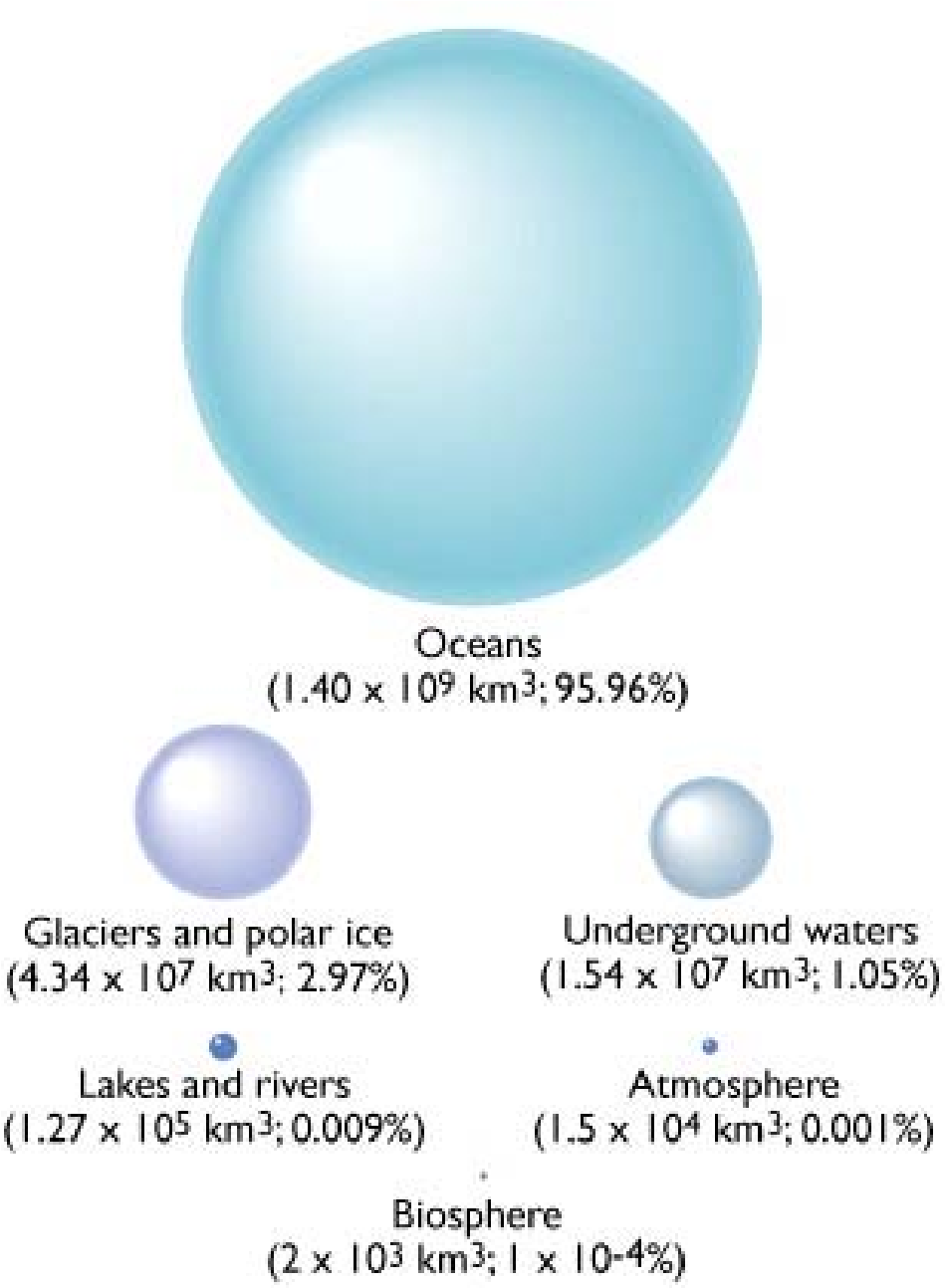
Hydrologic Cycle and Groundwater



Distribution of H_2O on Earth



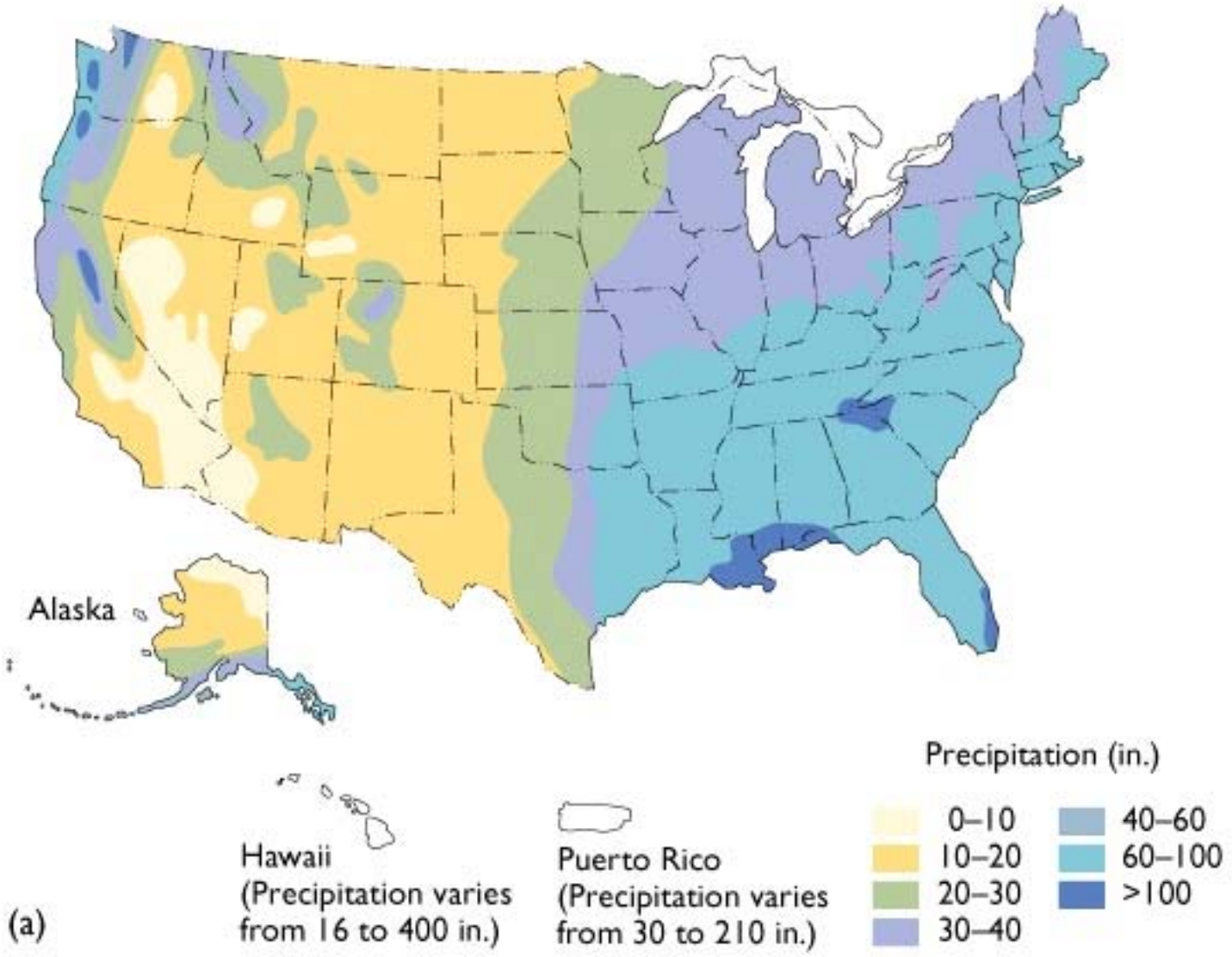
P = RO + I + ET

- P = PRECIPITATION
- RO = RUN OFF (ALL SURFACE FLOW)
- I = INFILTRATION (GROUNDWATER)
- ET = EVAPO-TRANSPIRATION

Uses of Water

Living	Engineering	Recreation
Drinking	Cooling	Swimming
Photosynthesizing	Heating	Fishing
Respiring	Cleaning	Sailing
Metabolizing	Flushing	Skating
	Irrigating	Skiing

Average Annual Precipitation in the U.S.



17 - Groundwater

- Water contained in spaces within soil, bedrock, and regolith
- About 1% of all H_2O on Earth
- 40 times more abundant than water found in lakes and streams

The study of groundwater and its effects is called ***Hydrology.***

Why is groundwater such a valuable resource?

1. Abundant - 70 times more in the subsurface than in surface reservoirs.

2. Because groundwater moves so slowly it is stored in the earth and remains available even in dry periods.

3. In some regions groundwater flows from humid environments to dry ones, making water much more available.

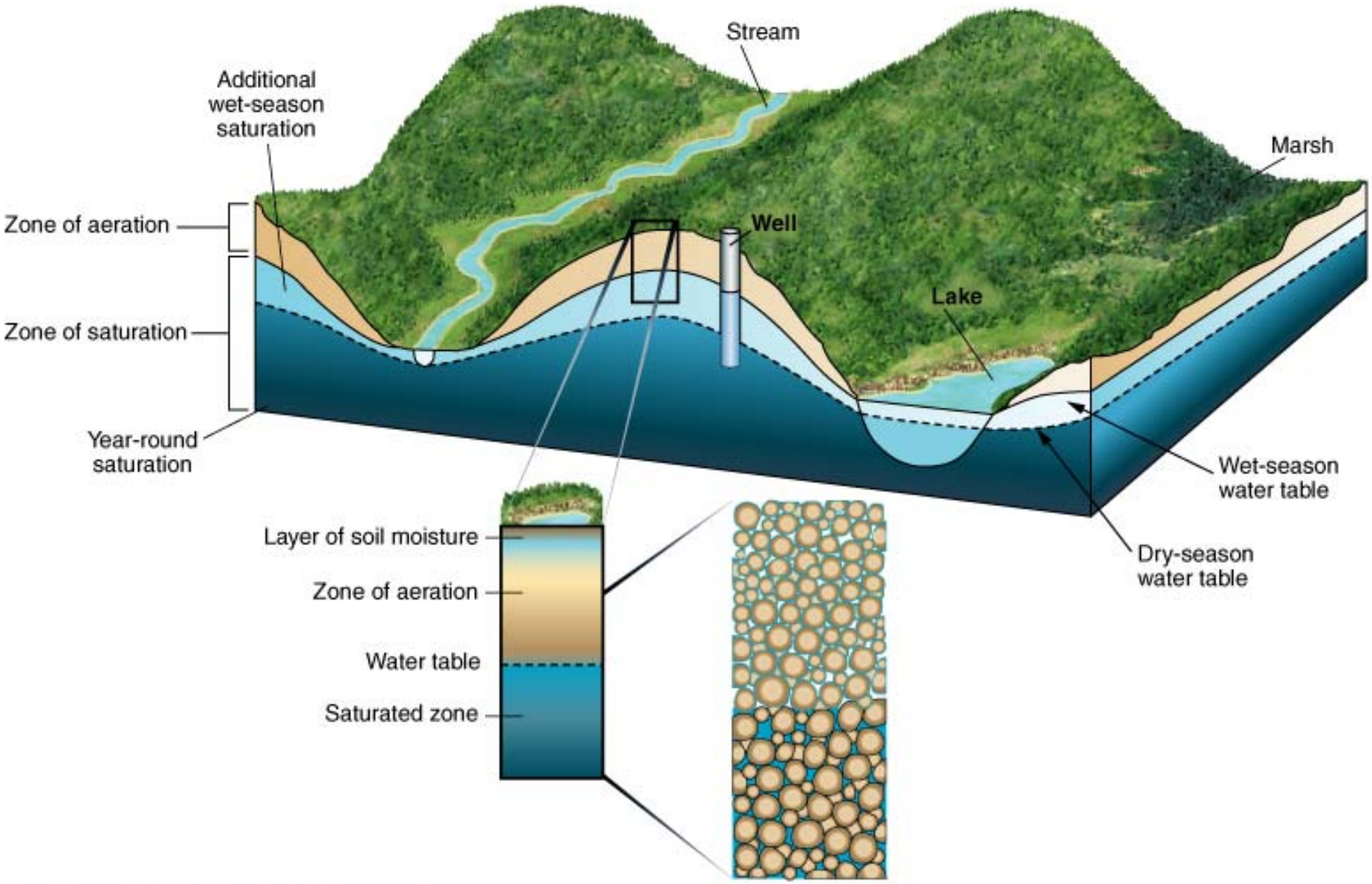
Where Do We Find This Groundwater ?

zone of aeration: portion of soil and rock near the surface in which open spaces are filled primarily with air (a.k.a vadose zone or unsaturated zone)

saturated zone: zone in which pore spaces are filled with water

water table: boundary between zone of aeration and saturated zone

Water in the Ground



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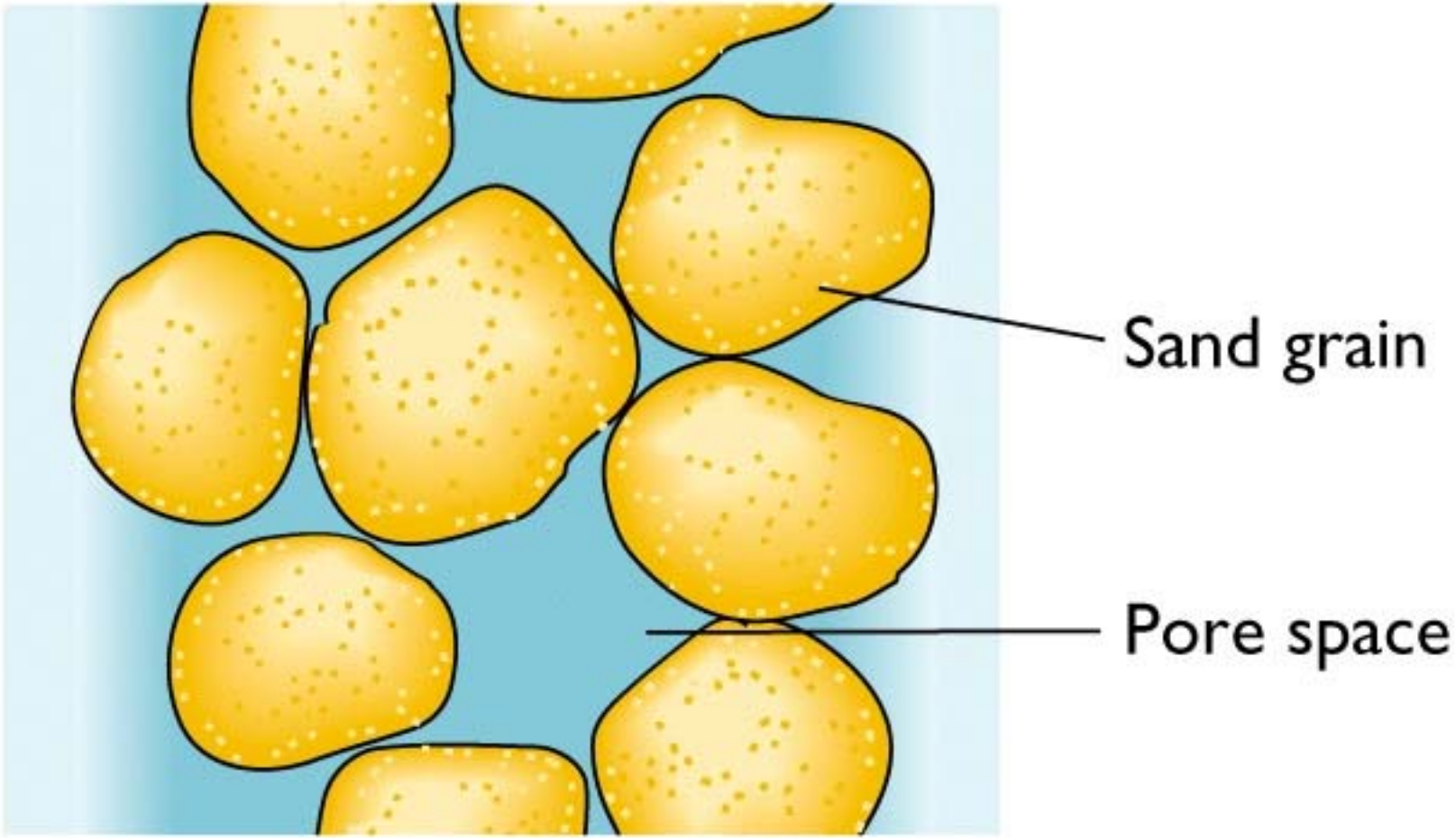
Soils and rocks are *not* completely solid.

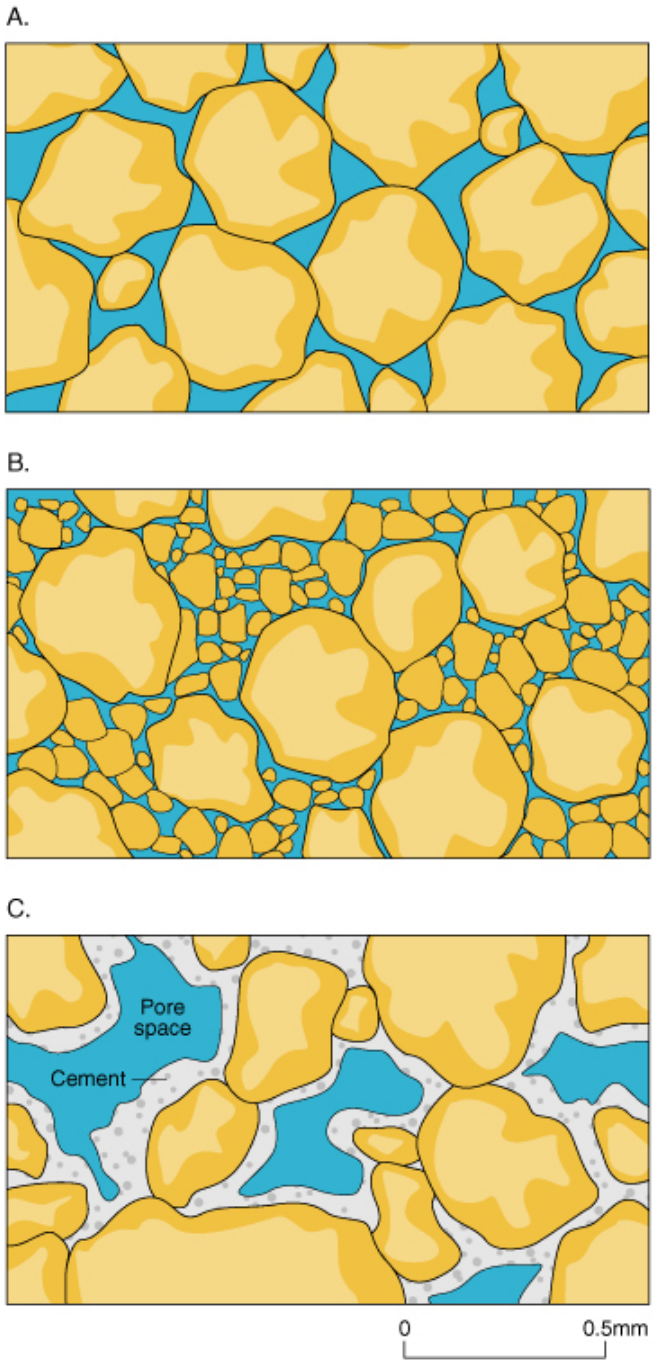
porosity: portion of volume of a material that consists of open spaces

permeability: measure of the speed at which fluid can travel through a porous medium - how well pores are connected

(Imagine two vertical pipes, one filled with gravel, one with sand. Which one will produce water flow faster?)

Porous Sandstone





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Porosity in sediments

A. 30% porosity in well-sorted sediment

B. 15% porosity in poorly sorted sediment

C. low porosity in well-sorted, cemented sediment

Fractured Shale

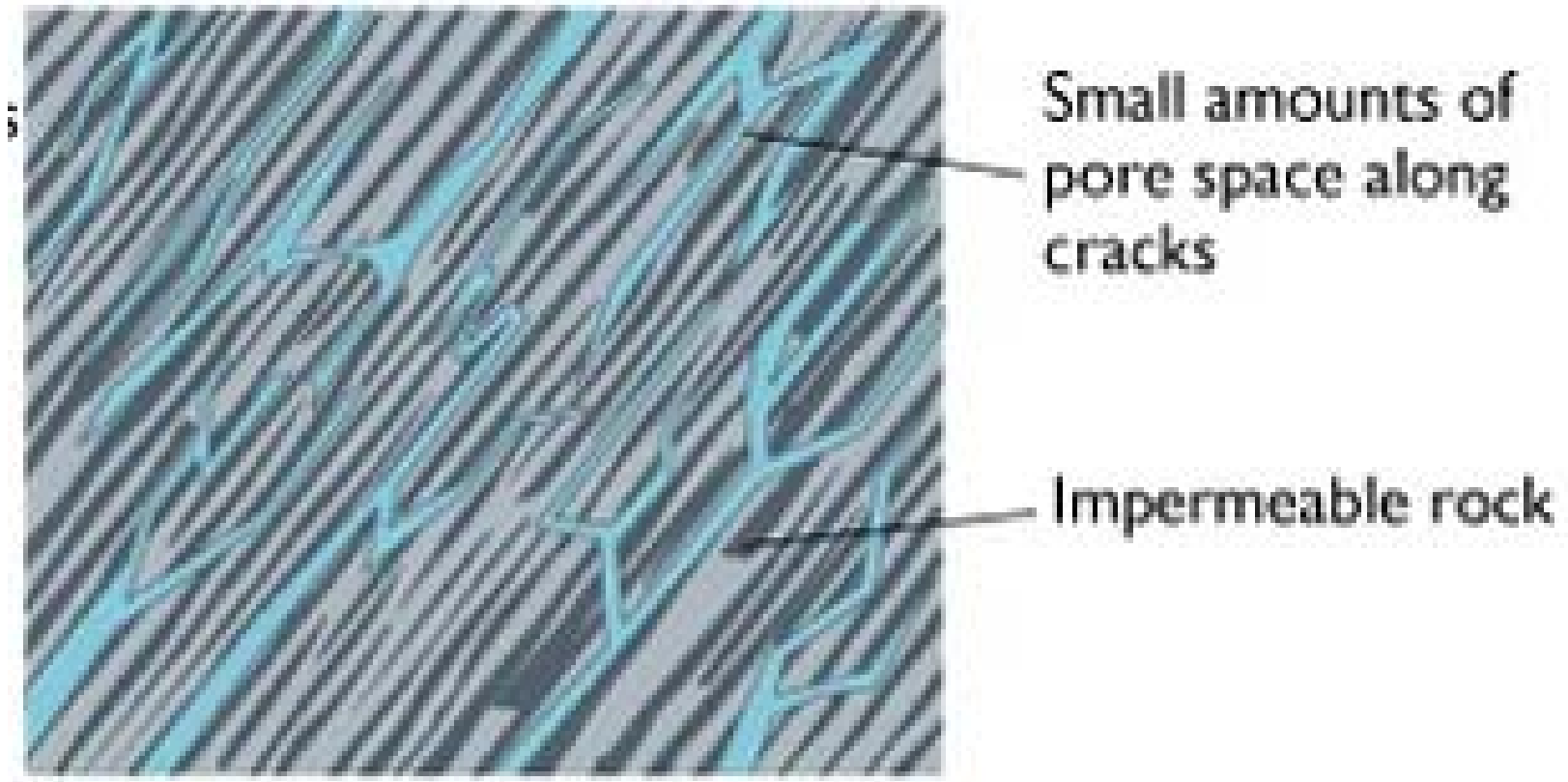
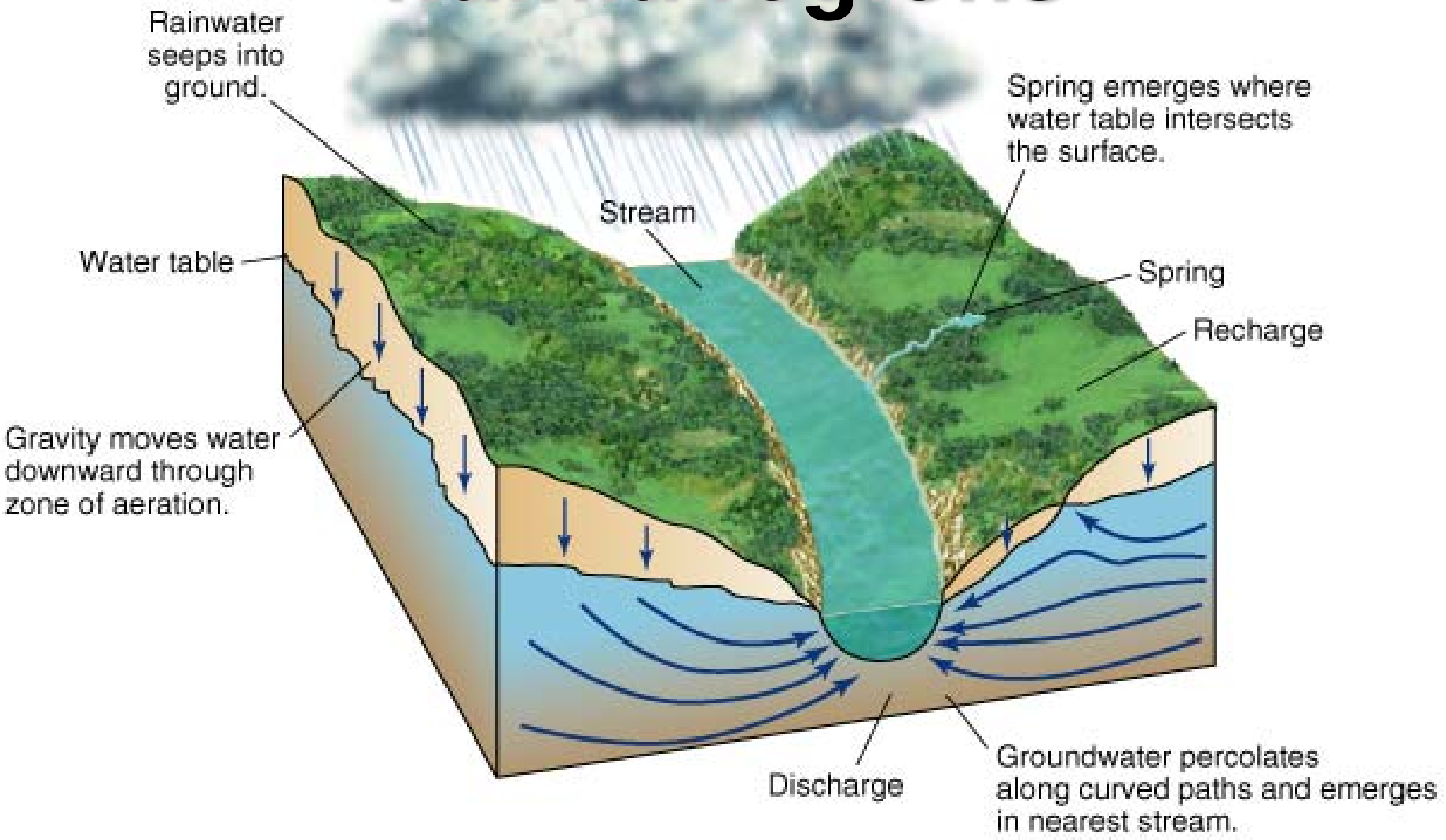


Table 12.2 Porosity and Permeability of Aquifer Rock Types

Rock Type	Porosity (Pore Space That May Hold Fluid)	Permeability (Ability to Allow Fluids to Pass Through)
Gravel	Very high	Very high
Coarse- to medium-grained sand	High	High
Fine-grained sand and silt	Moderate	Moderate to low
Sandstone, moderately cemented	Moderate to low	Low
Fractured shale or metamorphic rocks	Low	Very low
Unfractured shale	Very low	Very low

Paths of groundwater flow in humid regions

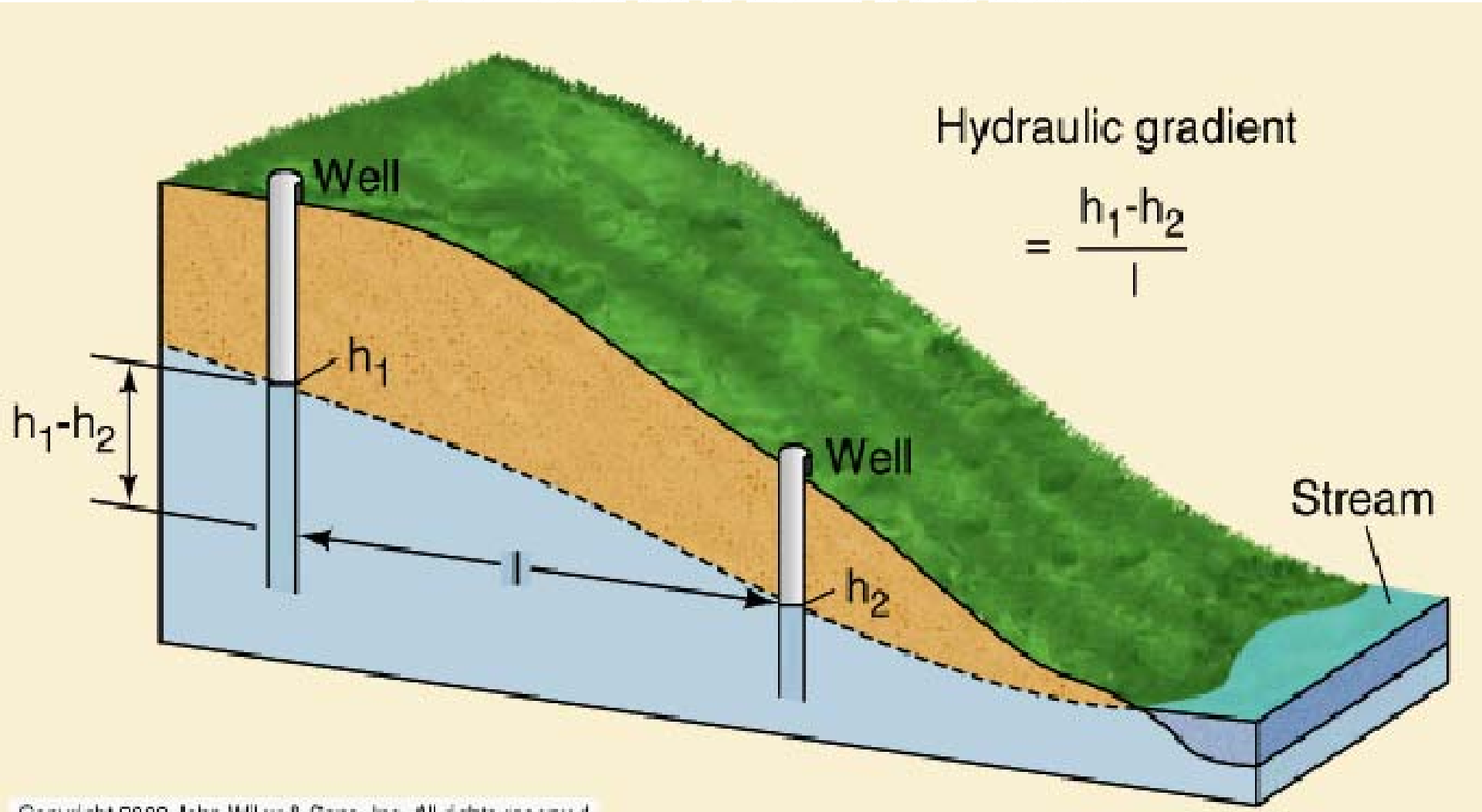


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Rates of groundwater movement

- Slow to very slow (depending on permeability)
- Generally within the range of 10 to 100 cm per day

Hydraulic gradient (slope) of water table



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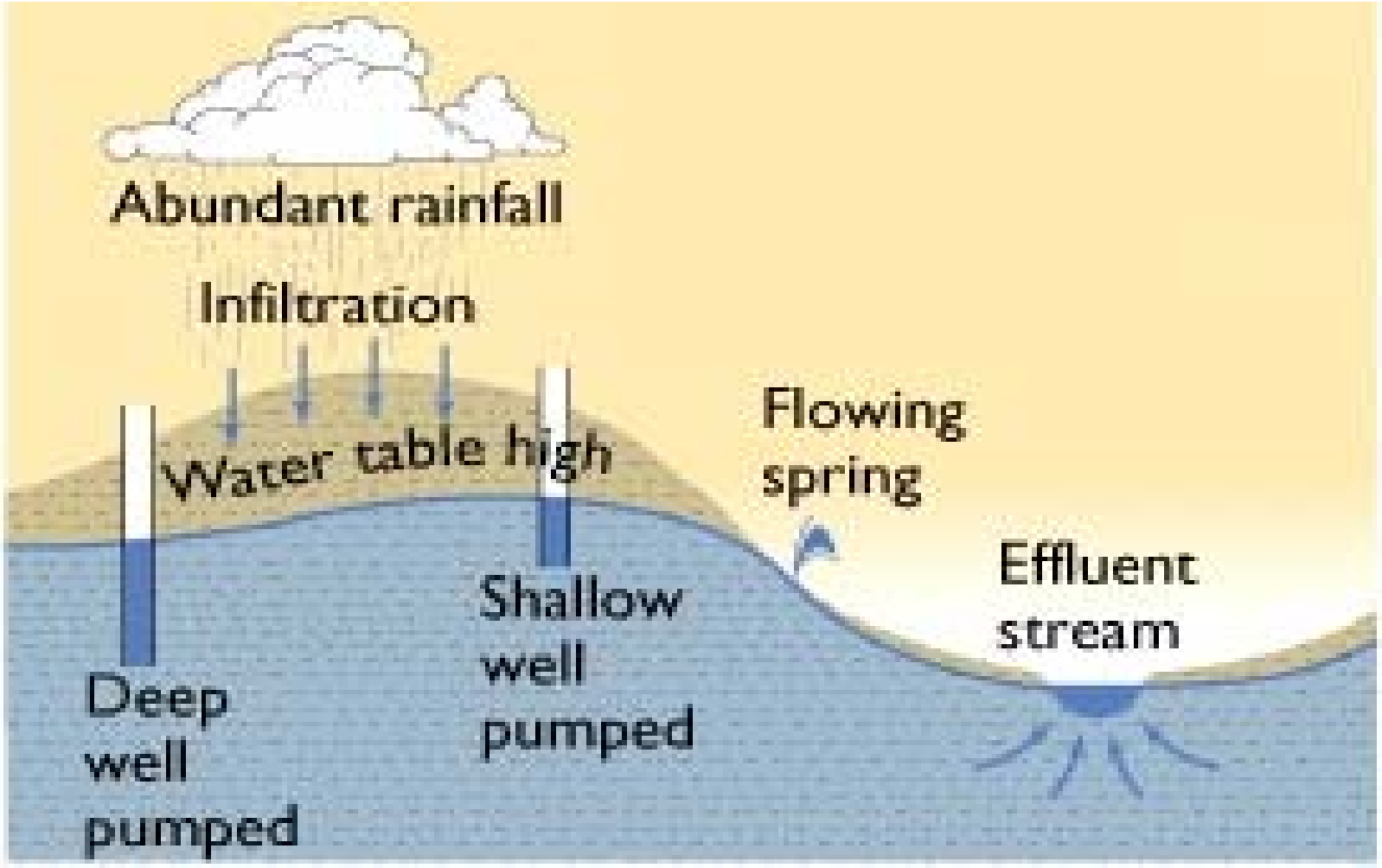
Groundwater Storage

aquifer: body of rock that is sufficiently water permeable to yield economically significant quantities to wells and springs

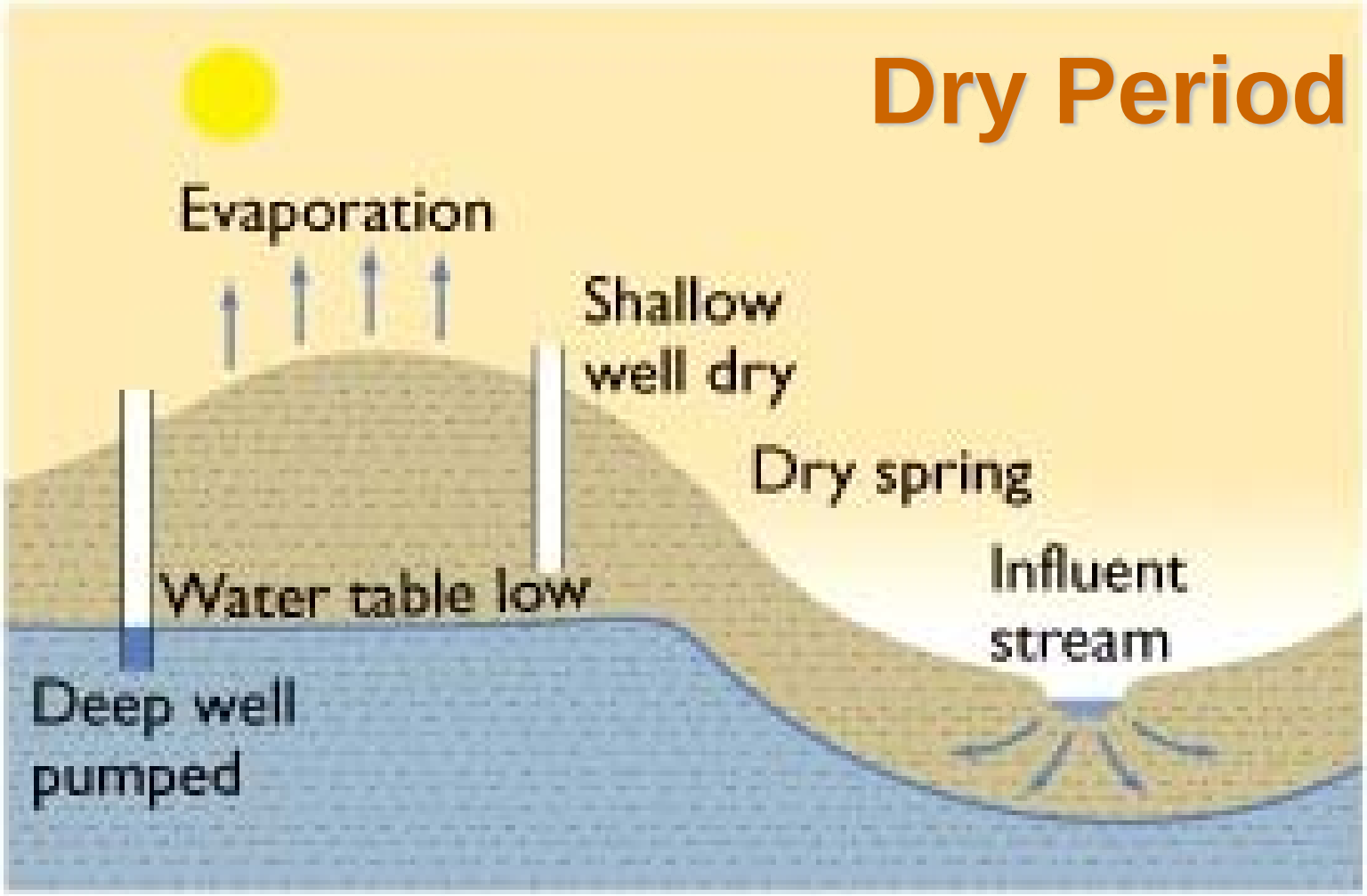
aquitard: body of rock that retards but does not prevent flow of water to or from an adjacent aquifer

aquiclude: body of relatively impermeable rock that is capable of absorbing water slowly but does not transmit it rapidly enough to supply a well or spring

Unconfined Aquifer during Wet Period

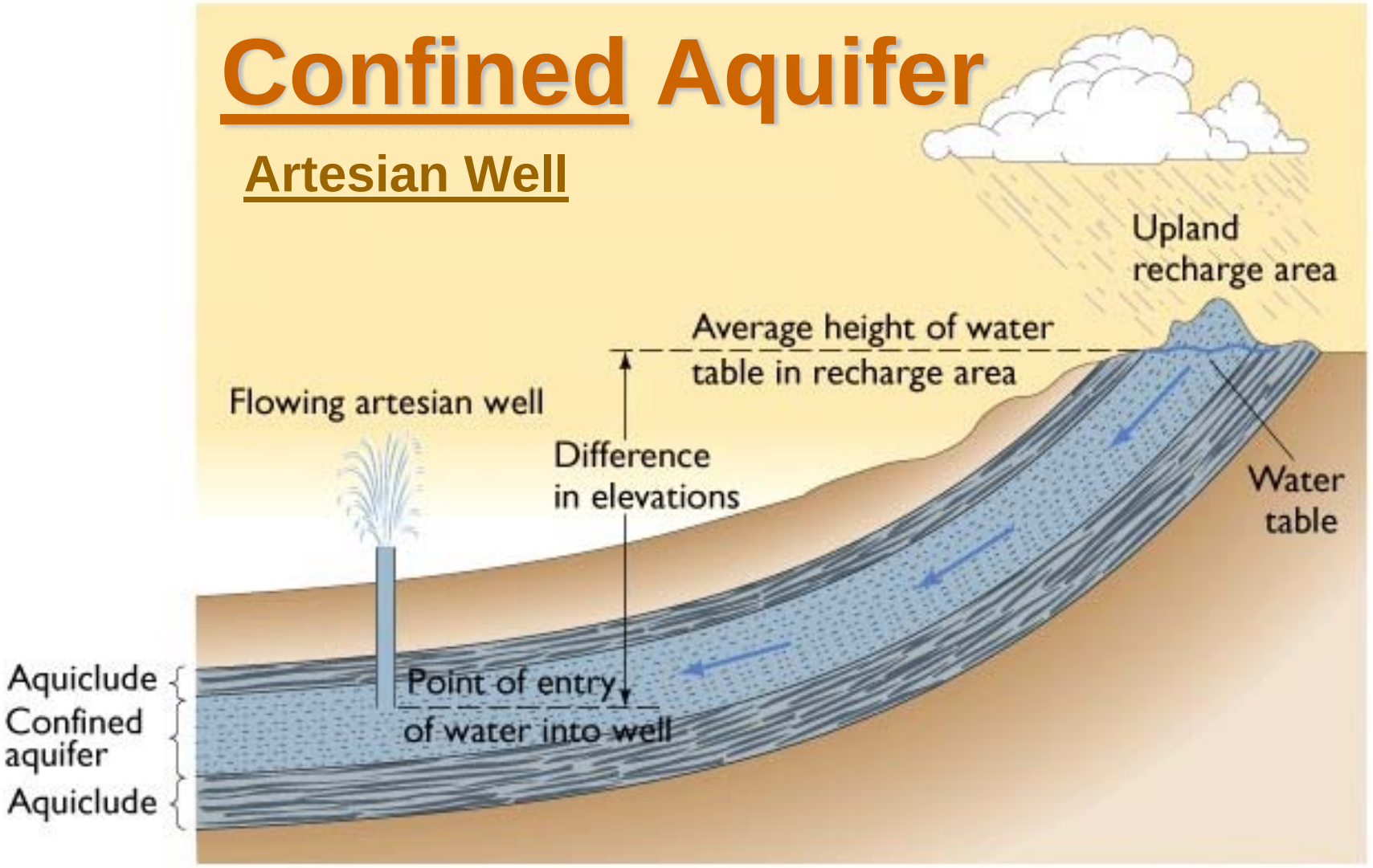


Dry Period

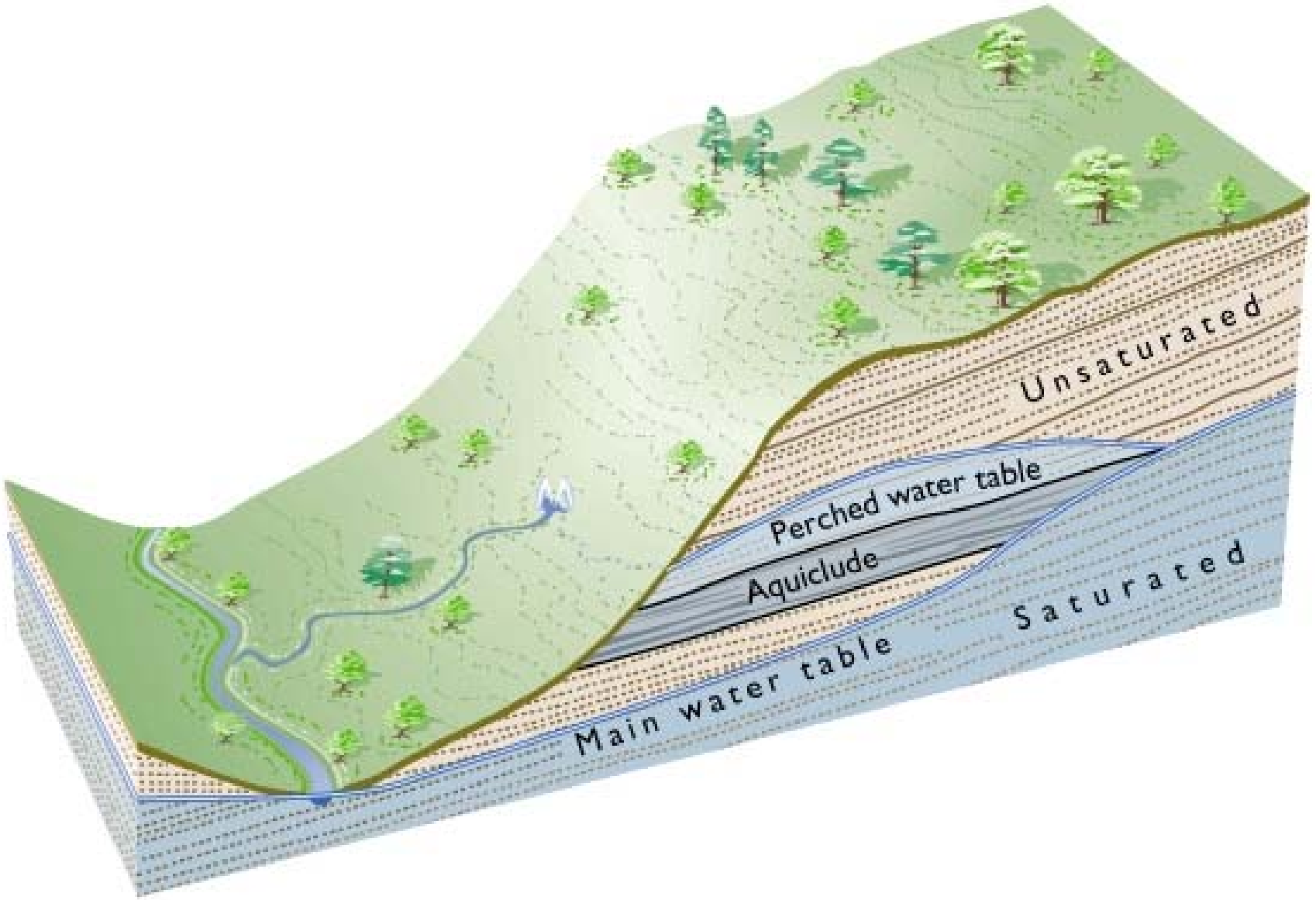

Evaporation
Shallow well dry
Dry spring
Water table low
Influent stream
Deep well pumped

Confined Aquifer

Artesian Well



Perched Water Table





Springs

Locations where a perched water table intersects the ground



Ogallala Aquifer: "Mining" Groundwater

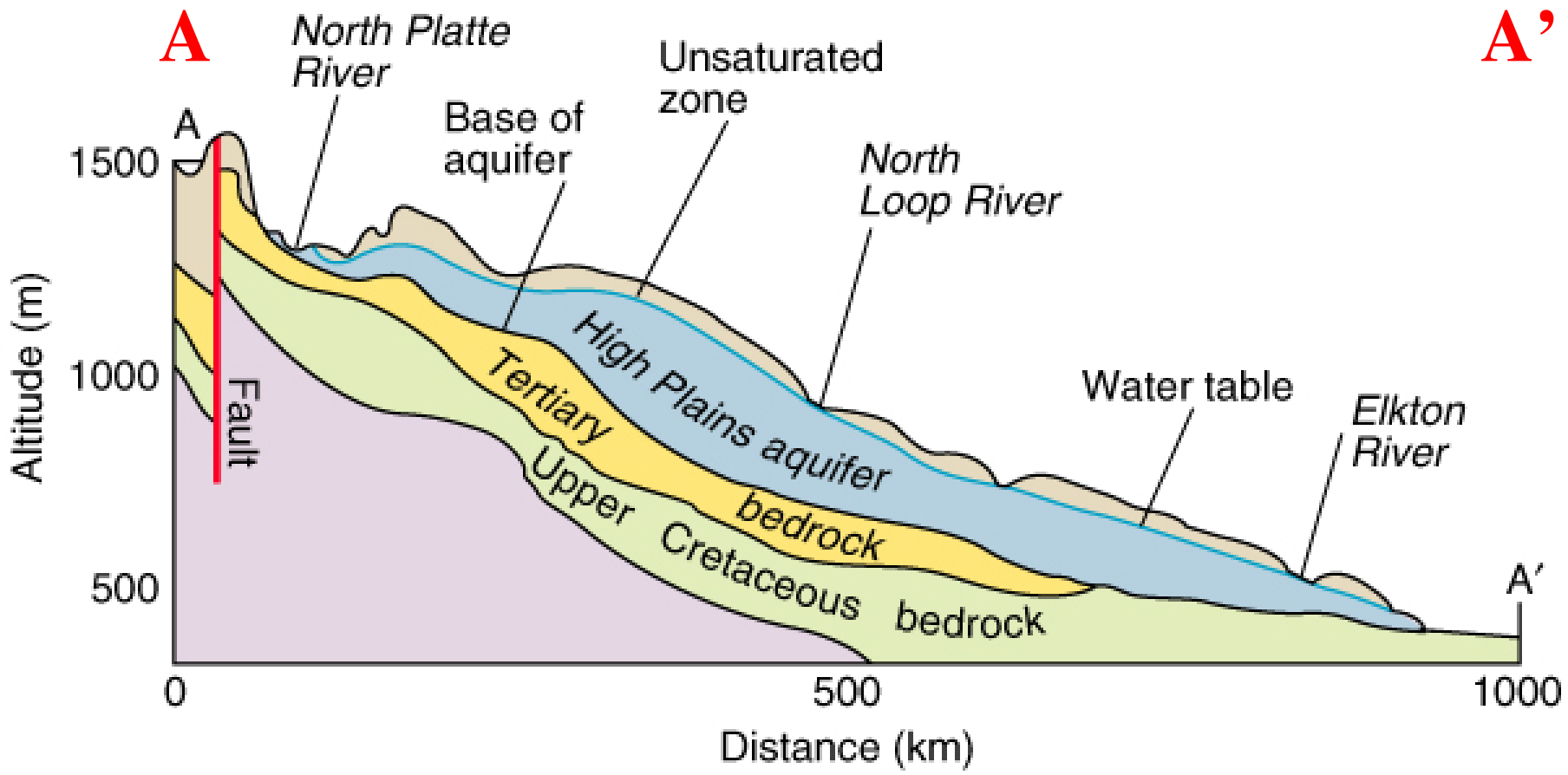


A.

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Regional extent of the High Plains aquifer- contours on top of water table

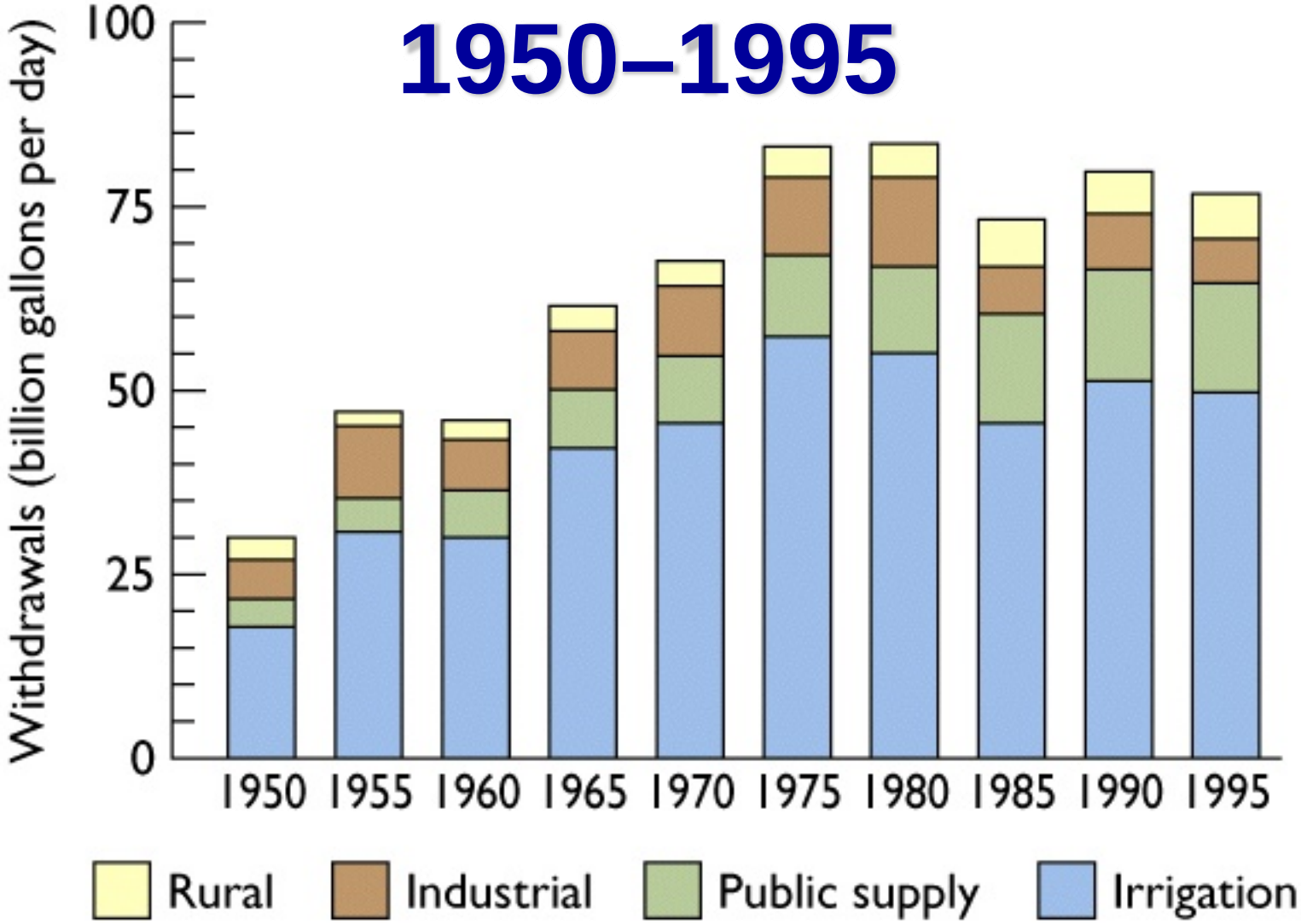
Cross section of High Plains aquifer along line A-A’



B.

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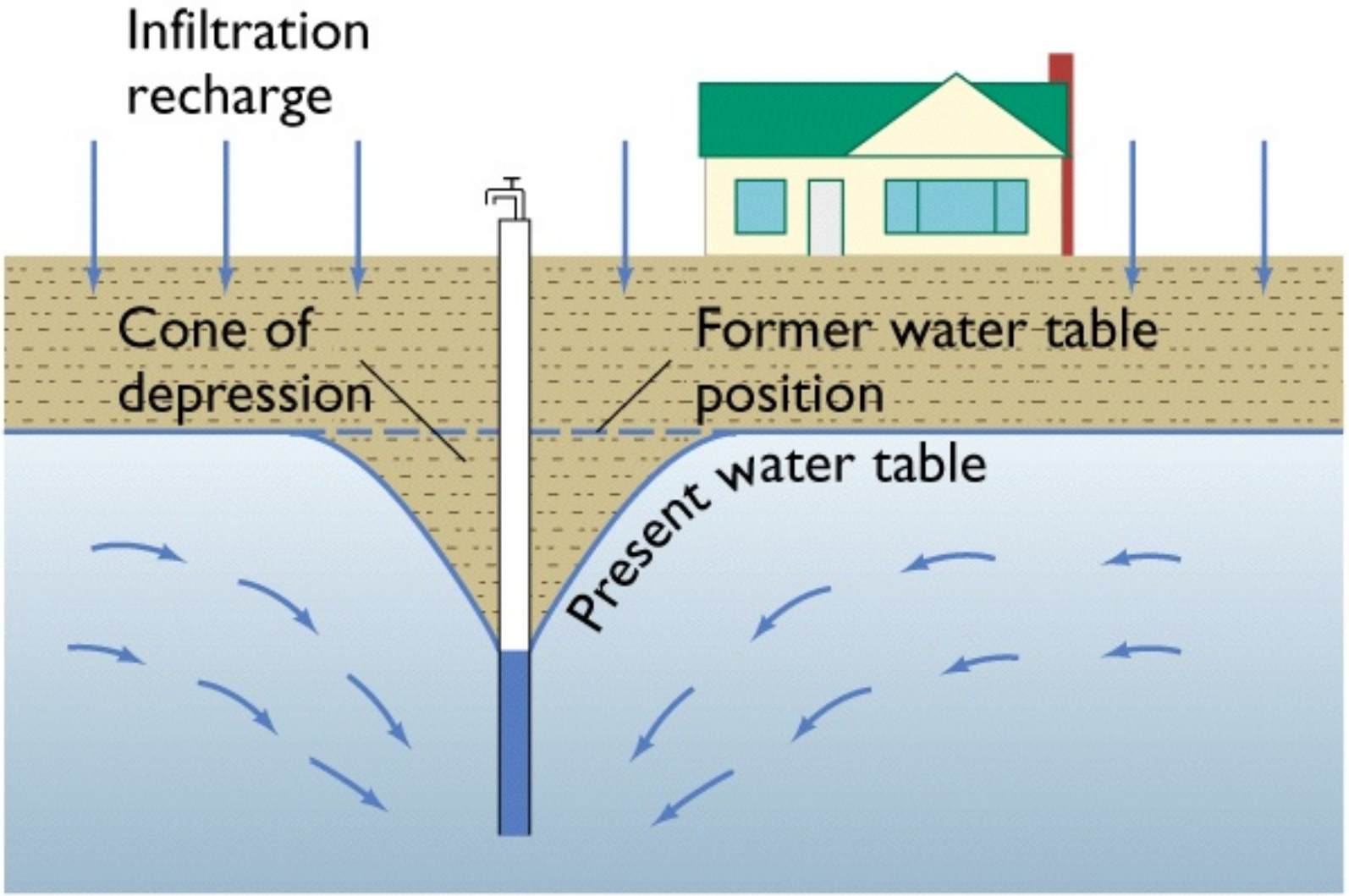
U.S. Groundwater Withdrawals 1950–1995



GROUNDWATER PROBLEMS

- DEPLETION - OVER PUMPING
  - Subsidence
  - Lose lens
  - DETERIORATION OF QUALITY
  - Contamination - organic, radioactive, chemical
  - Very expensive to clean up
- SOLUTIONS - DON”T DO ABOVE!

Drawdown Due to Pumping





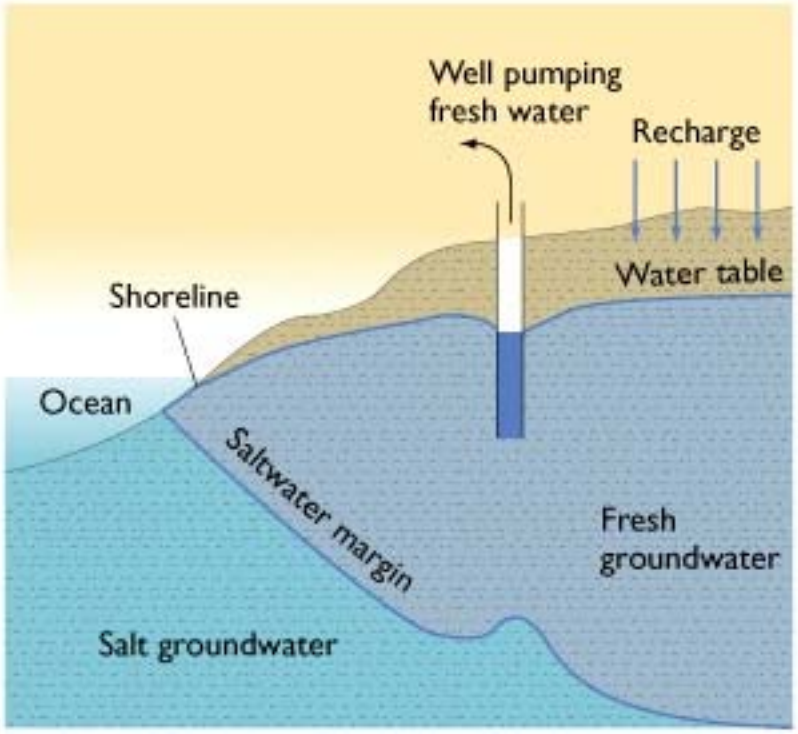
Fissures and Depressions Caused by Overpumping



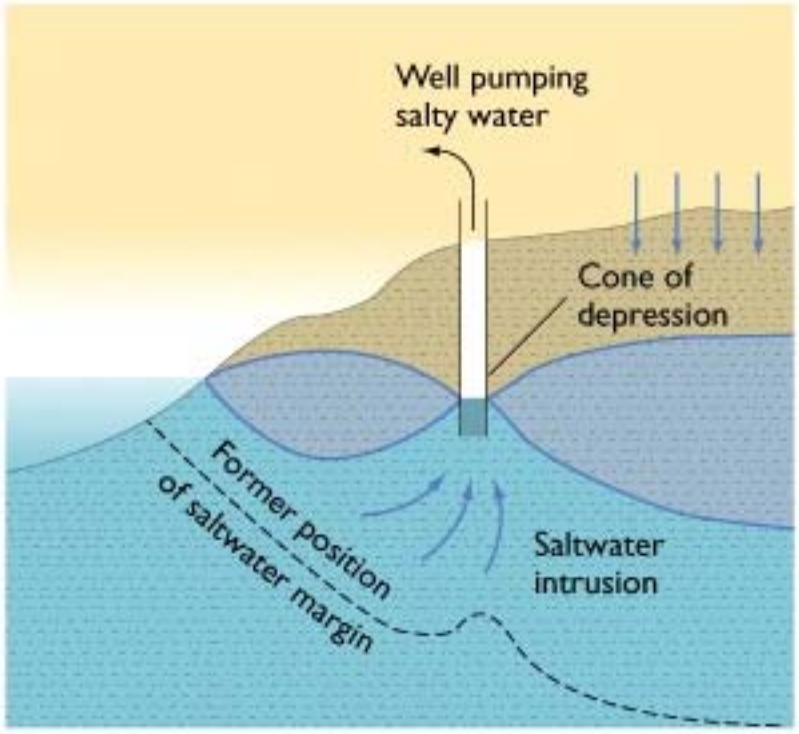
S. C. Porter

The Leaning Tower continues to lean!

Saltwater Intrusion

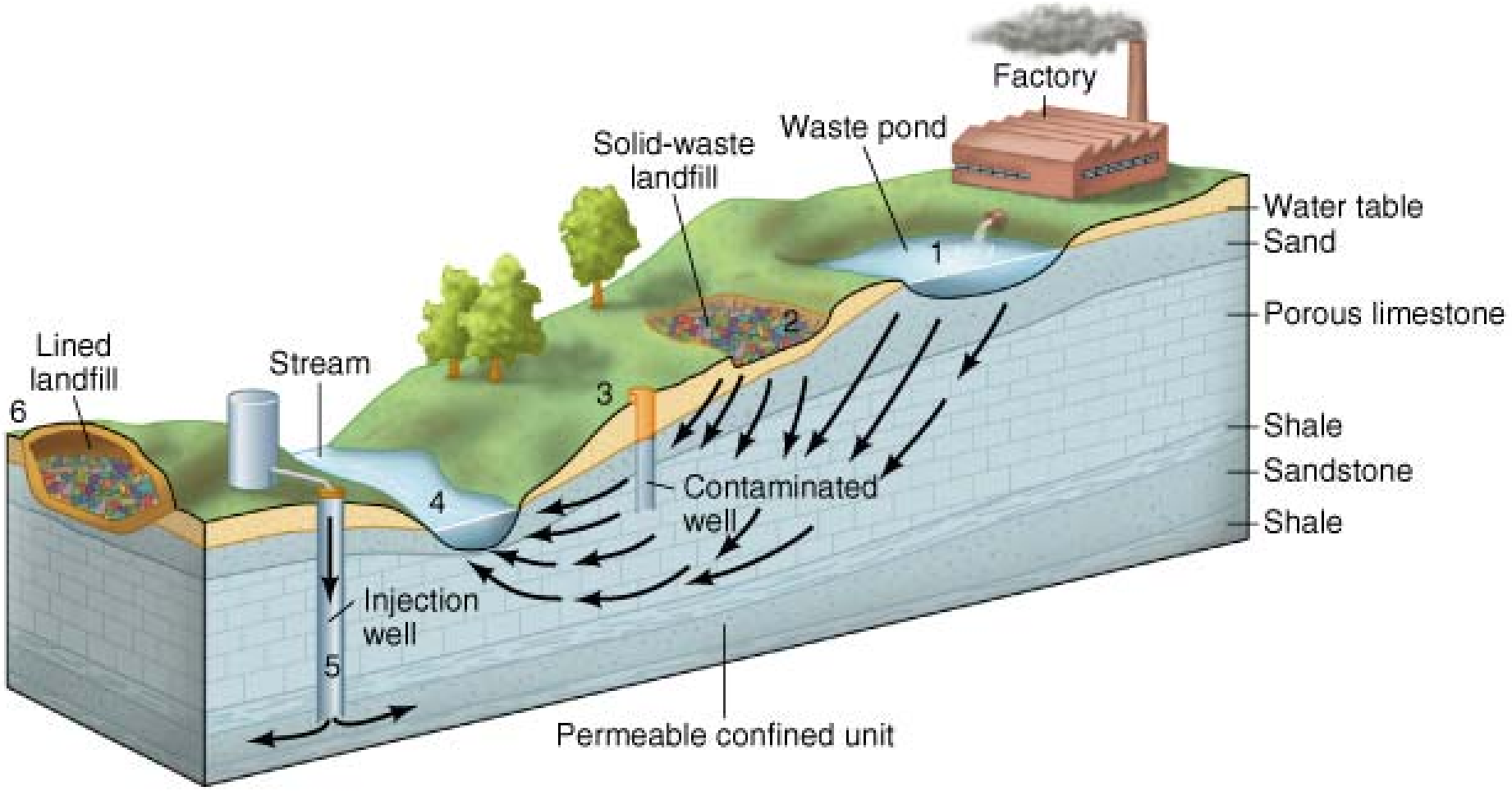


(a) Before extensive pumping



(b) After extensive pumping by many wells

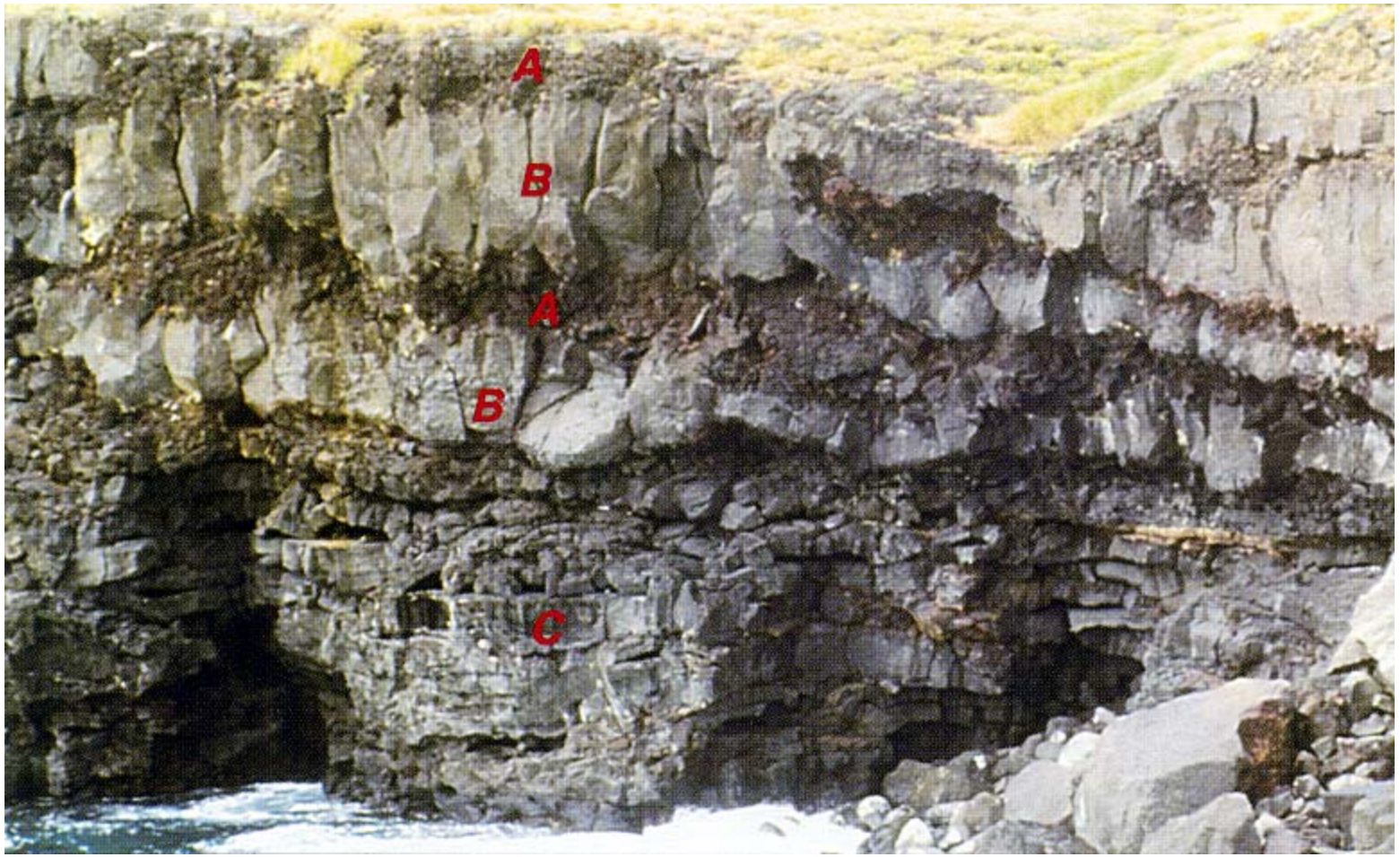
Groundwater System contaminated by toxic waste



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Hawaiian Rocks

- High porosity and permeability:
  - lava, especially pahoehoe and clinker zones in a‘a
  - sandstone
- Low porosity and permeability:
  - ash deposits (tuff)
  - weathered lava
  - fine-grained sediments
  - intrusions, especially dikes

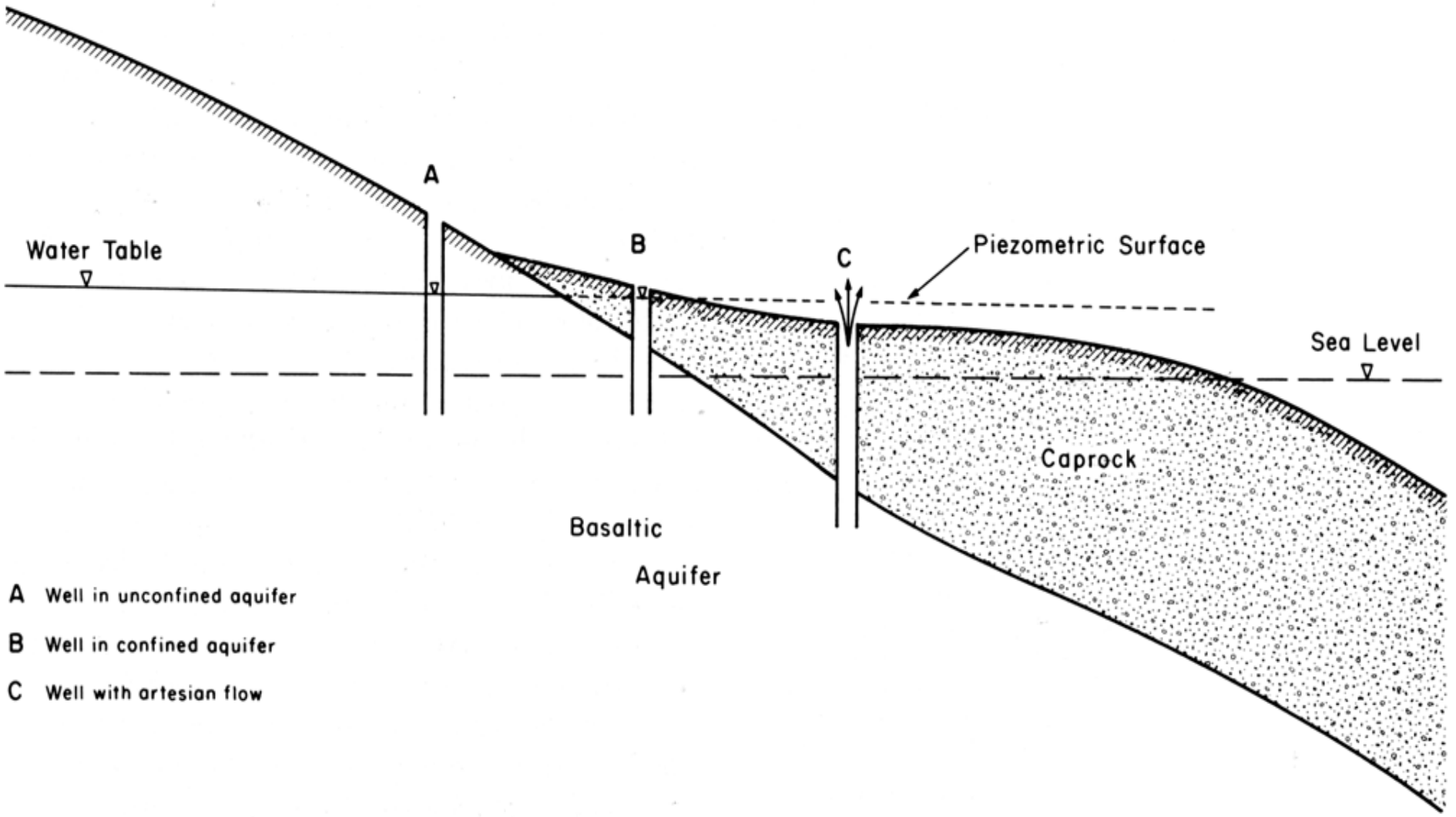


A High permeability clinker zones in a‘ā lava flows

B Lower permeability cores of a‘a lava flows

C High permeability pahoehoe lava flows

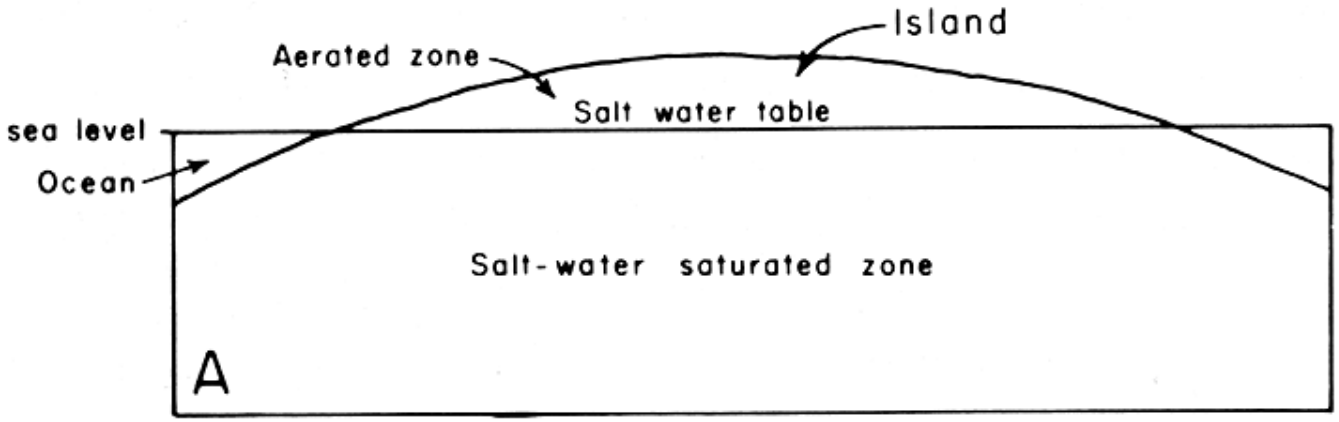
HAWAIIAN CAPROCK



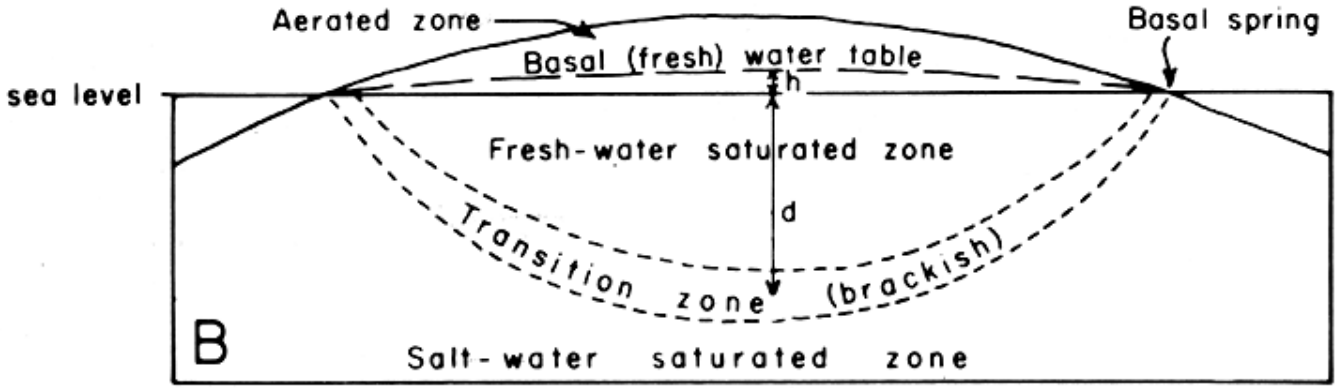
Basal Groundwater

- Fresh water is less dense than salt water, therefore it will float on salt water
- The contact between the fresh ground water and salt ground water is a brackish-water *transition zone*
- This transition zone is depressed below sea level from the weight of the overlying fresh water and the fresh water forms a lens-shaped body (Ghyben-Herzberg Lens)
- This fresh ground water is called *basal water*, and the lens-shaped body is called a *basal lens*

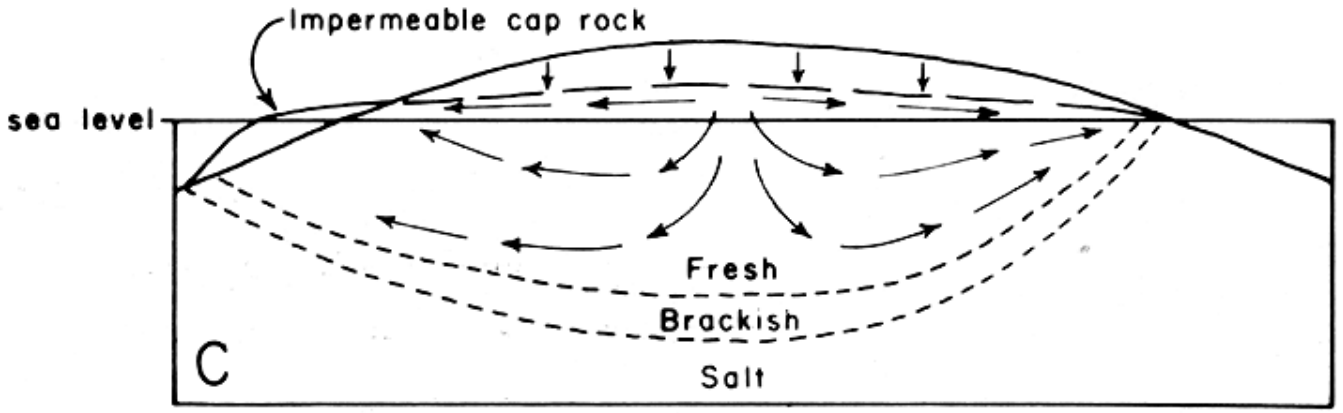
no rainfall



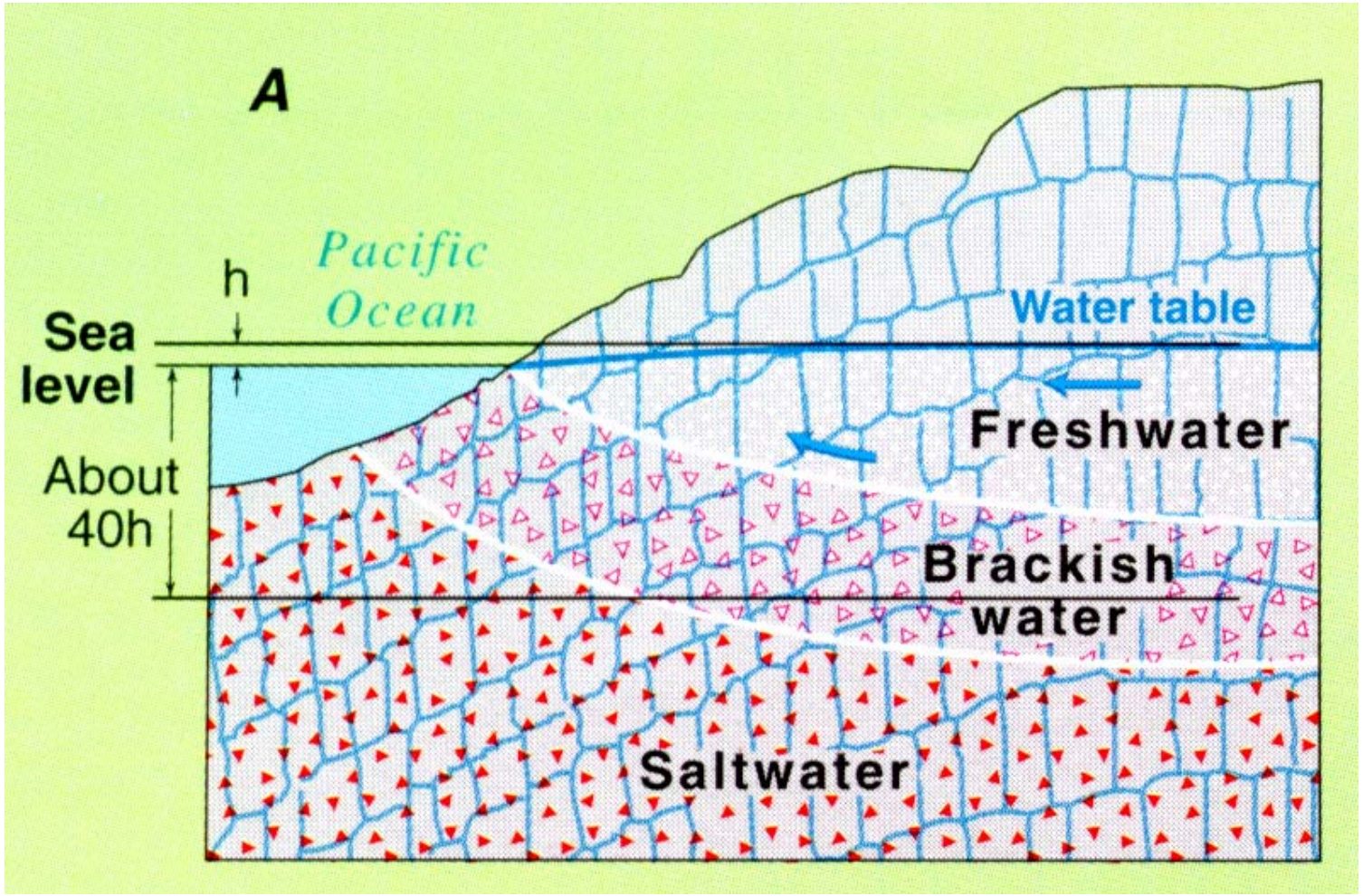
rainfall,
unconfined aquifer



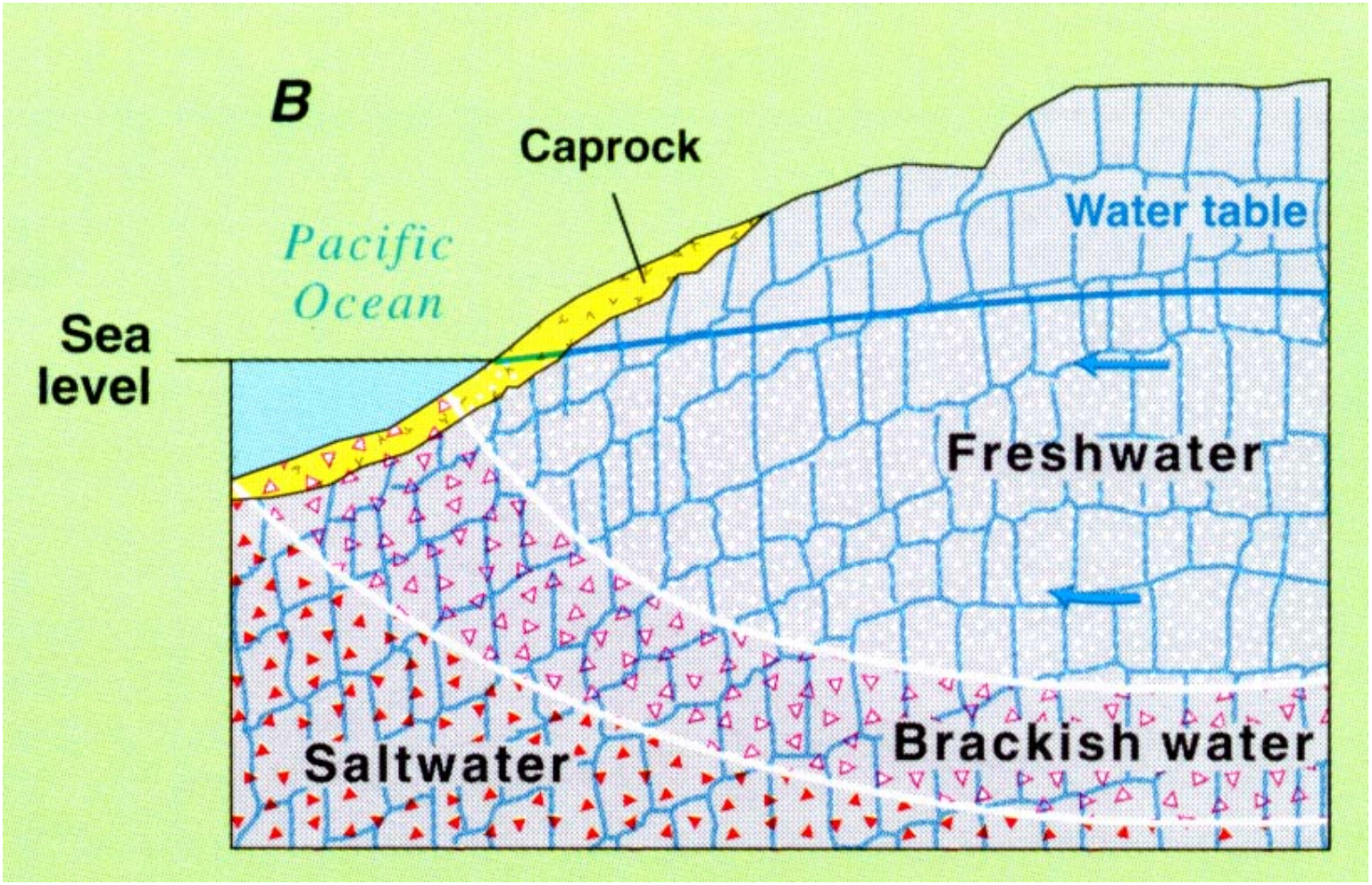
rainfall,
confined aquifer

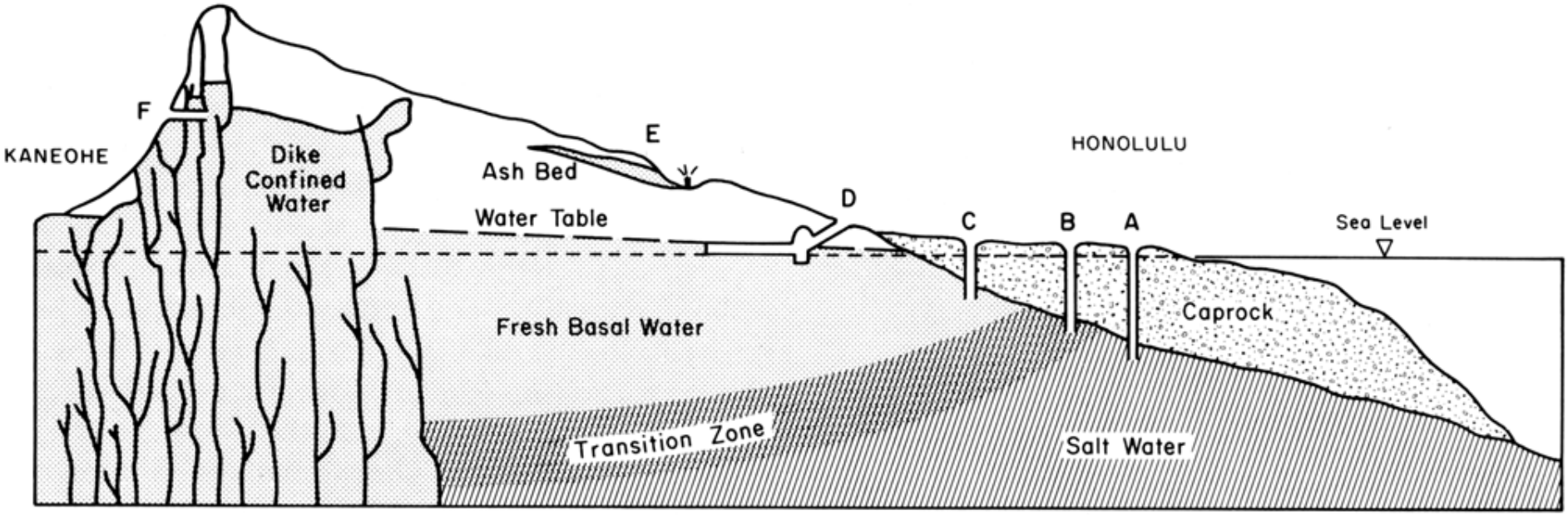


Brackish Water Transition Zone



Transition Zone With Caprock





A Artesian well producing salt water

B Artesian well producing brackish water

C Artesian well producing fresh water

D Maui shaft

E Perched water spring

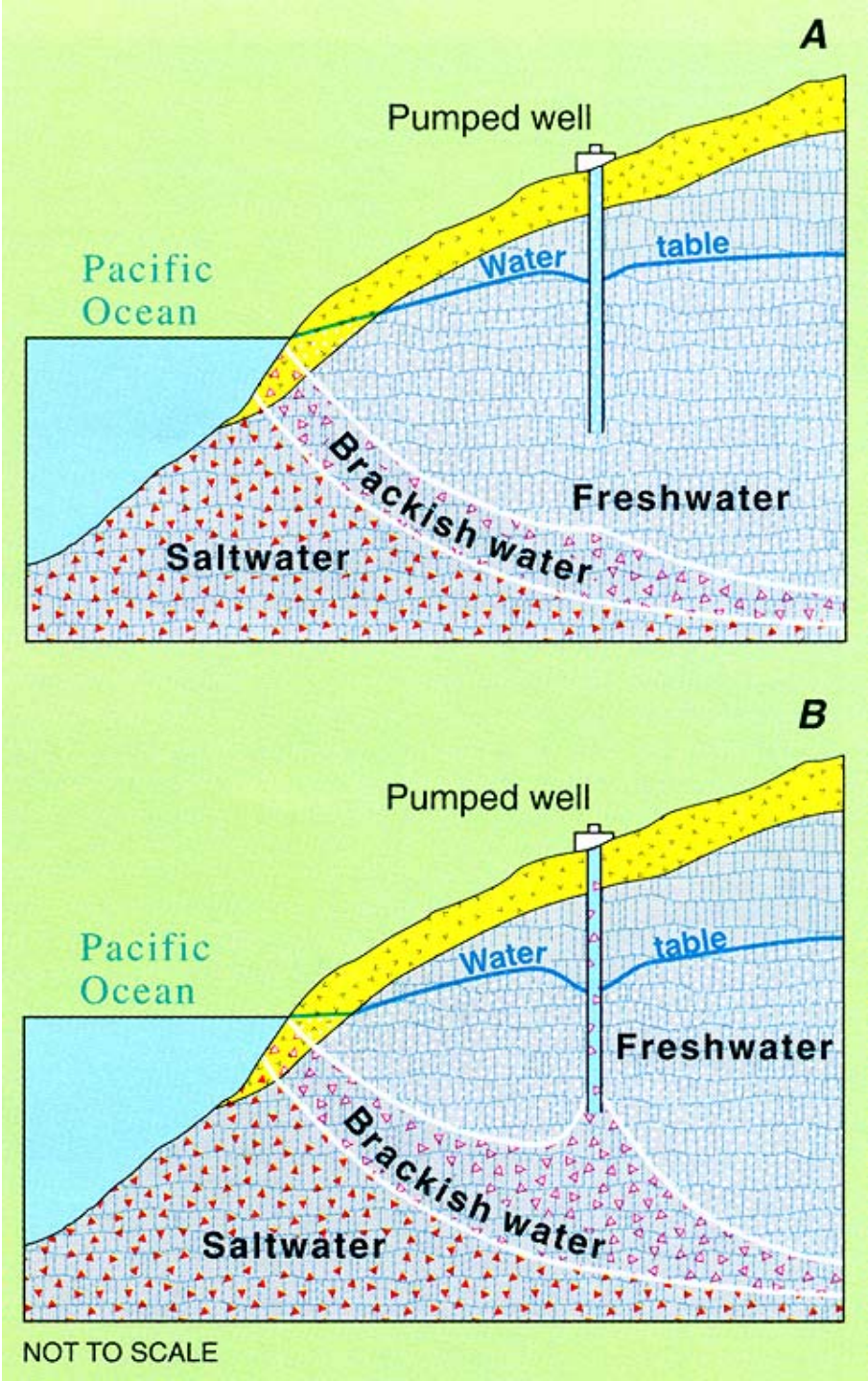
F High level tunnel tapping dike water

Recharge and Discharge

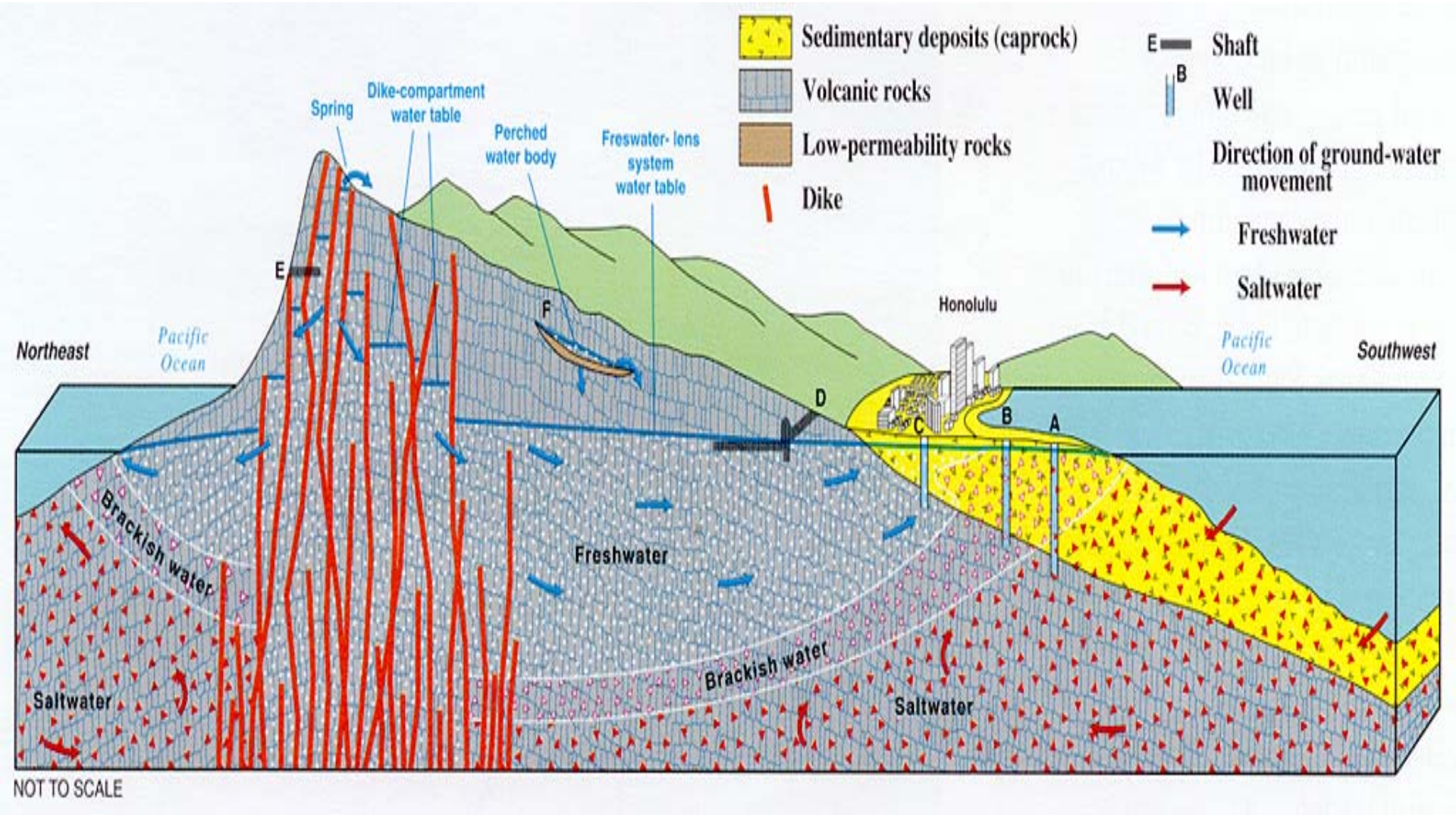
- *Recharge*--water (rain) entering the aquifer
- *Discharge*--groundwater leaving the aquifer
- If **recharge = discharge**, water table stays at a constant depth; basal lens stays same size
- If **recharge > discharge**, water table rises and basal lens will grow
- If **recharge < discharge**, water table falls and basal lens will shrink
- Discharge can be increased artificially by pumping
- **In Hawai‘i, a shrinking basal lens also means a rising transition zone**

A well pumping buoyant, fresh water out of a basal lens near the coast

As fresh water is withdrawn, the brackish water interface will move up to replace it and the well will eventually pump brackish water

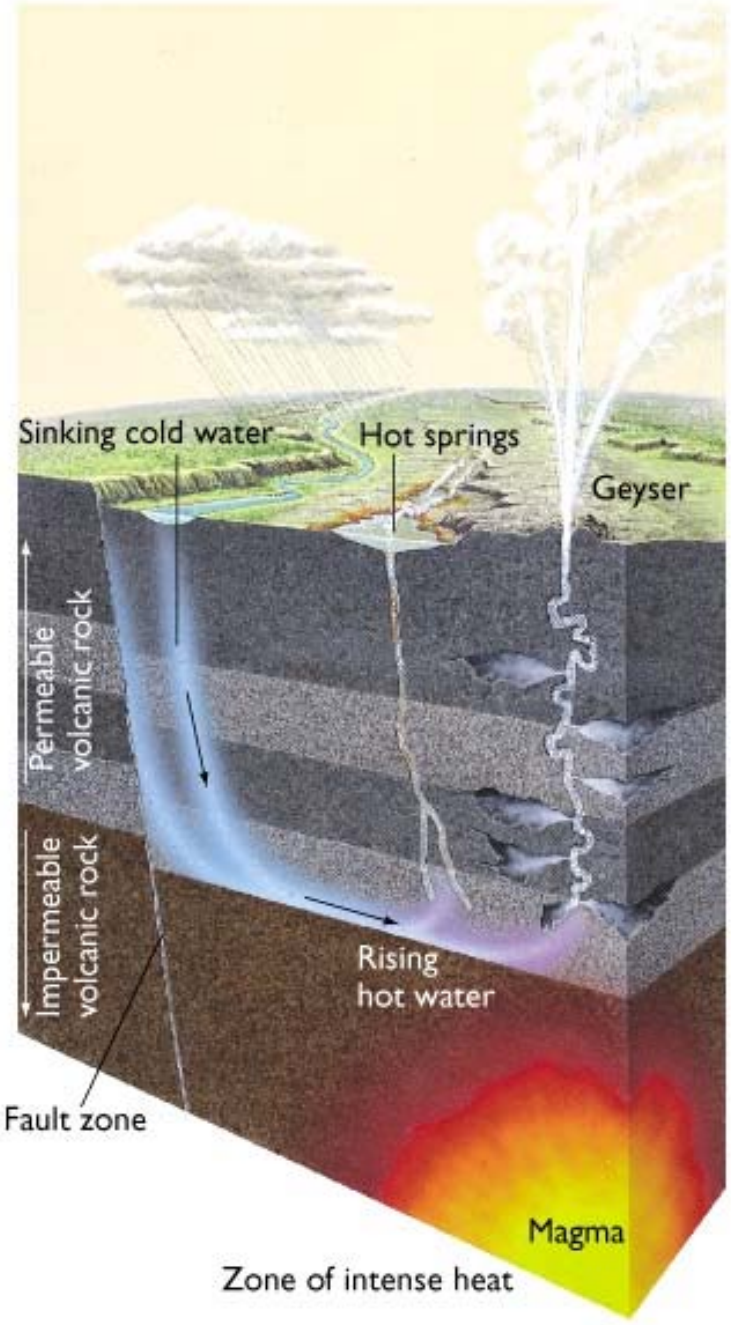


Groundwater on O‘ahu

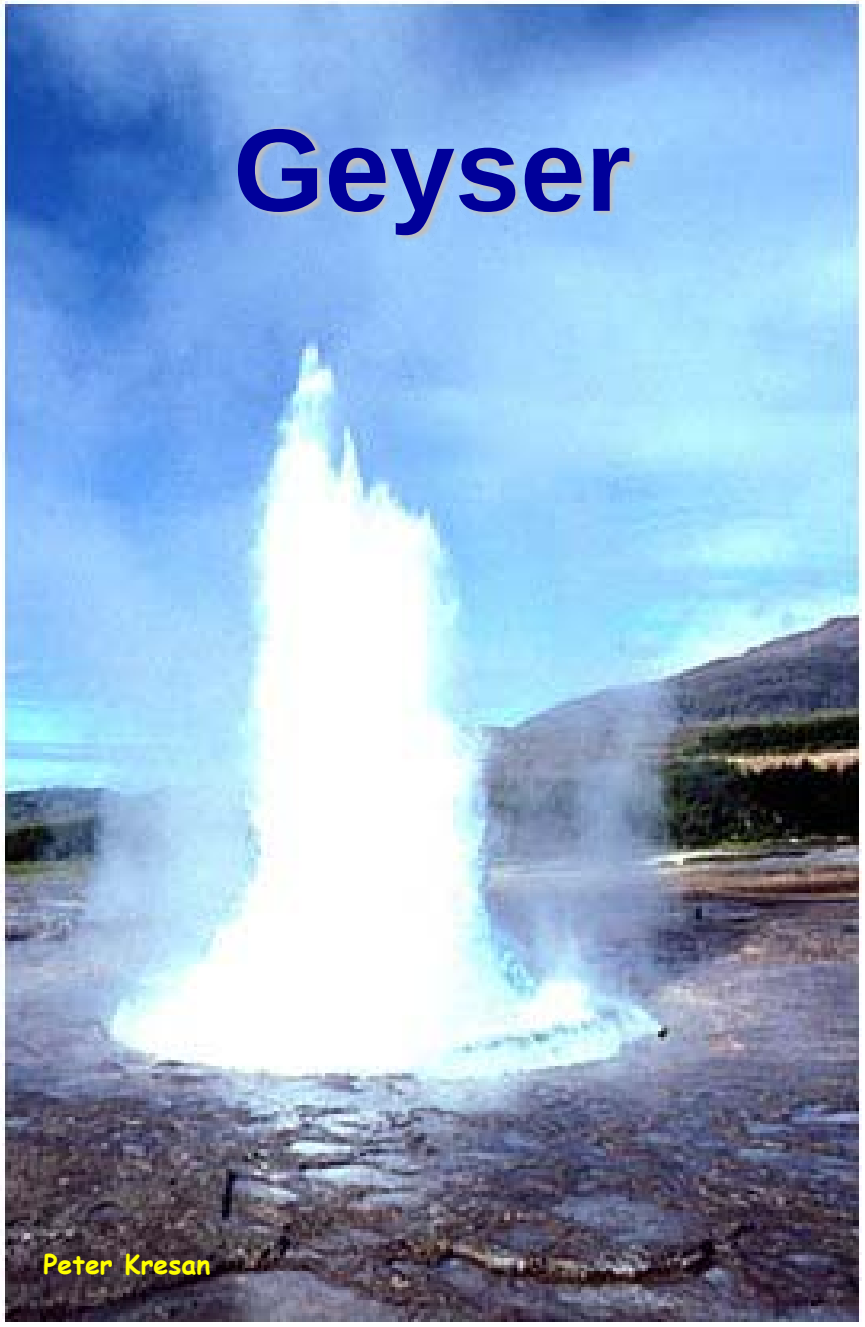


Hydrothermal Phenomena

- Groundwater affected by a shallow source of natural heat; i.e., hot rocks underground
  - Magma chamber: calderas
  - Dikes: rift zones
  - Solidifying lava lakes: calderas and pit craters
- Produces hot spring springs and *fumaroles* (steam vents)
- Rocks in contact with hot water can be altered; called hydrothermal alteration
  - results in the water also carrying elements away; e.g., sulfur
  - produces acid water and steam at the surface
  - fluid precipitates crystals when it cools
- Can be exploited as an energy source by geothermal power plants, but high permeability of Hawaiian rocks are rocks a problem

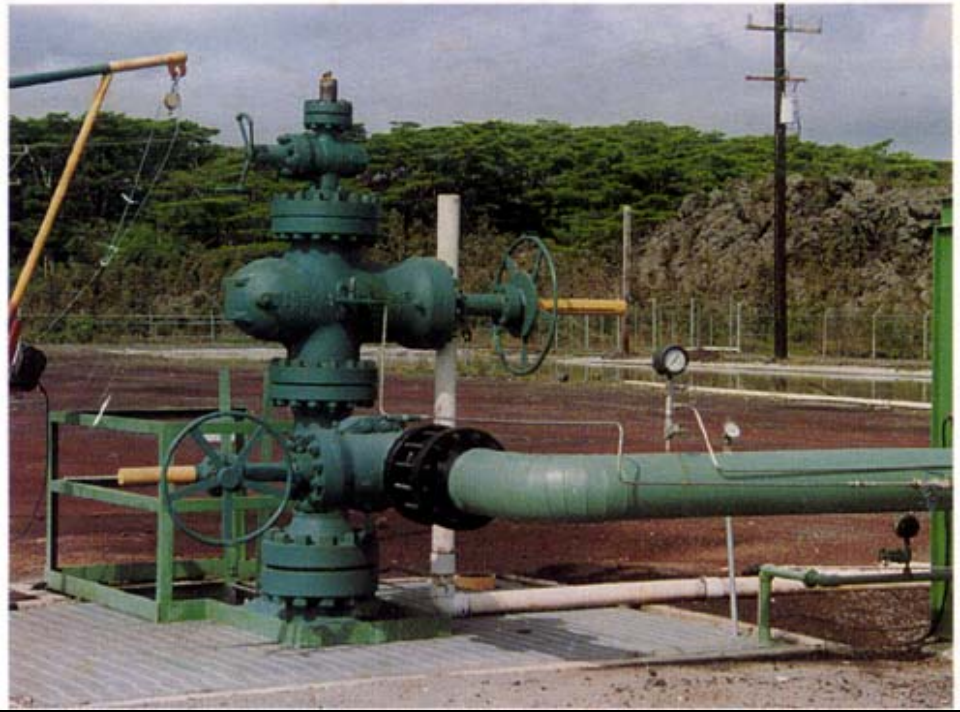

Sinking cold water
Hot springs
Geyser
Permeable volcanic rock
Impermeable volcanic rock
Rising hot water
Fault zone
Magma
Zone of intense heat

Geyser


Peter Kresan









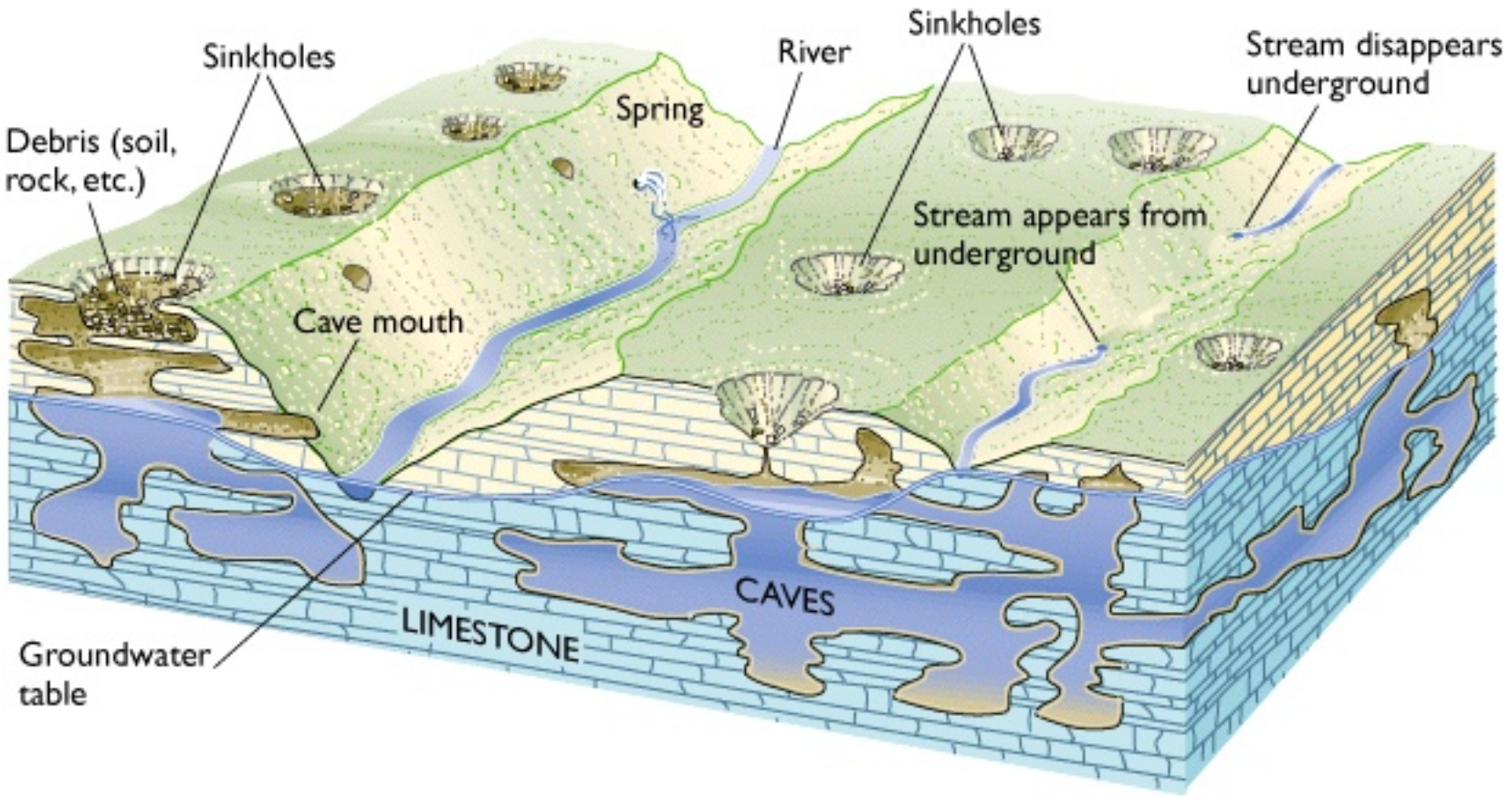
Geologic activity of groundwater

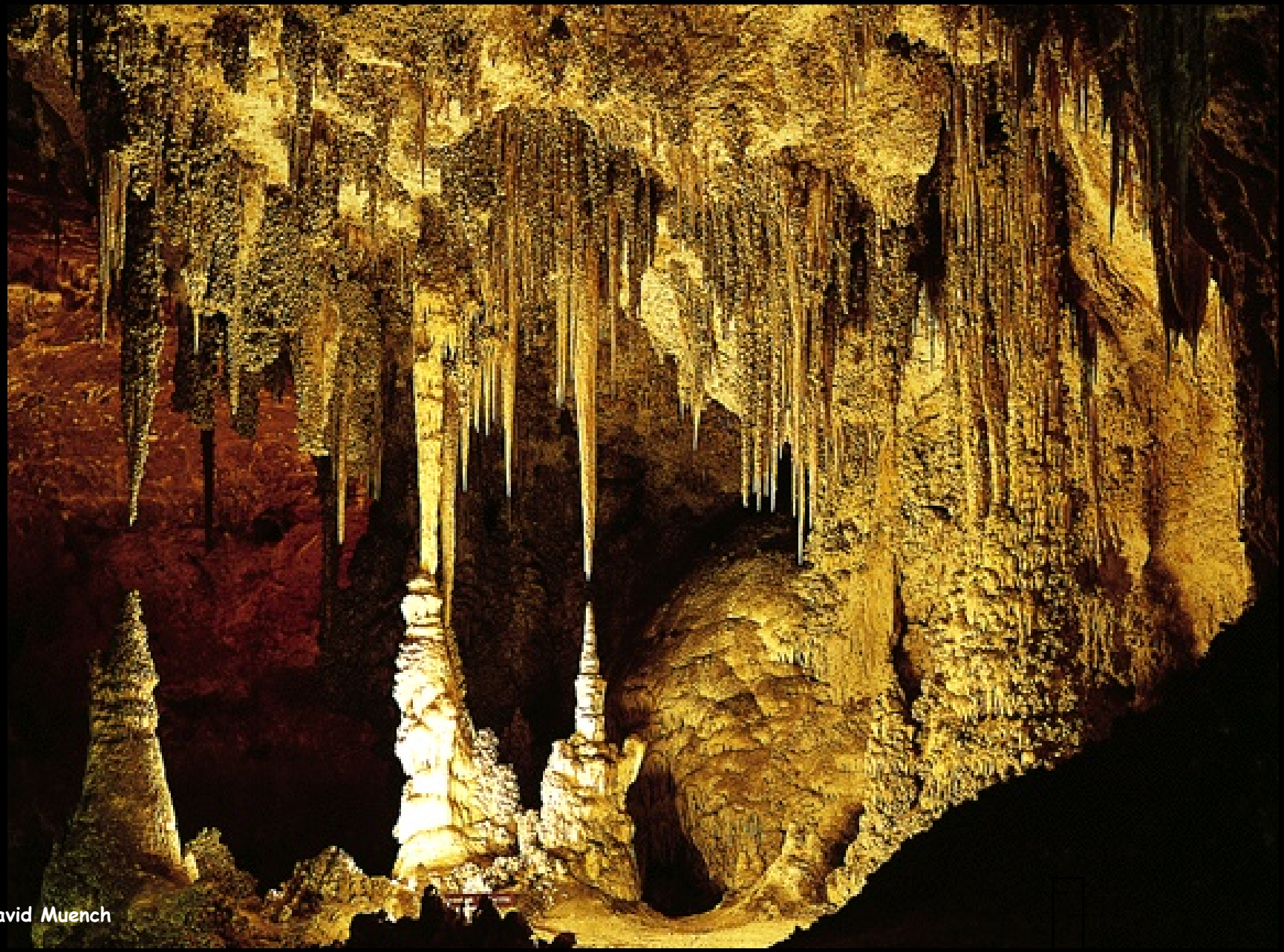
- Dissolution (most important in carbonates and evaporites)
- Cementation
- Replacement

Surface expression of the geology of dissolved limestone and work of near surface water

- Cave and Karsts landscapes are extremely sensitive- so need to be protected
- Landform
  - Sinkholes-circular surface depression
  - Disappearing Streams- flow through sinkholes may emerge as spring several kilometers away
  - Natural Bridge- series of neighboring sinkholes expand and join together

Major Features of Karst Topography




David Muench

Sinkhole in Florida



Pavement Karst in Ireland

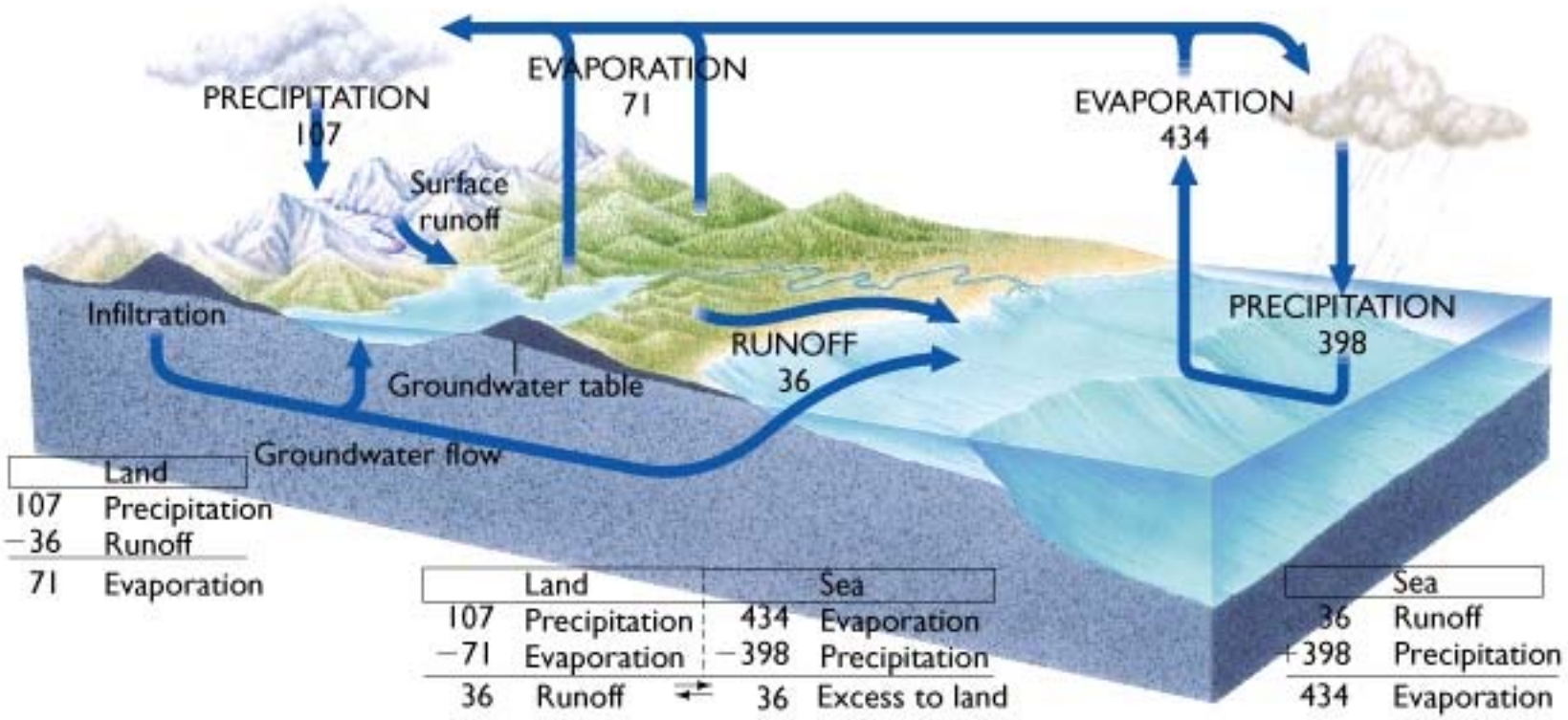


Radiotelescope in Cone Karst



THE END

Hydrologic Cycle



	Land
107	Precipitation
−36	Runoff
71	Evaporation

	Land		Sea
107	Precipitation	434	Evaporation
−71	Evaporation	−398	Precipitation
36	Runoff	36	Excess to land

	Sea
36	Runoff
+398	Precipitation
434	Evaporation