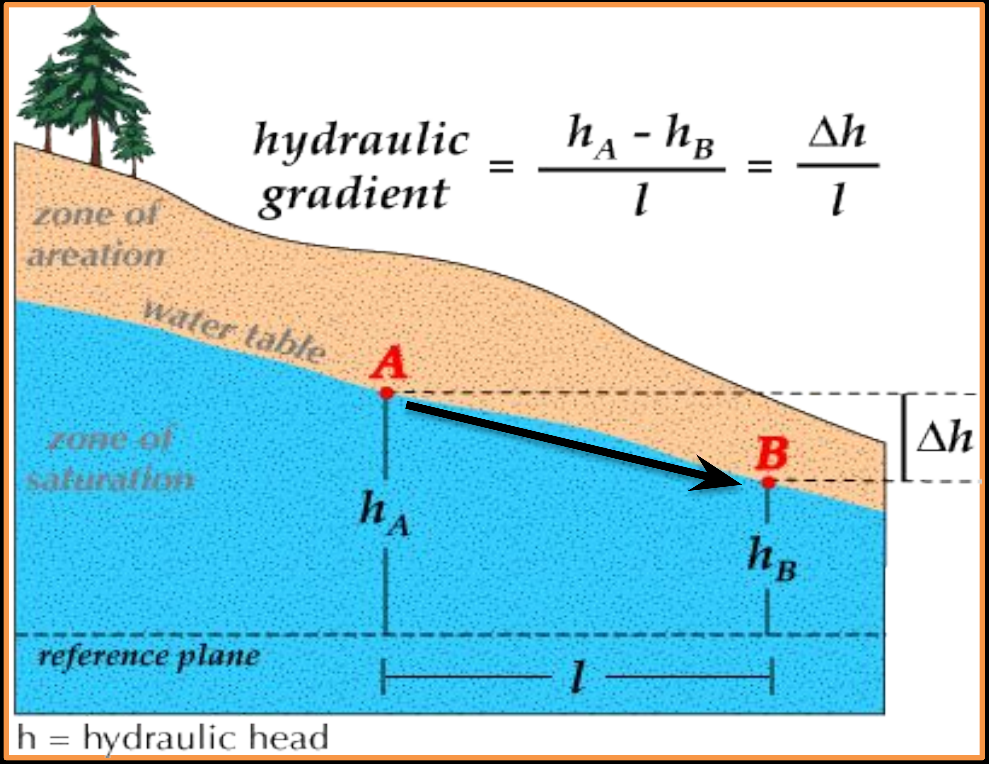
Hydraulic gradient (*i*) – the slope of a line between two or more hydraulic heads over the length of the flow path



How fast will the water leave the aquifer?

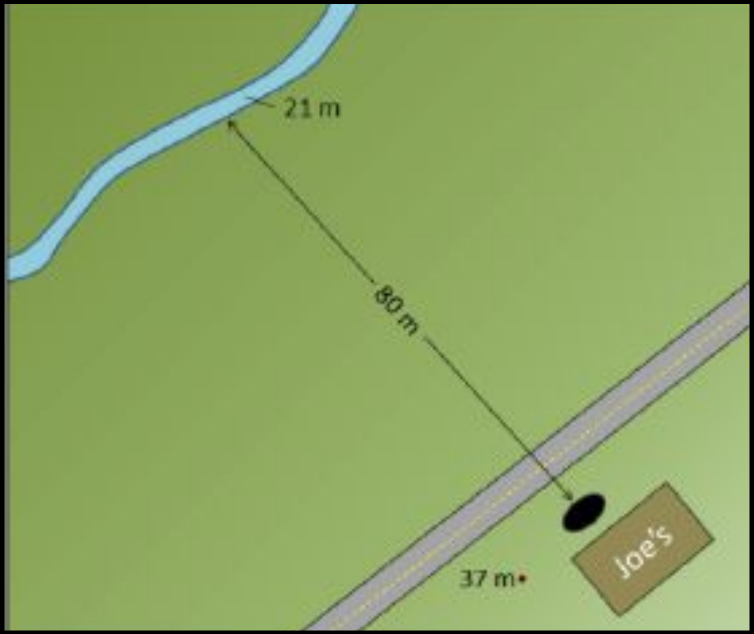
Velocity = hydraulic conductivity * hydraulic gradient

$V = K * i$



Sue, the owner of Joe's 24-Hour Gas, has discovered that her underground storage tank is leaking fuel. How long will it take for the fuel contamination to reach the nearest stream?

- The sandy sediment in this area has a hydraulic conductivity of 0.0002 m/s.
- The gas station is 37 m above sea level.
- The stream is 21 m above sea level.
- The stream is 80 m from the gas station at sea level.



How fast will the water leave the aquifer?

Velocity = hydraulic conductivity * hydraulic gradient

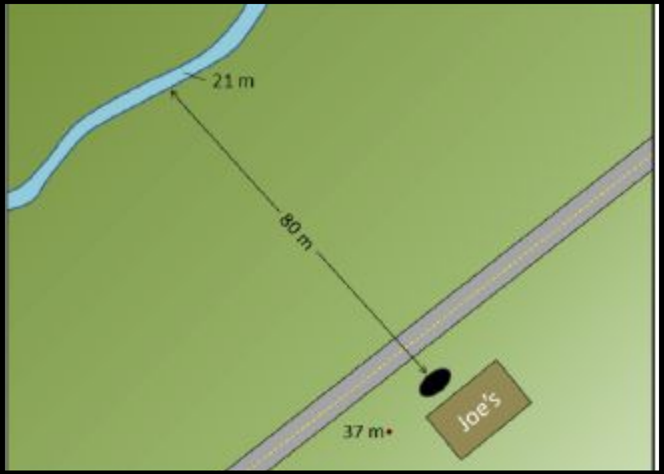
$V = K * i$

$i = (37-21)/80 = 0.2$

$V = 0.0002 * 0.2 = 0.00004$ m/s

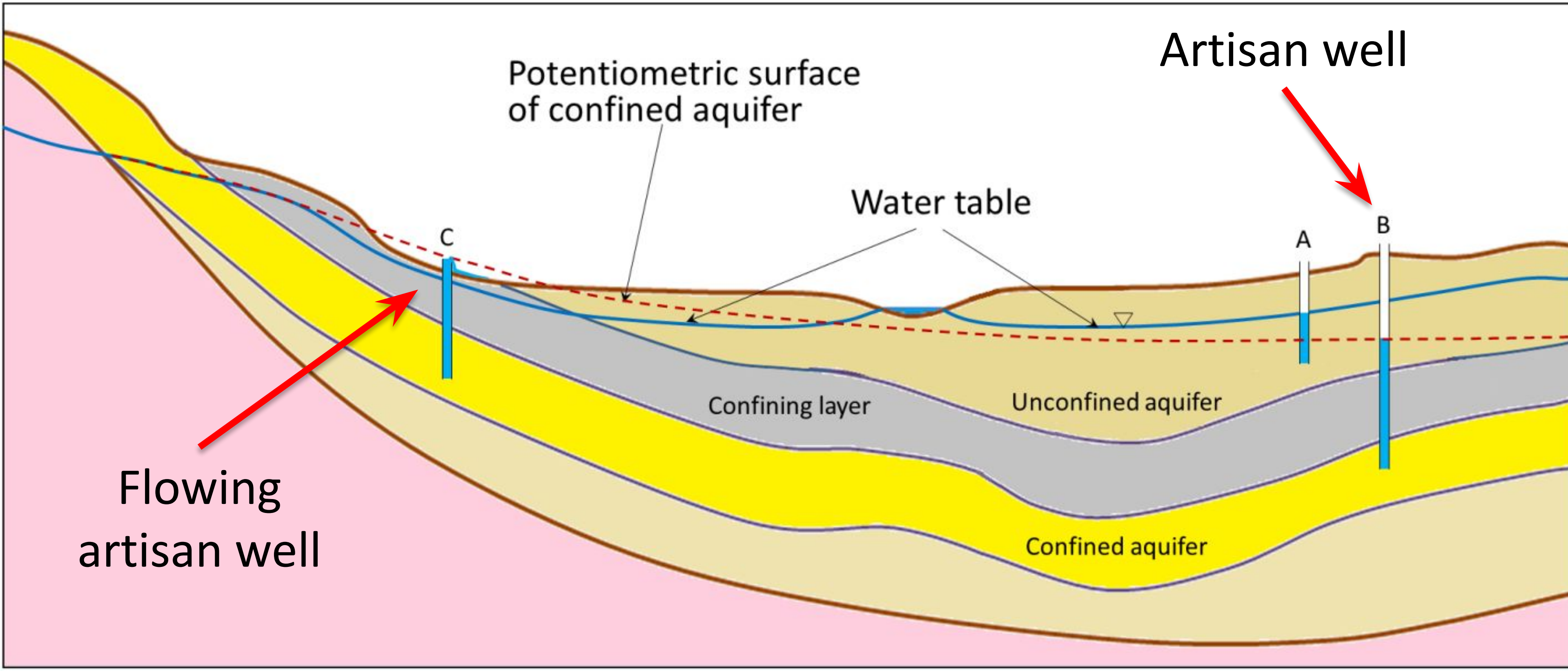
$V = 0.00004*60*60*24 = 3.456$ m/day

80/3.456 = 23.1 days



Potentiometric surface – height to which water will rise from a confined aquifer

- Water is under pressure and will rise up into the well



Because aquifers are partially enclosed spaces, water does not flow in a straight line, rather it bends a corner and even flows upward.

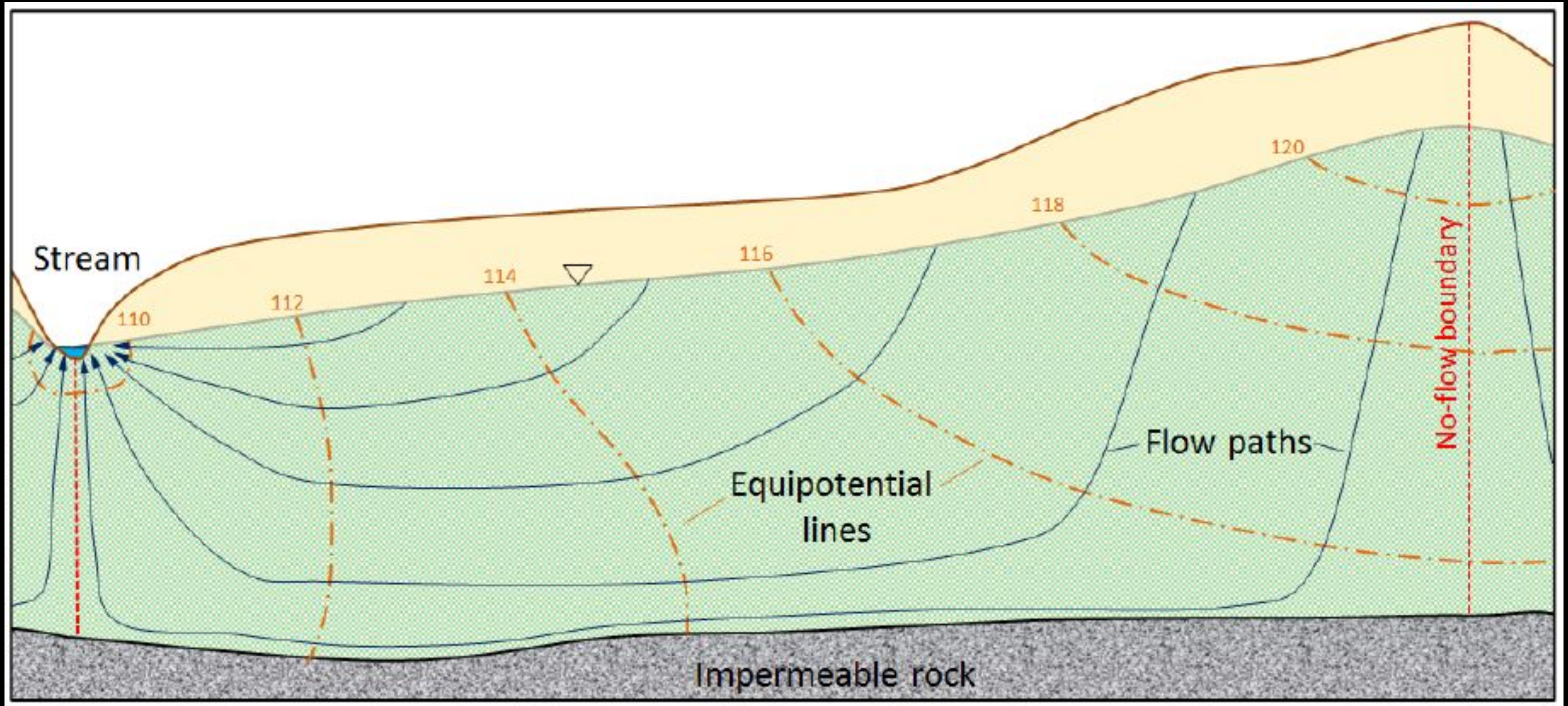
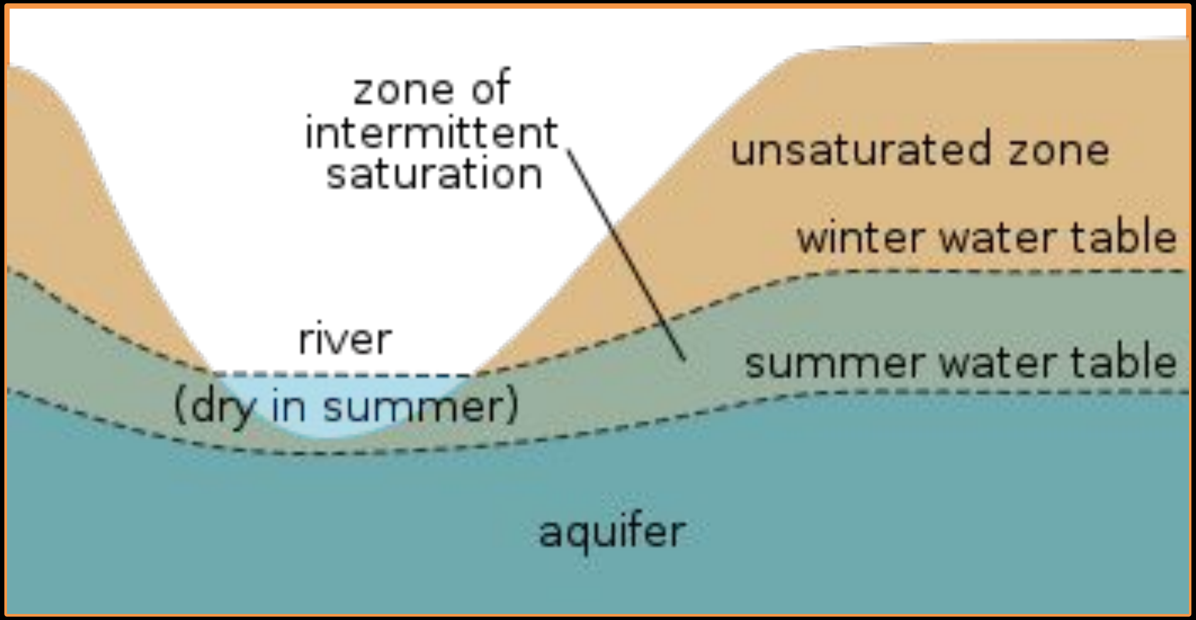


Figure 14.8 Predicted equipotential lines (orange) and groundwater flow paths (blue) in an unconfined aquifer. The orange numbers are the elevations of the water table at the locations shown, and therefore they represent the pressure along the equipotential lines. [SE]

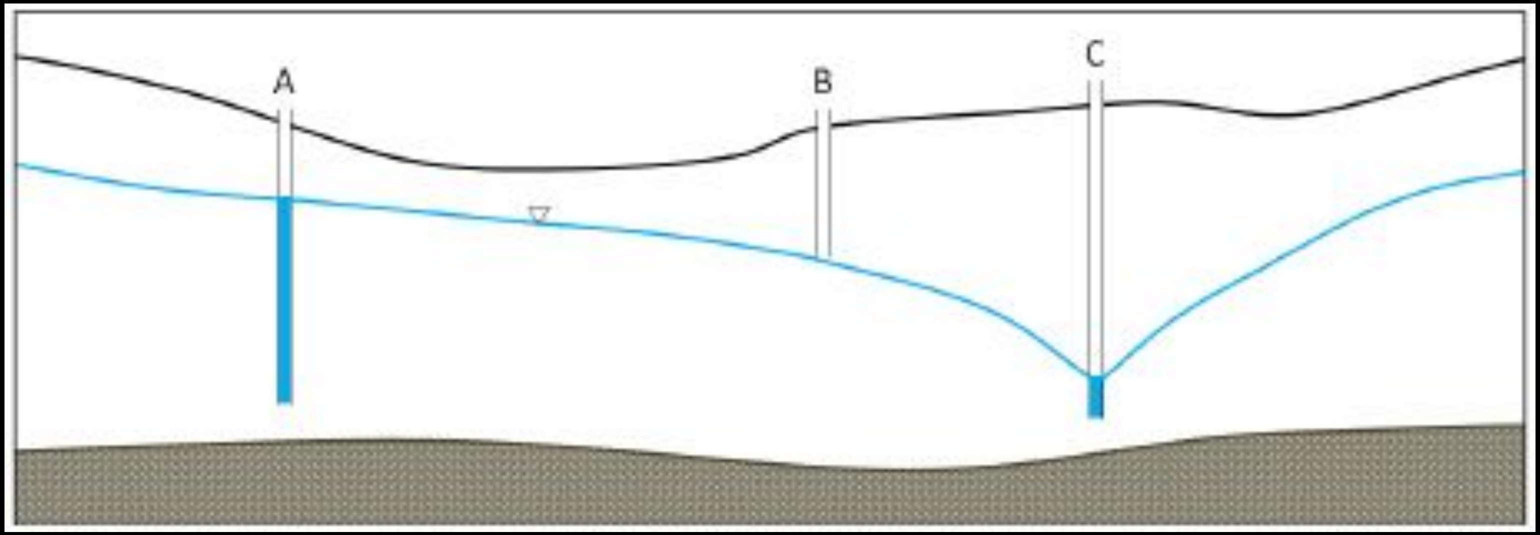
The water table can change

- Seasonal changes in precipitation, evaporation, and runoff



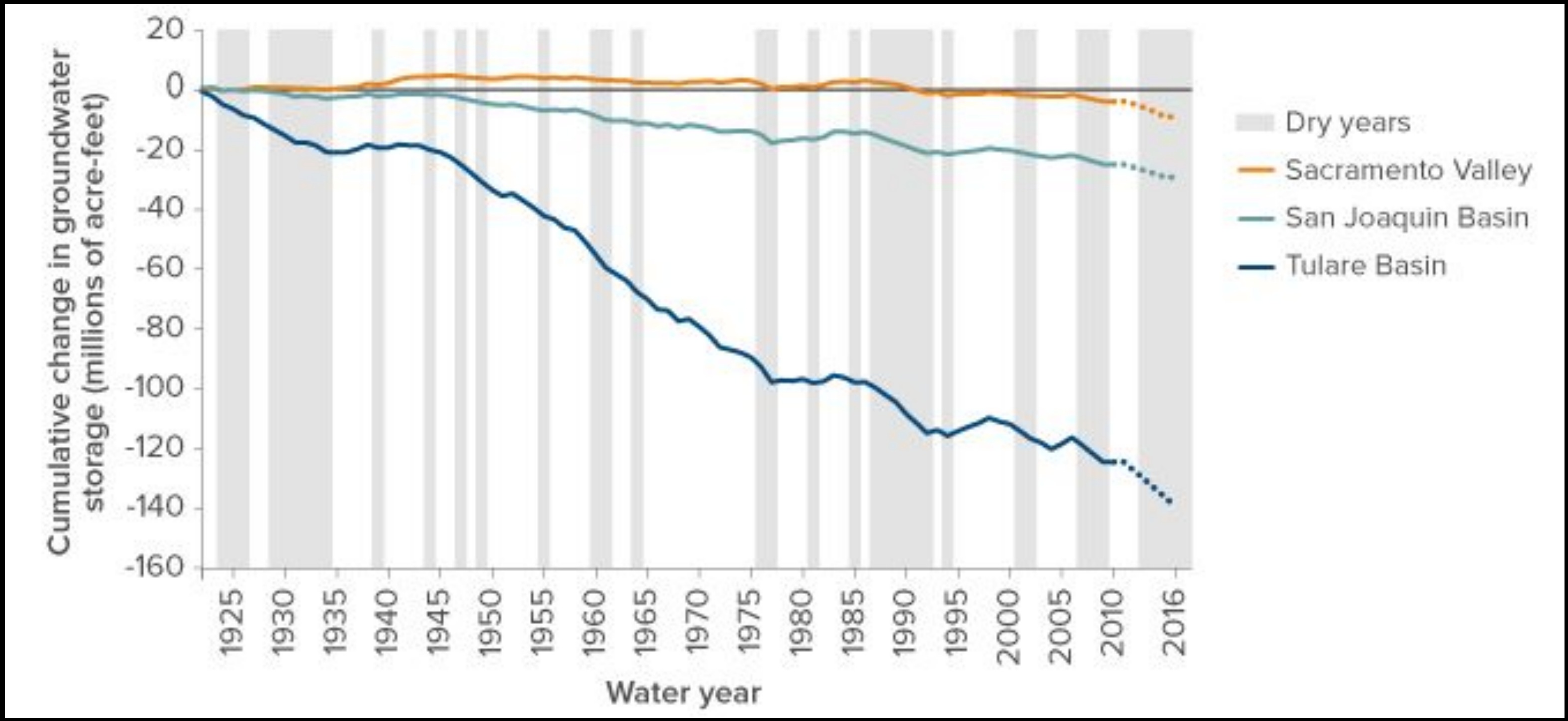
The water table can change

- Pumping more water out than infiltrates in (e.g. too many wells in one location)
- Cone of depression – change in the water table created by pumping

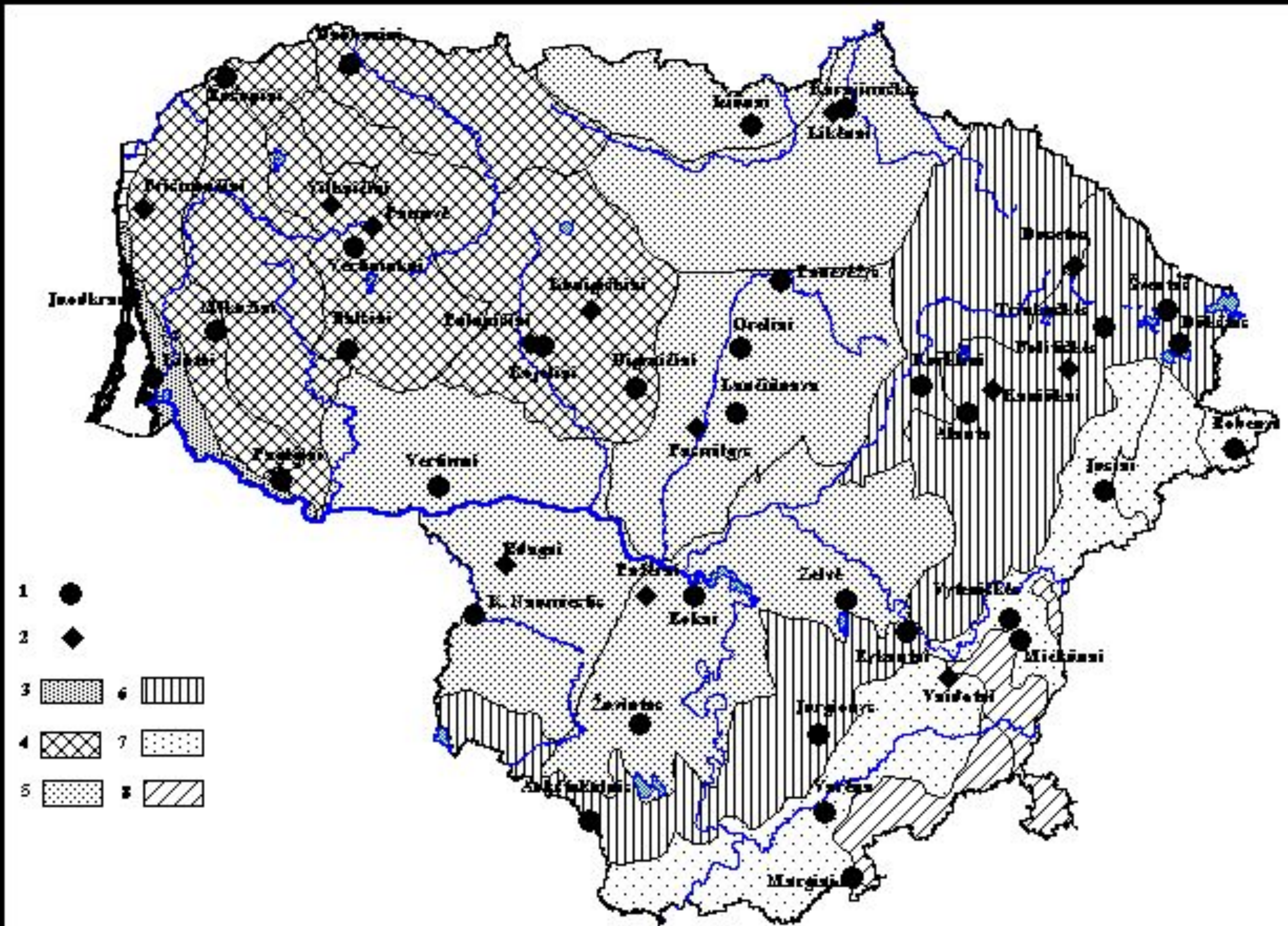


The water table can change

- Drought (e.g. California)



Monitoring the Water Table: Observation Wells in Lithuania



Hard Water

Groundwater absorbs minerals from the surrounding rocks/sediment

- Calcium
- Magnesium carbonate

Some of which can be dangerous for humans

- Copper
- Arsenic
- Mercury
- Fluorine
- Sodium
- Boron

Pollution

- Agriculture (fertilizer, animal waste, sprays)
- Landfills
- Industrial operations
- Mines
- Leaking fuel storage tanks
- Broken septic systems
- Runoff from roads