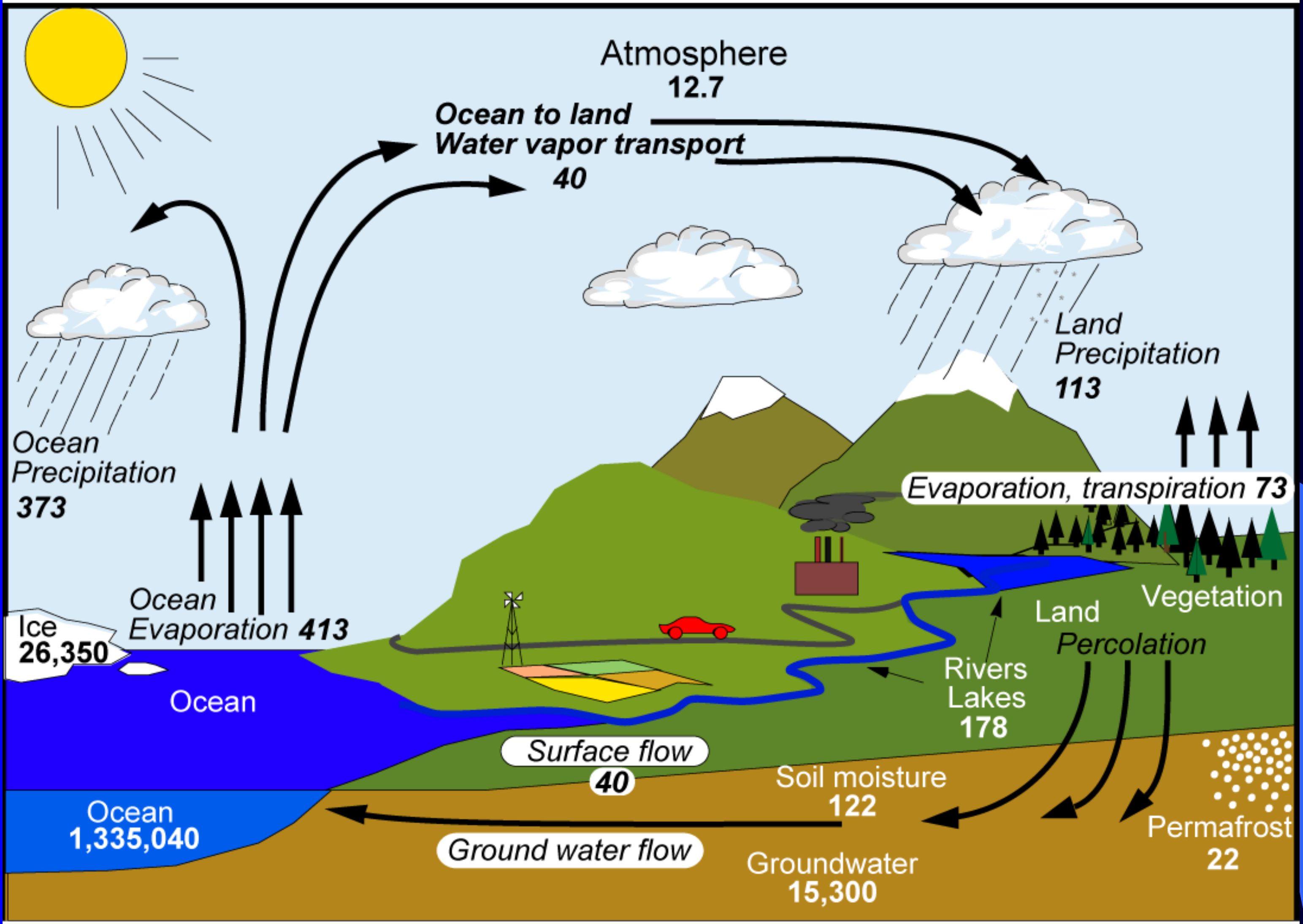
ENVI.2010 – Systems I: Surface and Groundwater

Hydrological Cycle



Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges

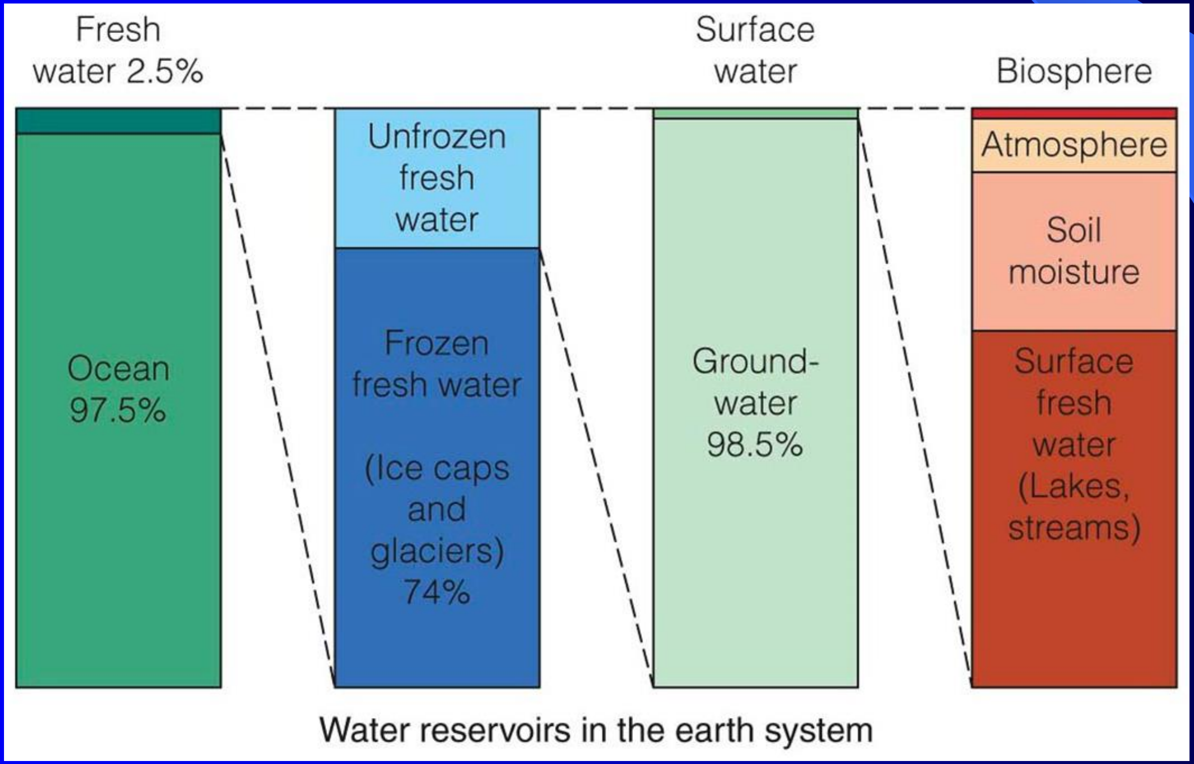
The largest reservoir in the hydrologic cycle is the ocean

- Contains more than 97.5% of Earth's water
- Most of the water in the hydrologic cycle is saline, and not usable by humans

The largest reservoir of fresh water is the polar ice sheets

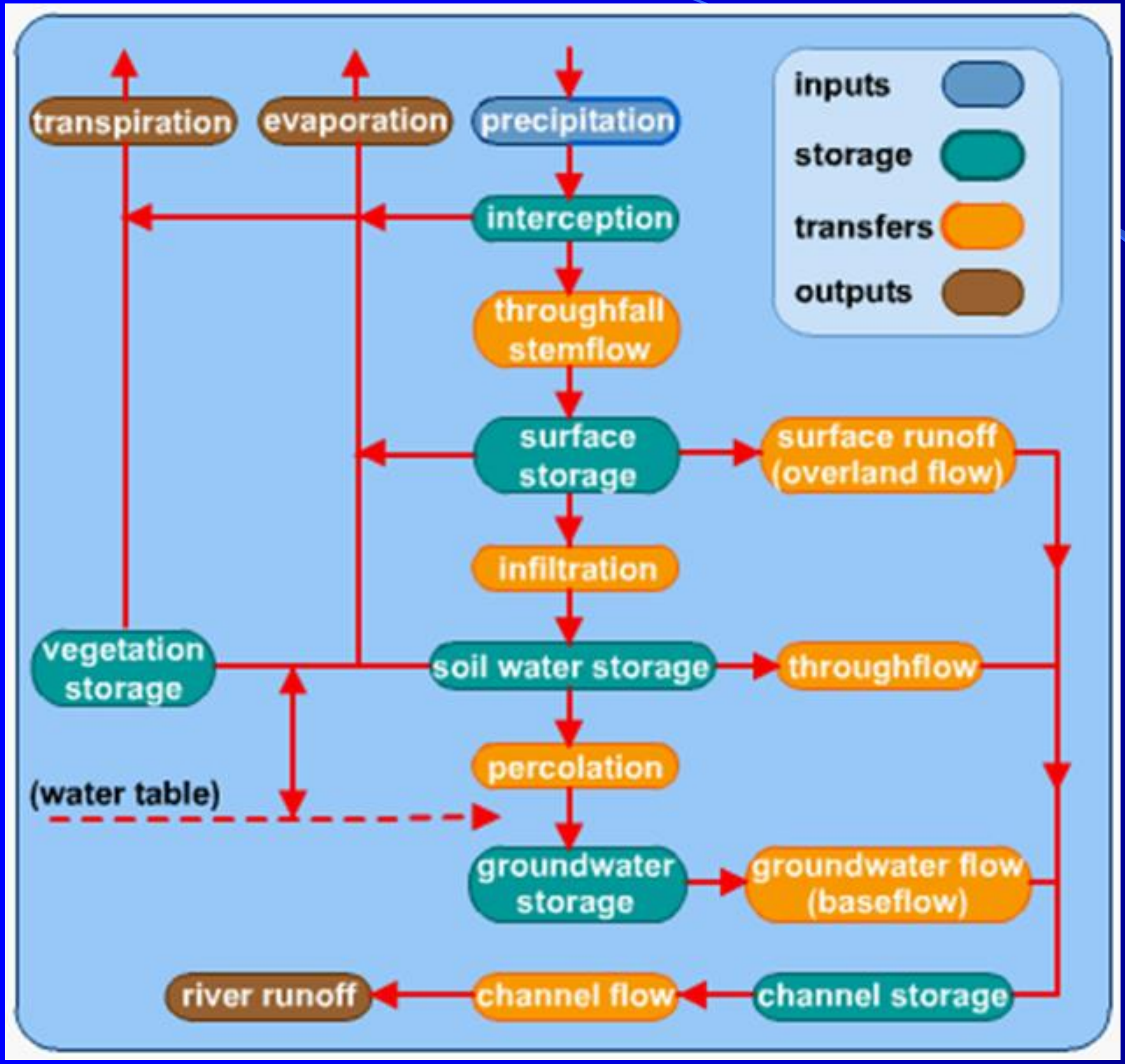
- Contain 74% of the Earth's fresh water

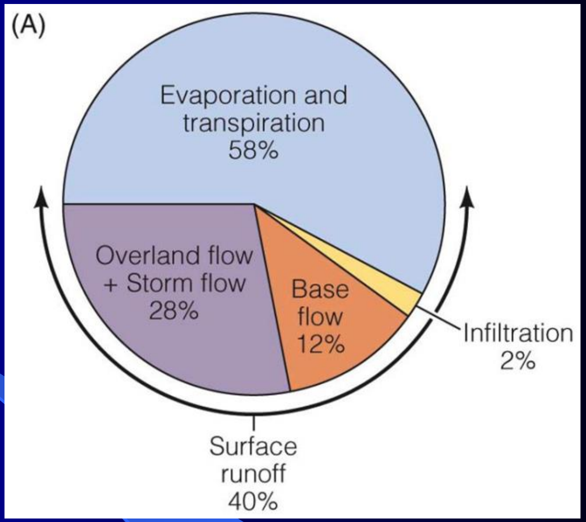
The largest reservoir of unfrozen fresh water is groundwater

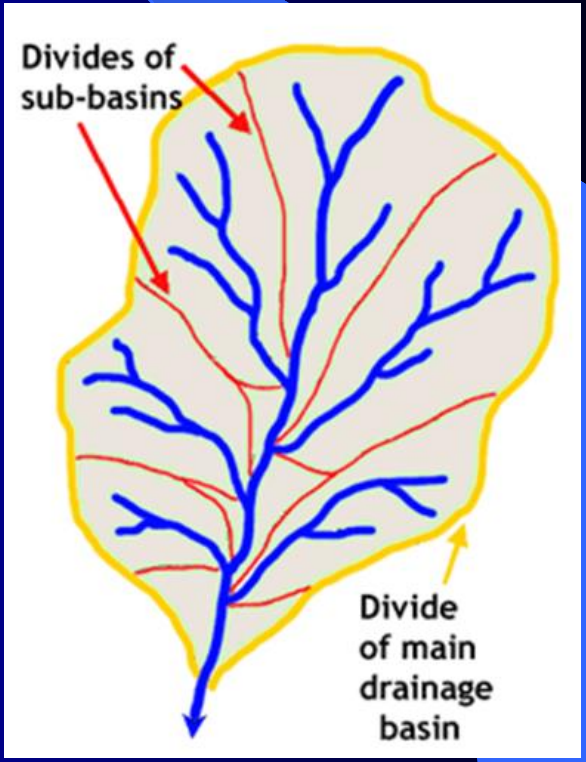


Surface Water

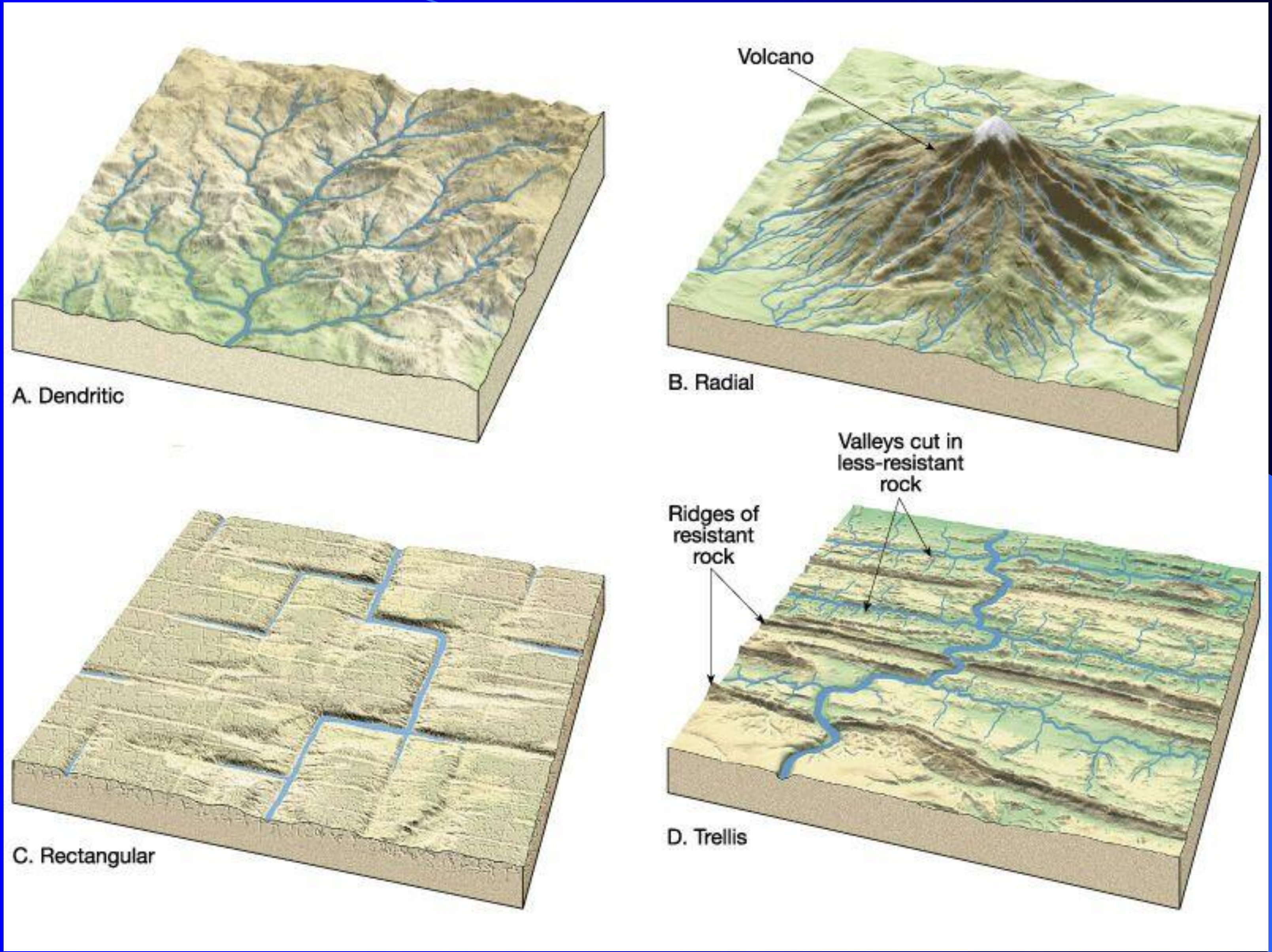
Precipitation and streams

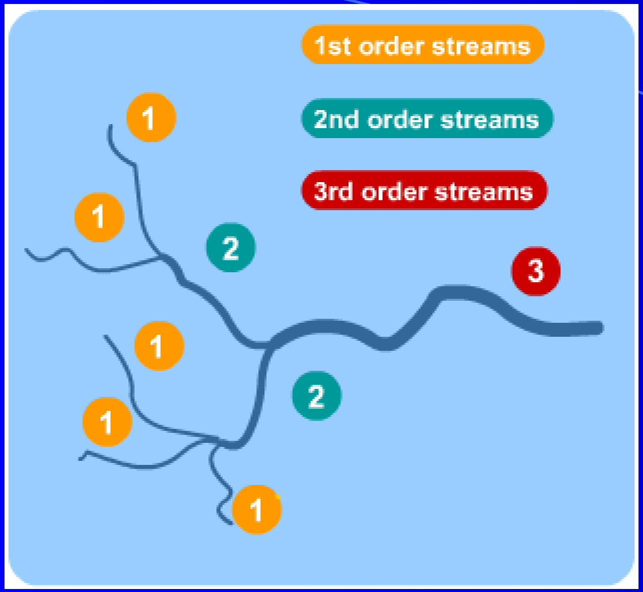


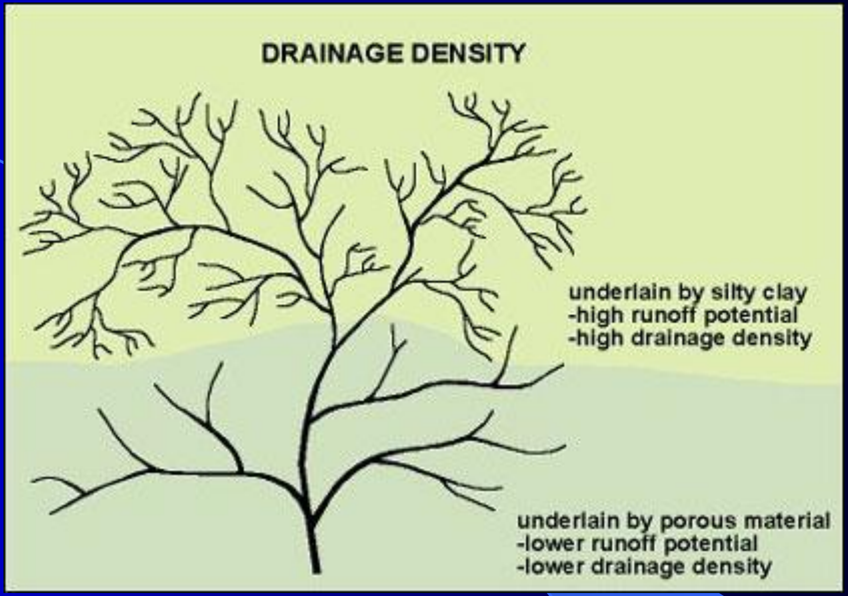


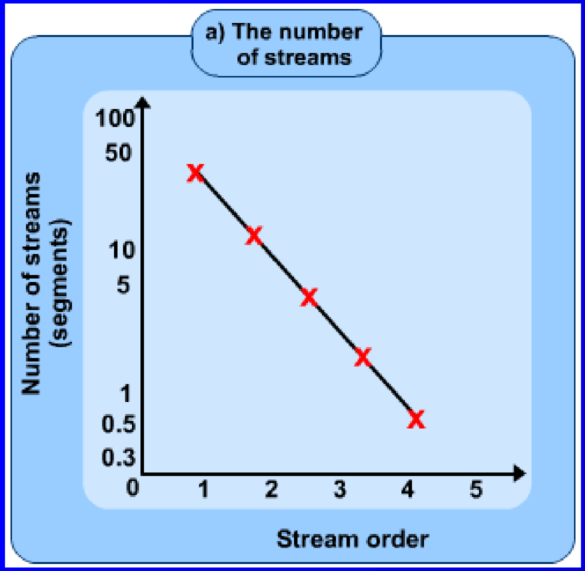


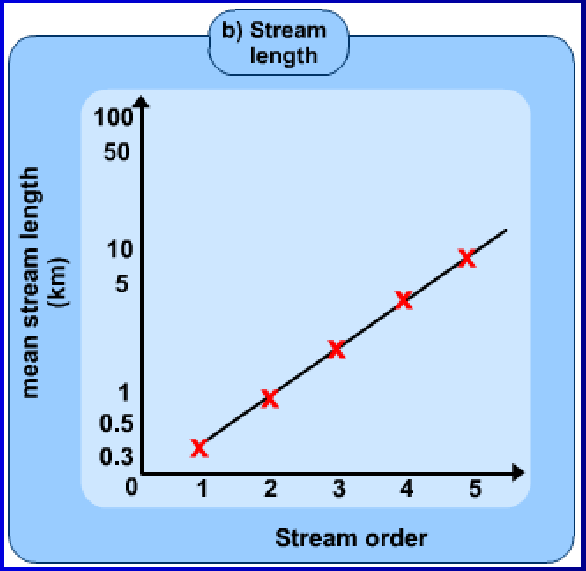
Drainage patterns

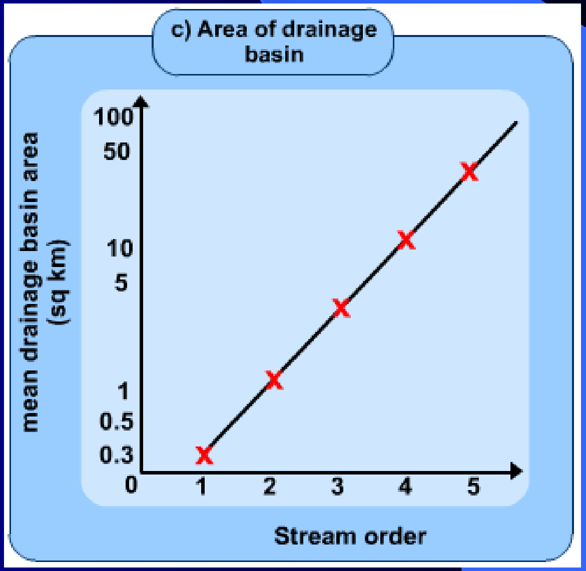



1st order streams
2nd order streams
3rd order streams
1
1
2
3
1
2
1
1


DRAINAGE DENSITY
underlain by silty clay
-high runoff potential
-high drainage density
underlain by porous material
-lower runoff potential
-lower drainage density


a) The number of streams
Number of streams (segments)
100
50
10
5
1
0.5
0.3
0
1
2
3
4
5
Stream order


b) Stream length
mean stream length (km)
100
50
10
5
1
0.5
0.3
0
1
2
3
4
5
Stream order


c) Area of drainage basin
mean drainage basin area (sq km)
100
50
10
5
1
0.5
0.3
0
1
2
3
4
5
Stream order

The Hydrologic Budget

$$(P + GW_{in} + SW_{in}) - (E + ET) = (\Delta SW + \Delta GW + \Delta SM)$$

← inflows → ← outflows → ← change in storage →

where:

P is precipitation as rain or snow,

GW_{in} is ground-water inflow volume,

SW_{in} is surface-water inflow volume,

E is open-water evaporation,

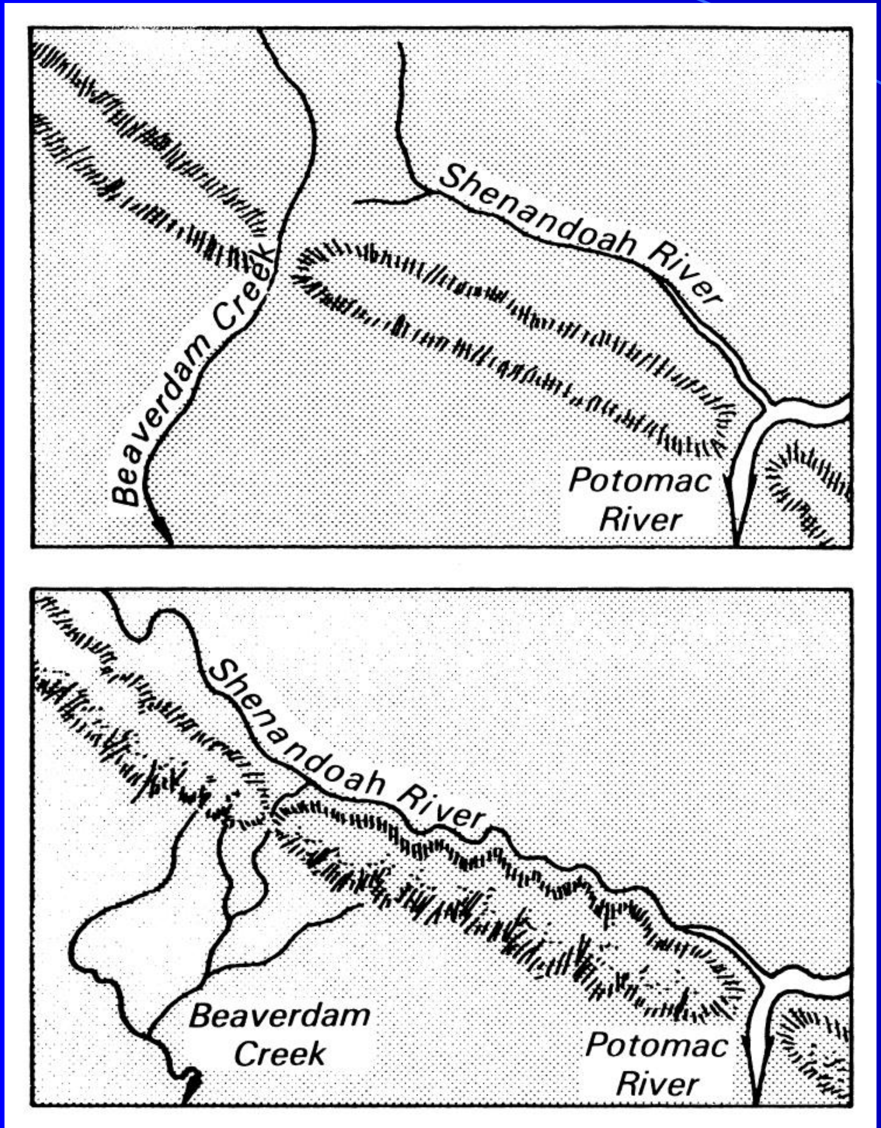
ET is evapotranspiration from emergent vegetation,

ΔSW is change in standing volume of surface water,

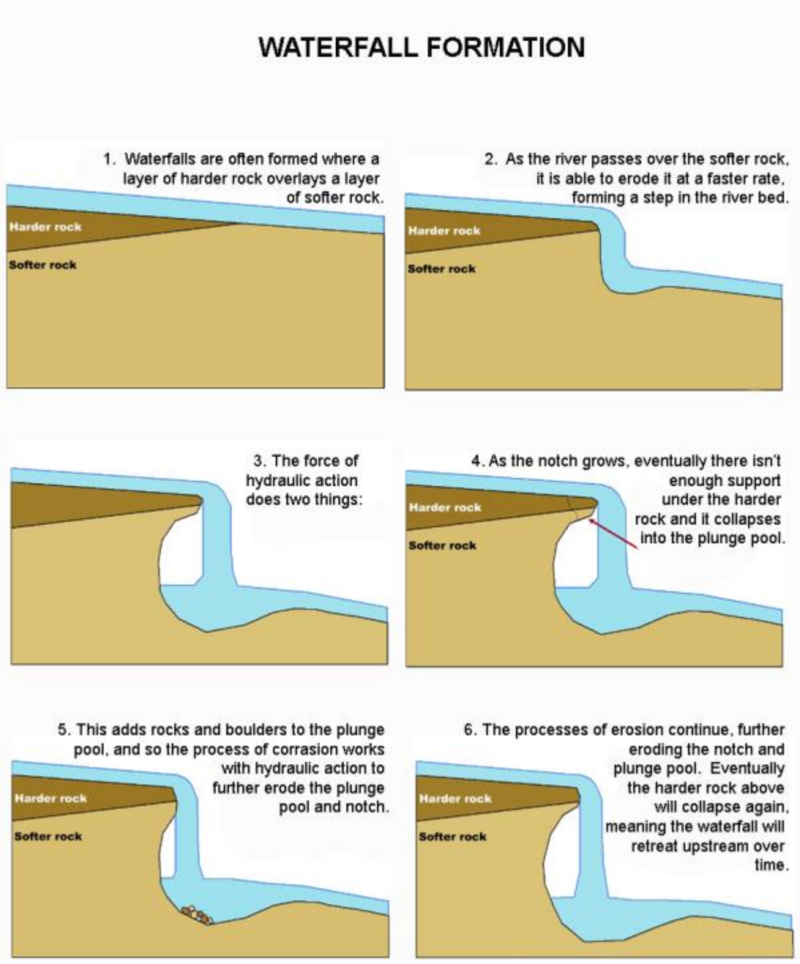
ΔGW is change in ground-water volume of the saturated zone, and

ΔSM is change in ground-water volume of the unsaturated zone.

Stream capture



Waterfall formation

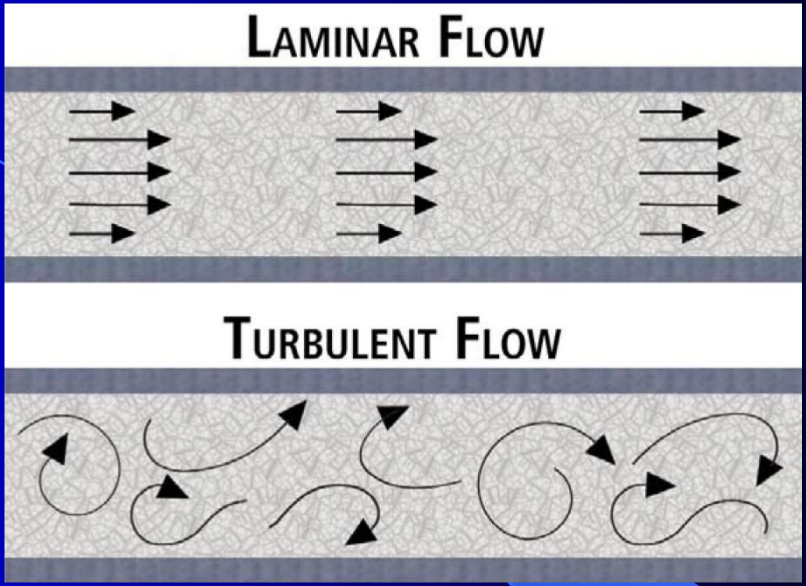


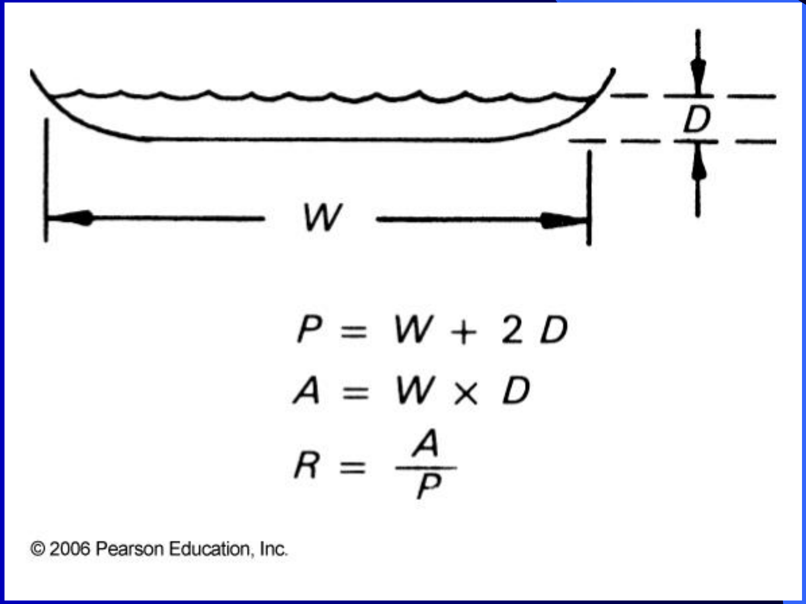
Reynolds Number
Laminar versus turbulent flow

$$Re = \frac{\rho_w v R}{\mu}$$

P_w = density of water (1000 kg/m^3)
v = velocity (m/s)
R = hydraulic radius (m)
μ = dynamic viscosity (for water at 20^{o}C = 1.002 x 10^{-3} Pa s)

	Reynolds Number
Laminar flow	<2000
Unstable flow	2000 – 4000
Turbulent flow	>4000

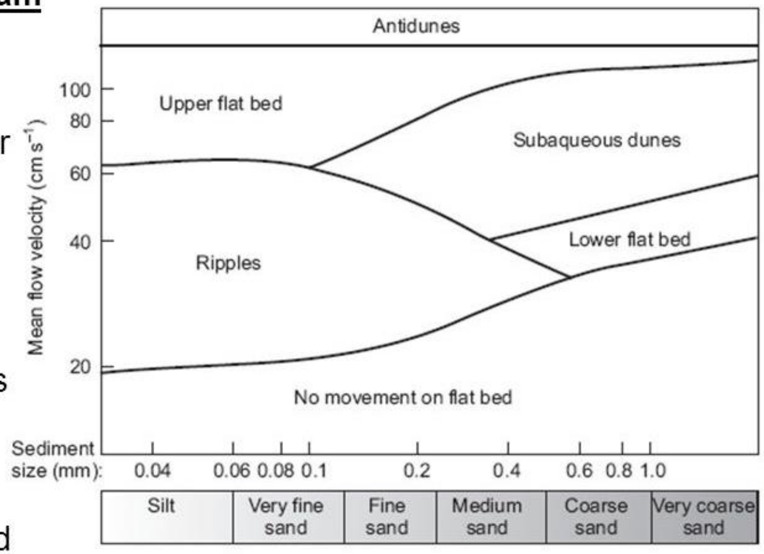




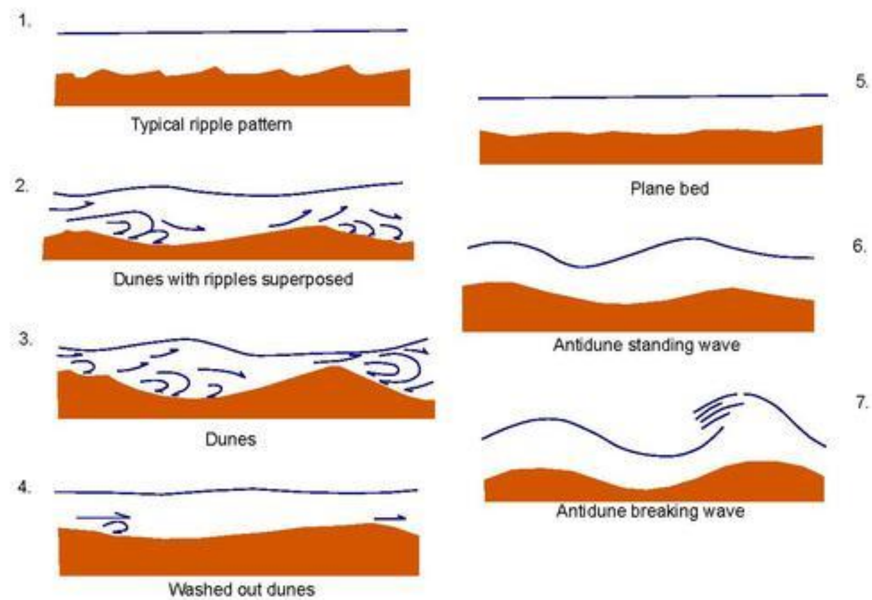
Bedform stability diagram

This bedform stability diagram indicates the bedform that will occur for a given grain size and velocity and has been constructed from experimental data.

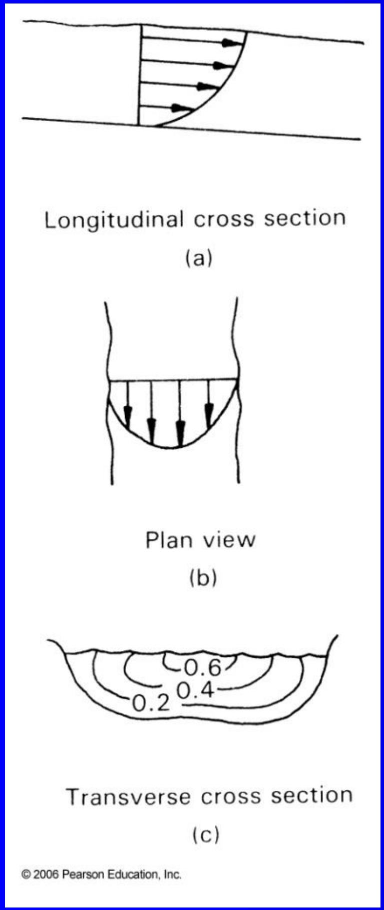
Two general flow regimes are recognised: a lower flow regime in which ripples, dunes and lower plane beds are stable and an upper flow regime where plane beds and antidunes form.

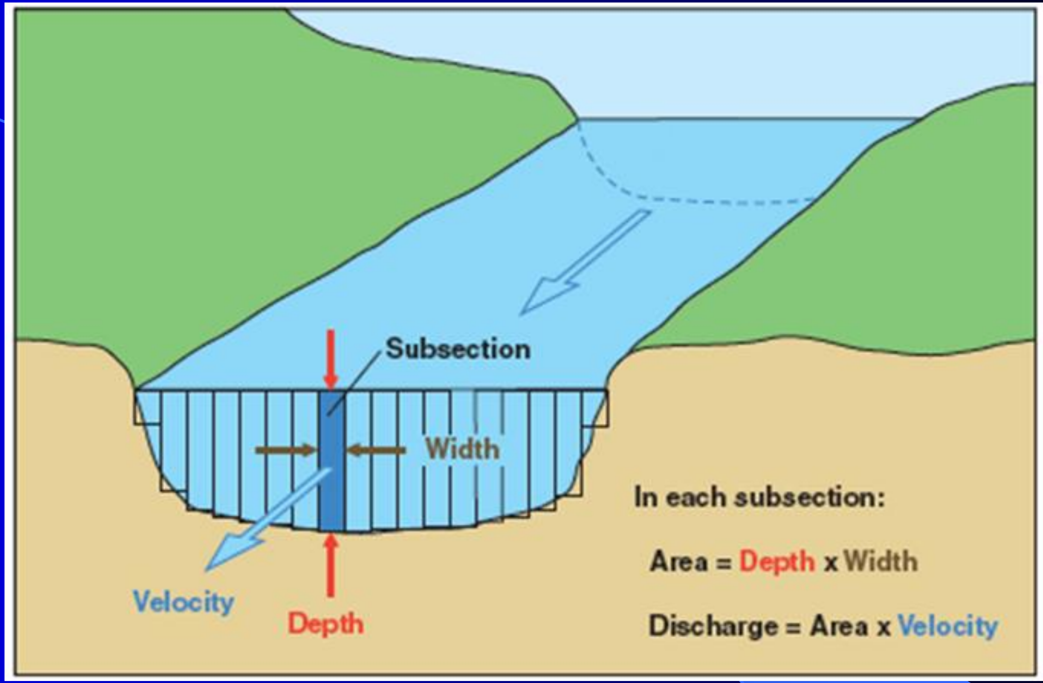


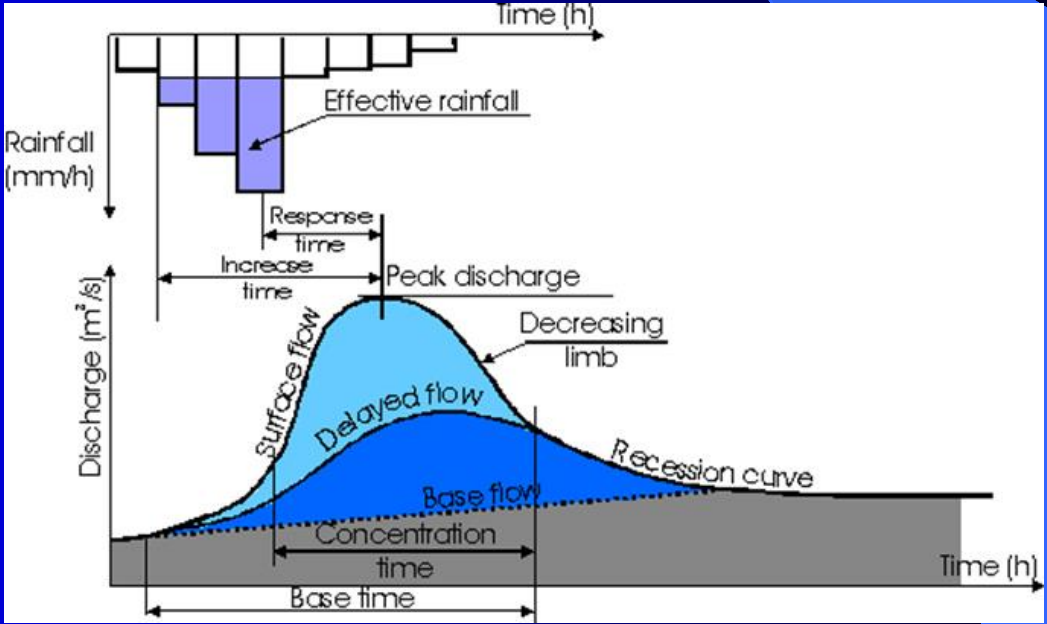
A bedform stability diagram which shows how the type of bedform that is stable varies with both the grain size of the sediment and the velocity of the flow.



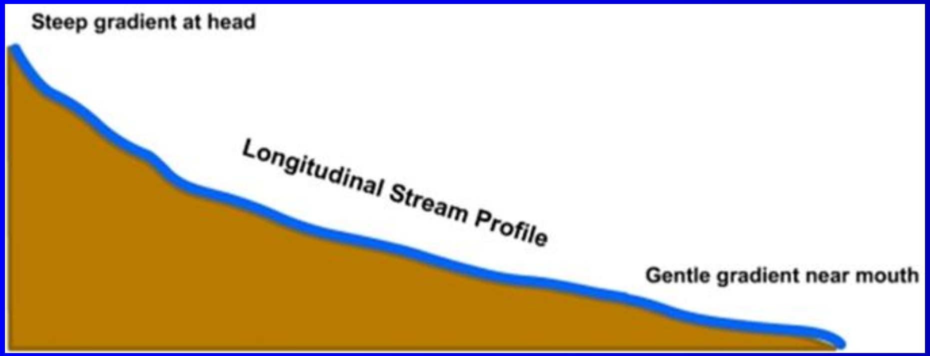
Stream discharge and Velocity

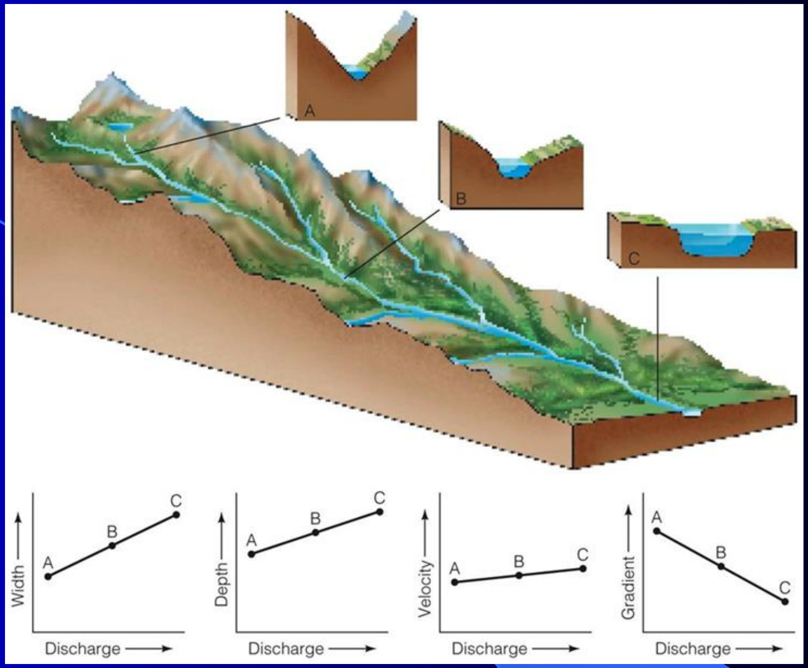


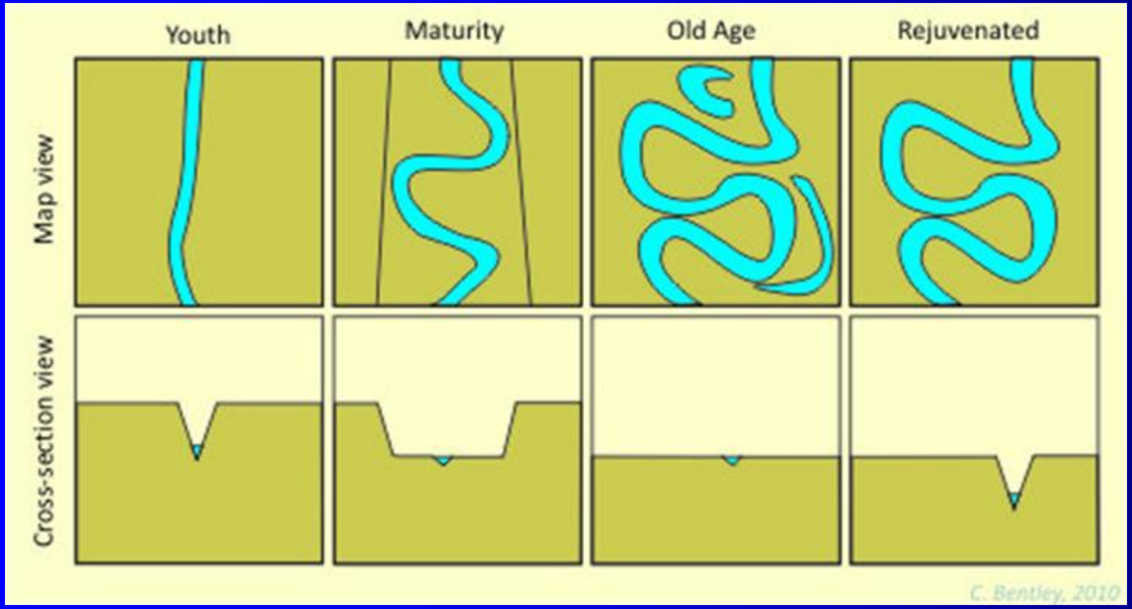




Stream profiles, discharge, and stream maturity





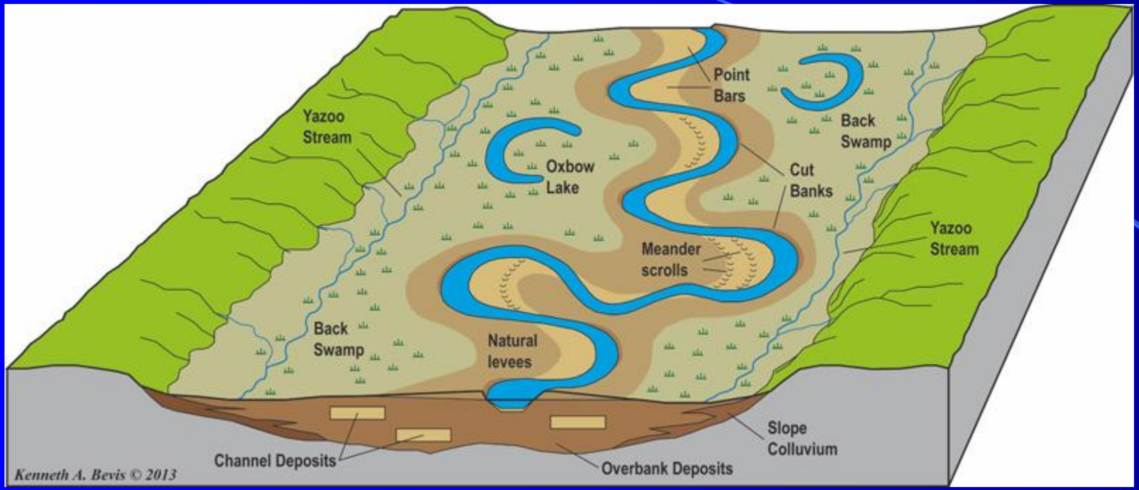


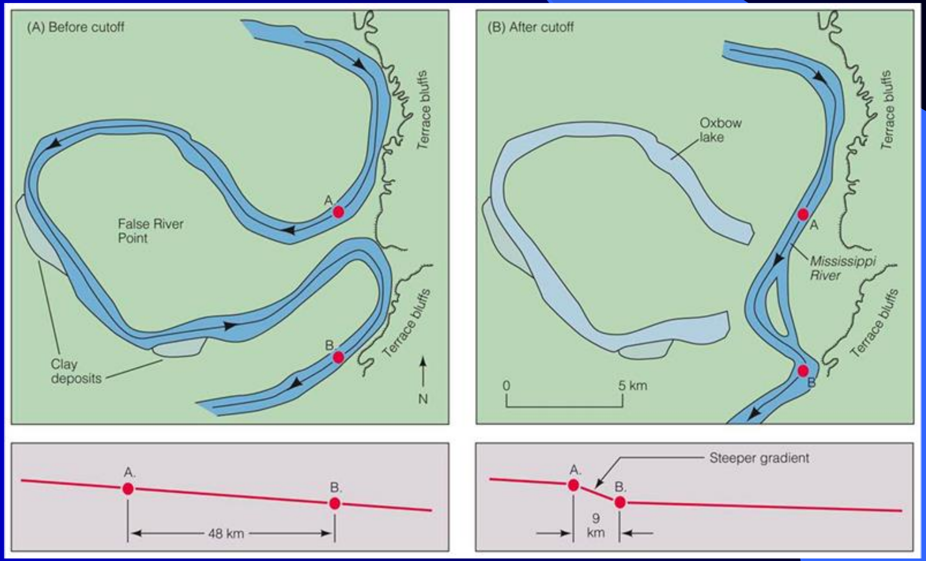
Stream behavior is controlled by 5 basic factors

1. Average channel width and depth
2. Channel gradient
3. Average water velocity
4. Discharge
5. Sediment load

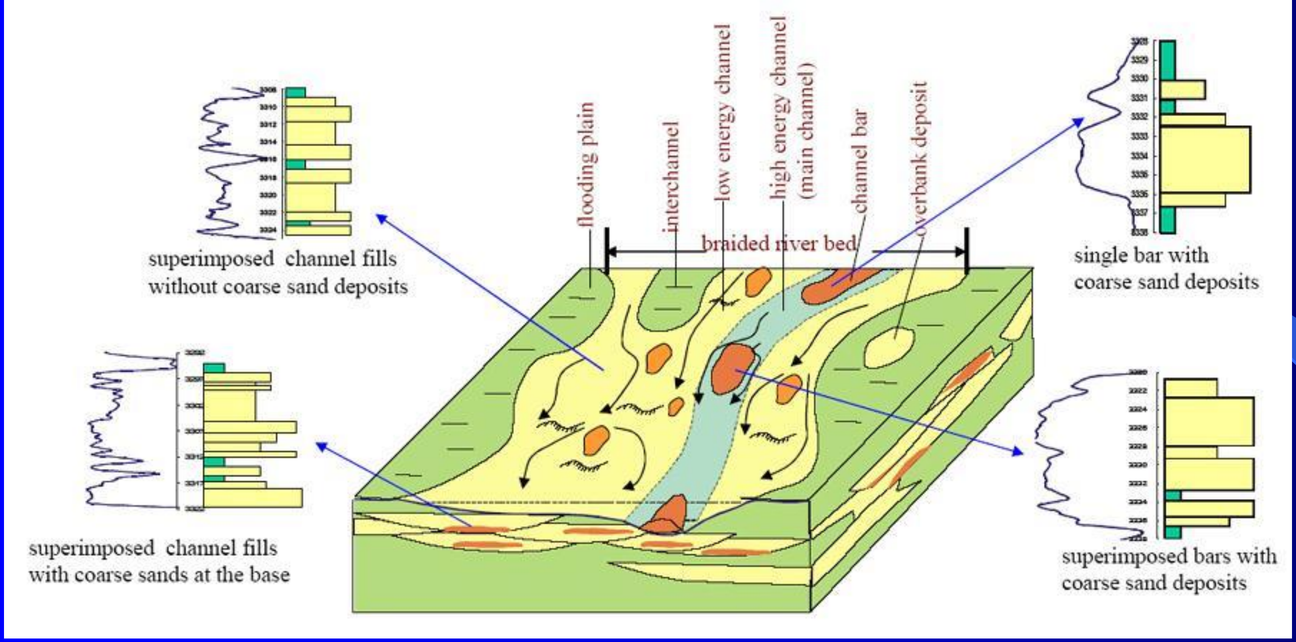
All streams experience a continuous interplay among these factors

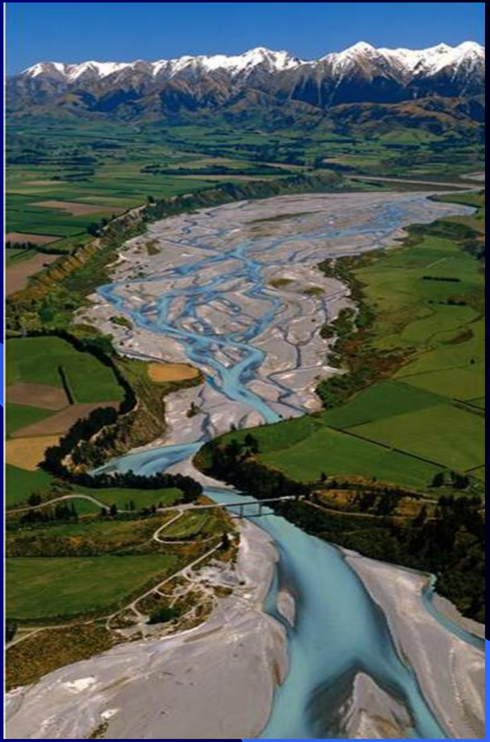
Meandering River



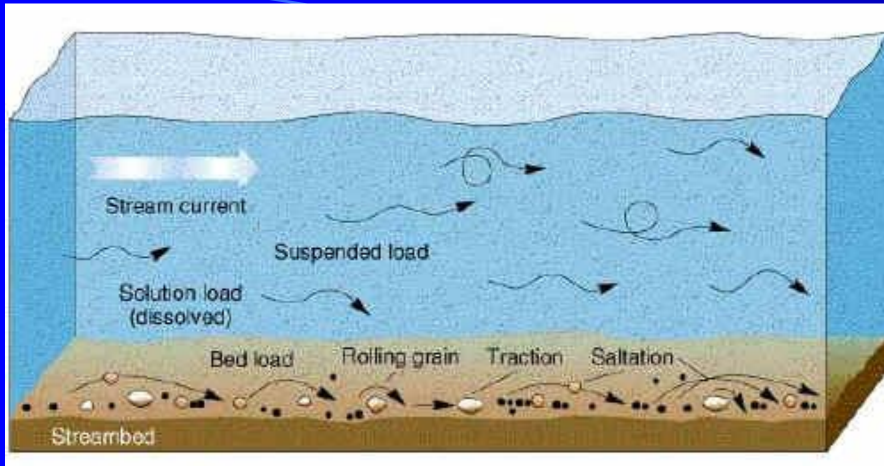


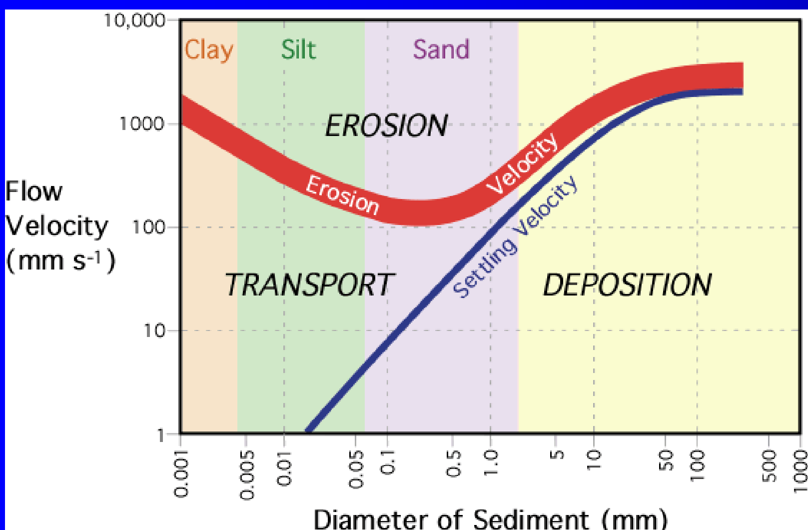
Braided River

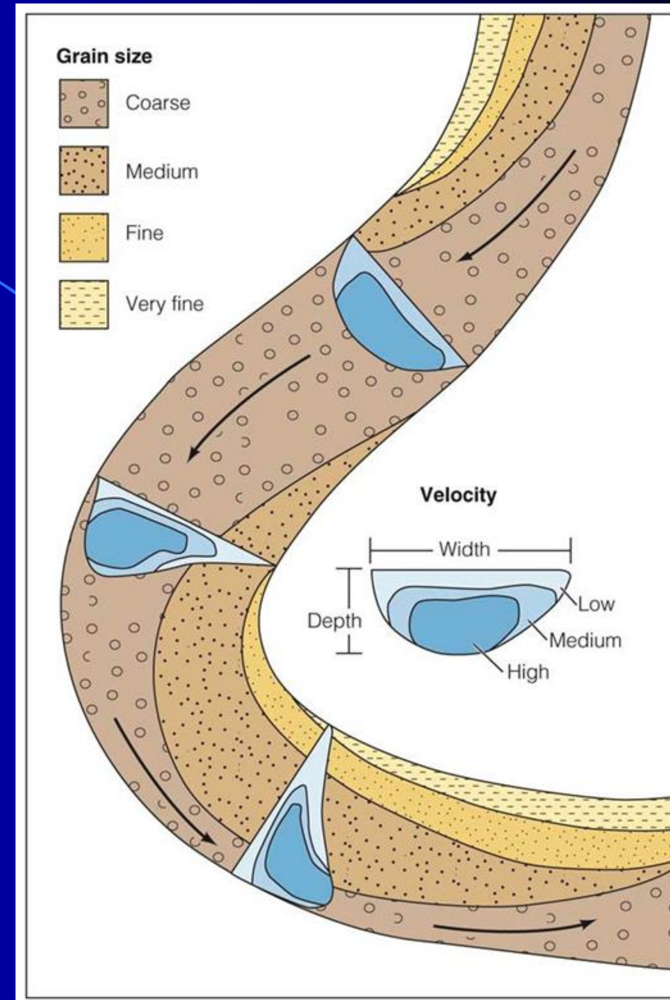


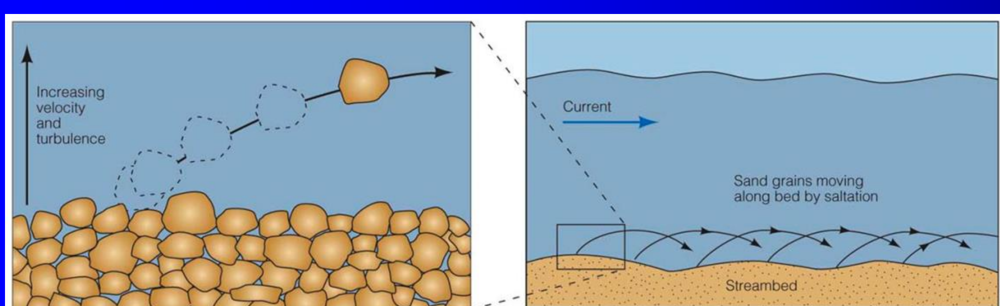


- The size of clasts a stream can transport is mainly related to velocity
- The size of clasts decreases downstream from the rocky headwaters
- A stream's load consists of three parts
  - Bed load
  - 5-50% of total sediment load
  - Move by rolling, sliding, or saltation
  - Suspended load
  - Particles of silt and clay provide the muddy character of many streams
  - Dissolved load
  - Comprised primarily of 7 ions
    - Bicarbonate, calcium, sulfate, chloride, sodium, magnesium, and potassium


Stream current
Suspended load
Solution load (dissolved)
Bed load
Rolling grain
Traction
Saltation
Streambed


Clay
Silt
Sand
EROSION
TRANSPORT
DEPOSITION
Erosion Velocity
Settling Velocity
Flow Velocity (mm s-1)
10,000
1000
100
10
1
0.001
0.005
0.01
0.05
0.1
0.5
1.0
5
10
50
100
500
1000
Diameter of Sediment (mm)


Grain size
Coarse
Medium
Fine
Very fine
Velocity
Width
Depth
Low
Medium
High


Increasing velocity and turbulence
Current
Sand grains moving along bed by saltation
Streambed

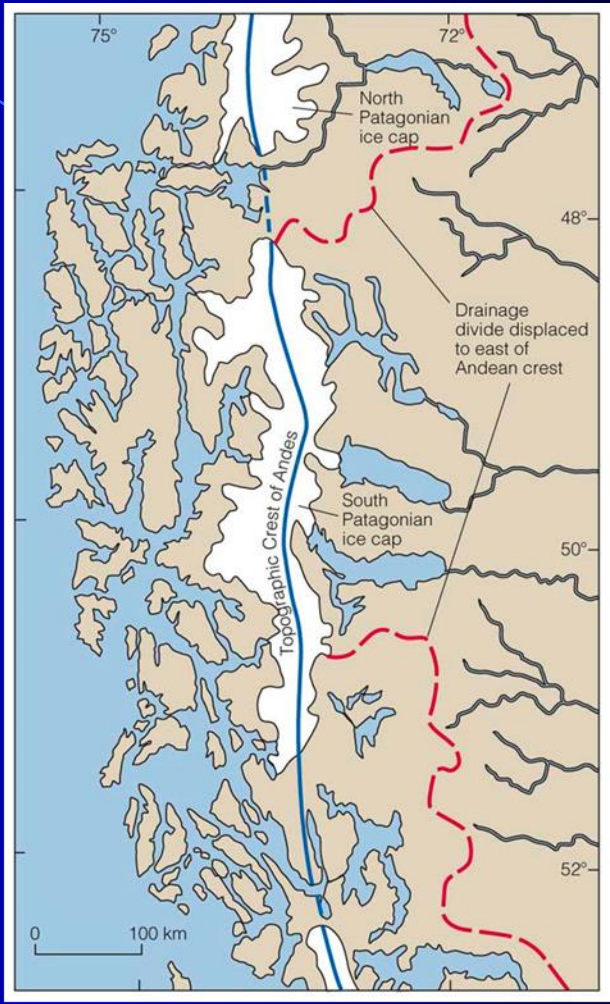
Streams form three major depositional landforms

Floodplain: deposition of fine sediment beyond natural levees during a flood

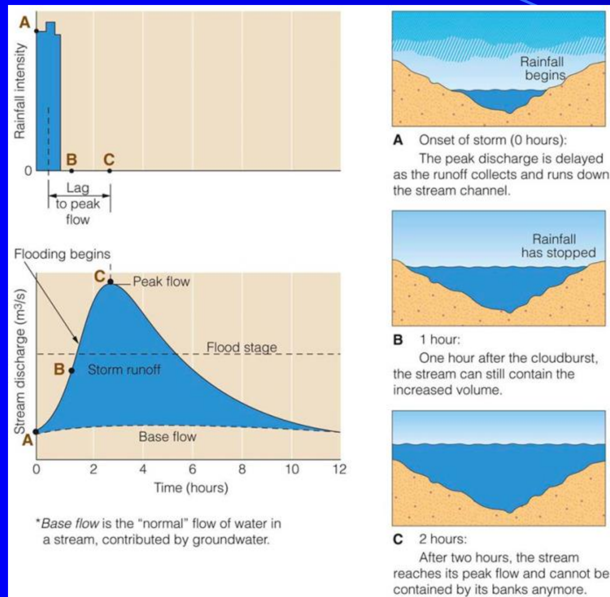
Alluvial fan: a fan-shaped body of alluvium at the base of an upland area

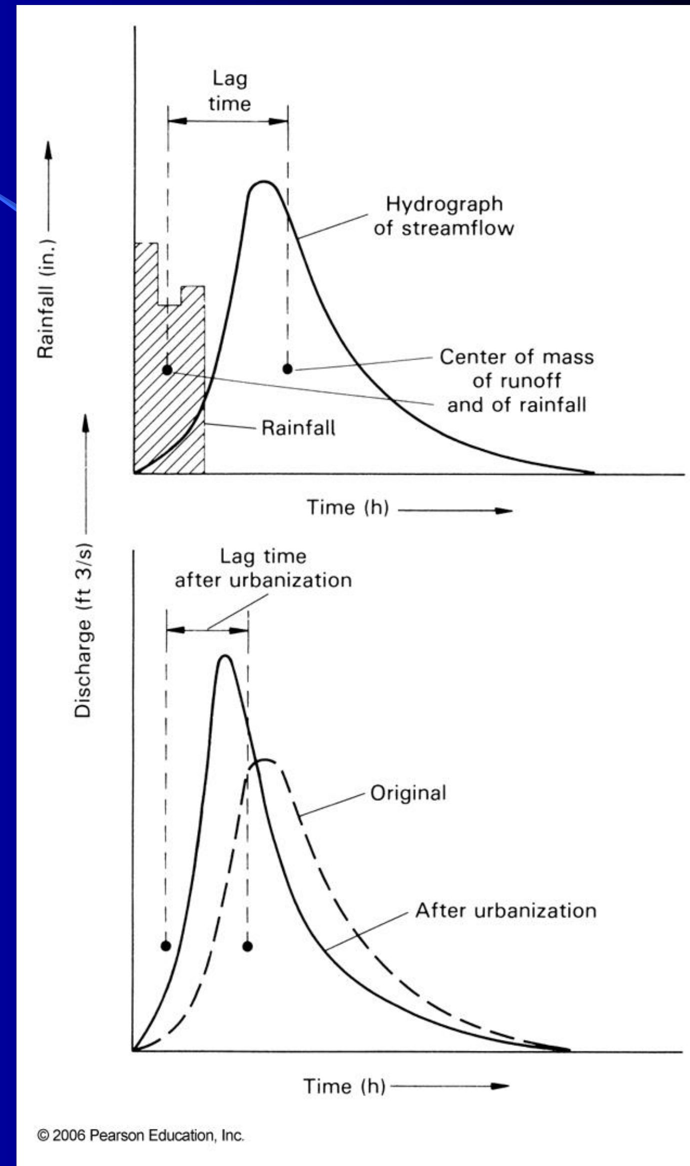
Delta: triangular shaped deposit formed when a stream enters the standing water of a sea or lake

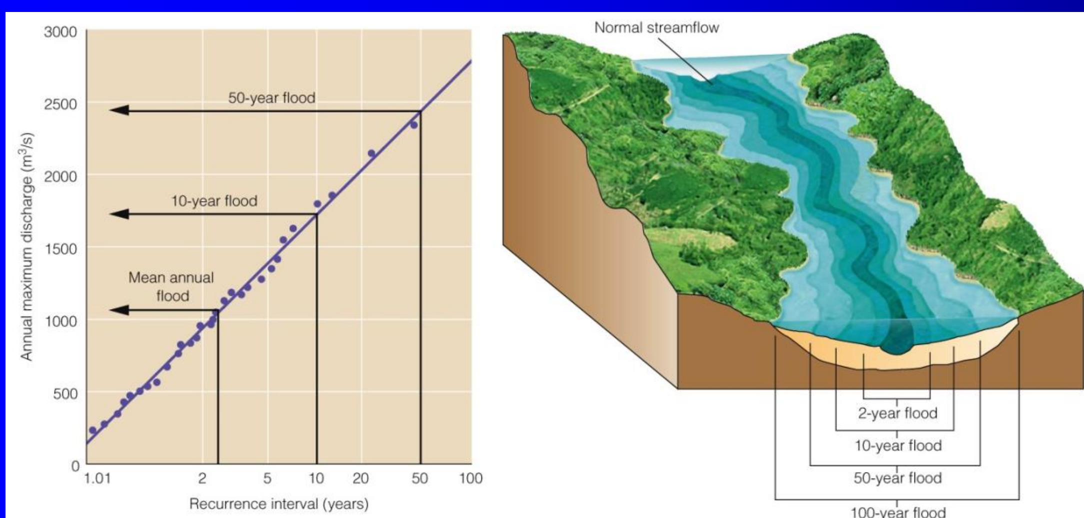
Continental Divides

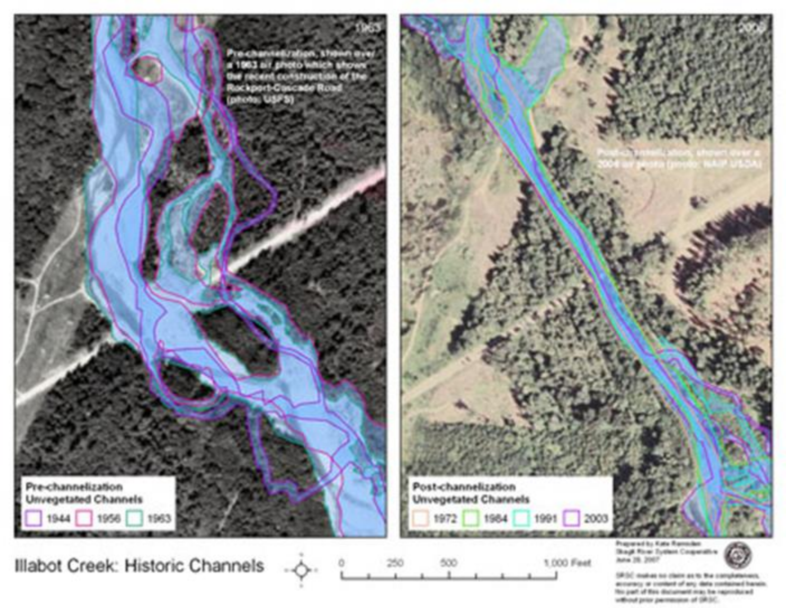


Flooding and Flood control

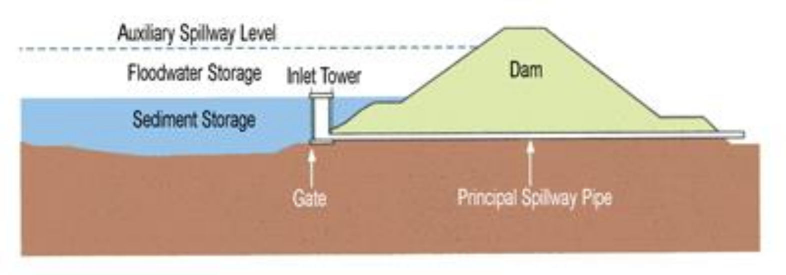






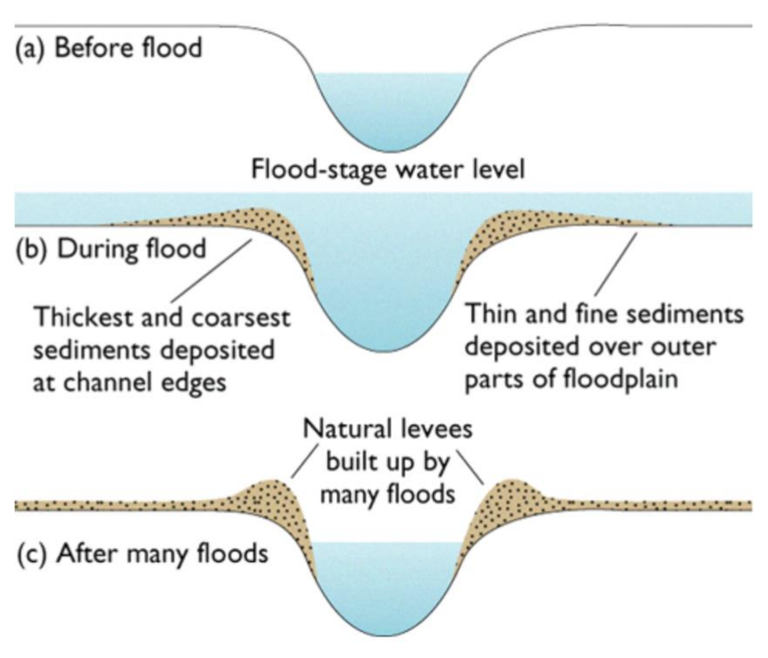


Channelization

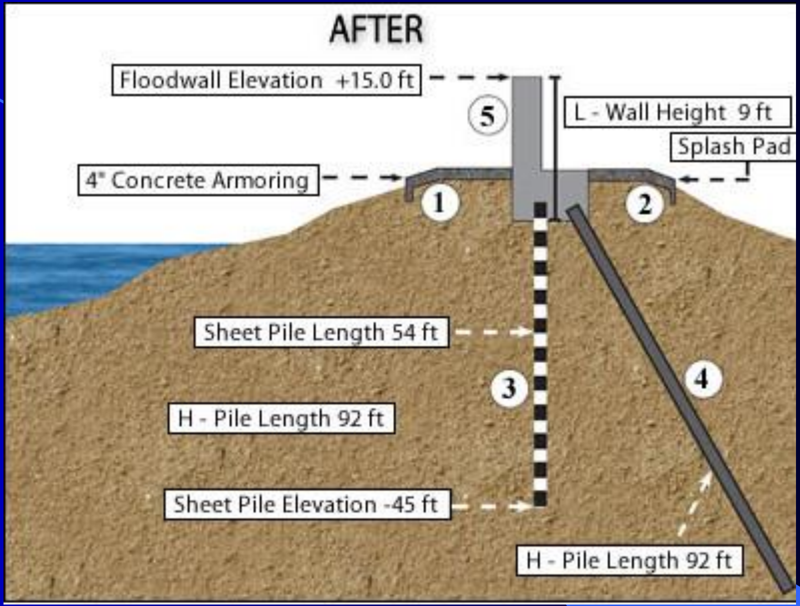


Dams

Levees



(a) Before flood
Flood-stage water level
(b) During flood
Thickest and coarsest sediments deposited at channel edges
Thin and fine sediments deposited over outer parts of floodplain
Natural levees built up by many floods
(c) After many floods

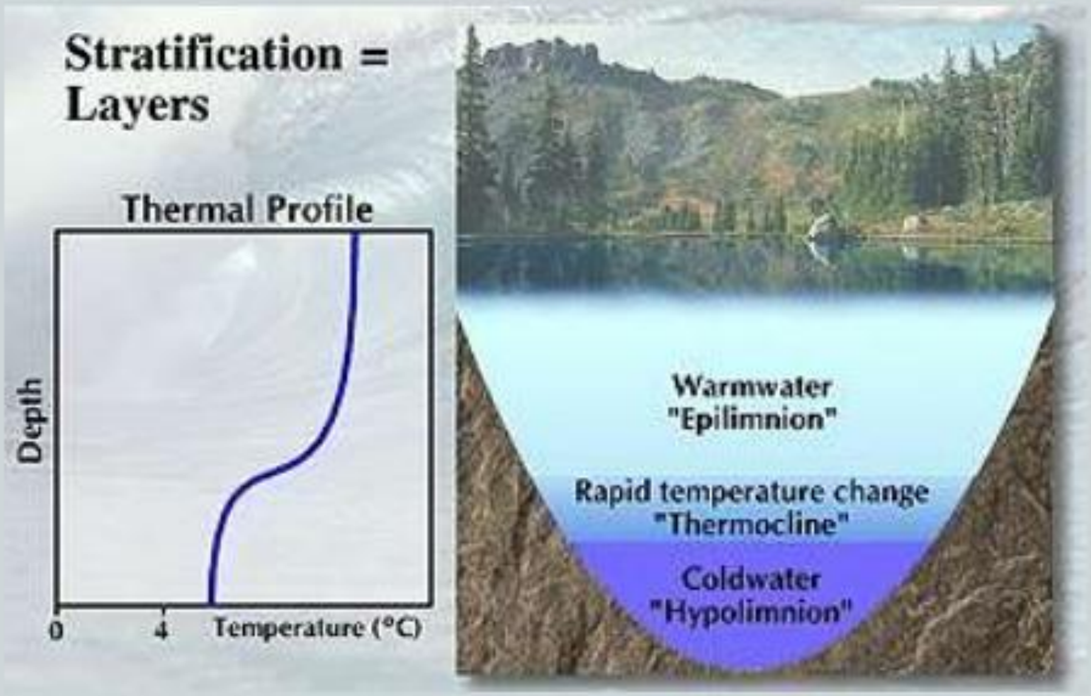


AFTER
Floodwall Elevation +15.0 ft
L - Wall Height 9 ft
Splash Pad
4" Concrete Armoring
Sheet Pile Length 54 ft
H - Pile Length 92 ft
Sheet Pile Elevation -45 ft
H - Pile Length 92 ft
1
2
3
4
5

Lakes

Lentic Ecosystems

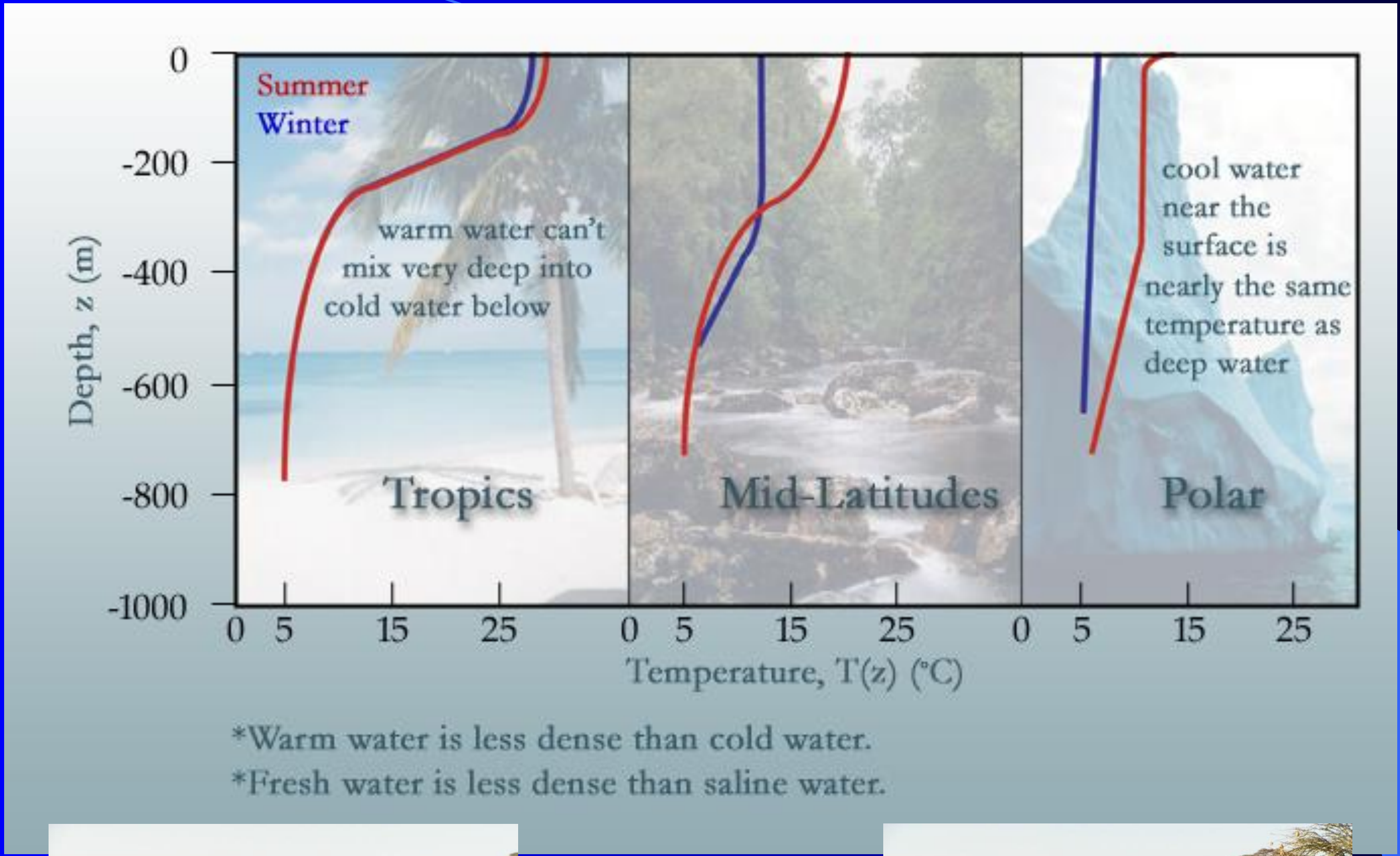
In temperate regions, lakes often become thermally stratified during summer and again in winter



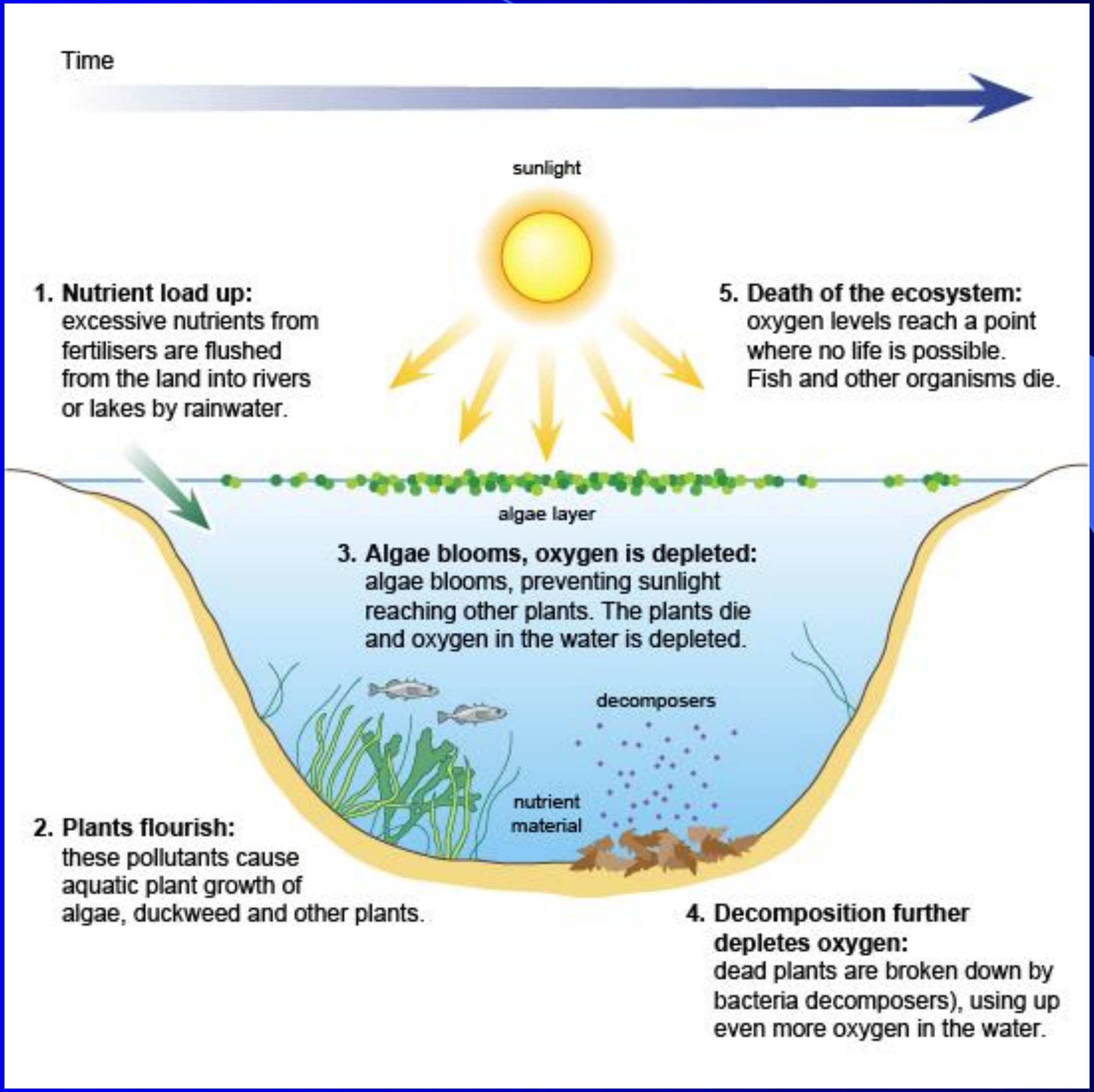
During spring and fall, the entire body of water approaches the same temperature, mixing occurs, occurs. Blooms of phytoplankton's often follow these turnovers, as nutrients from the bottom become available in the photic zone.

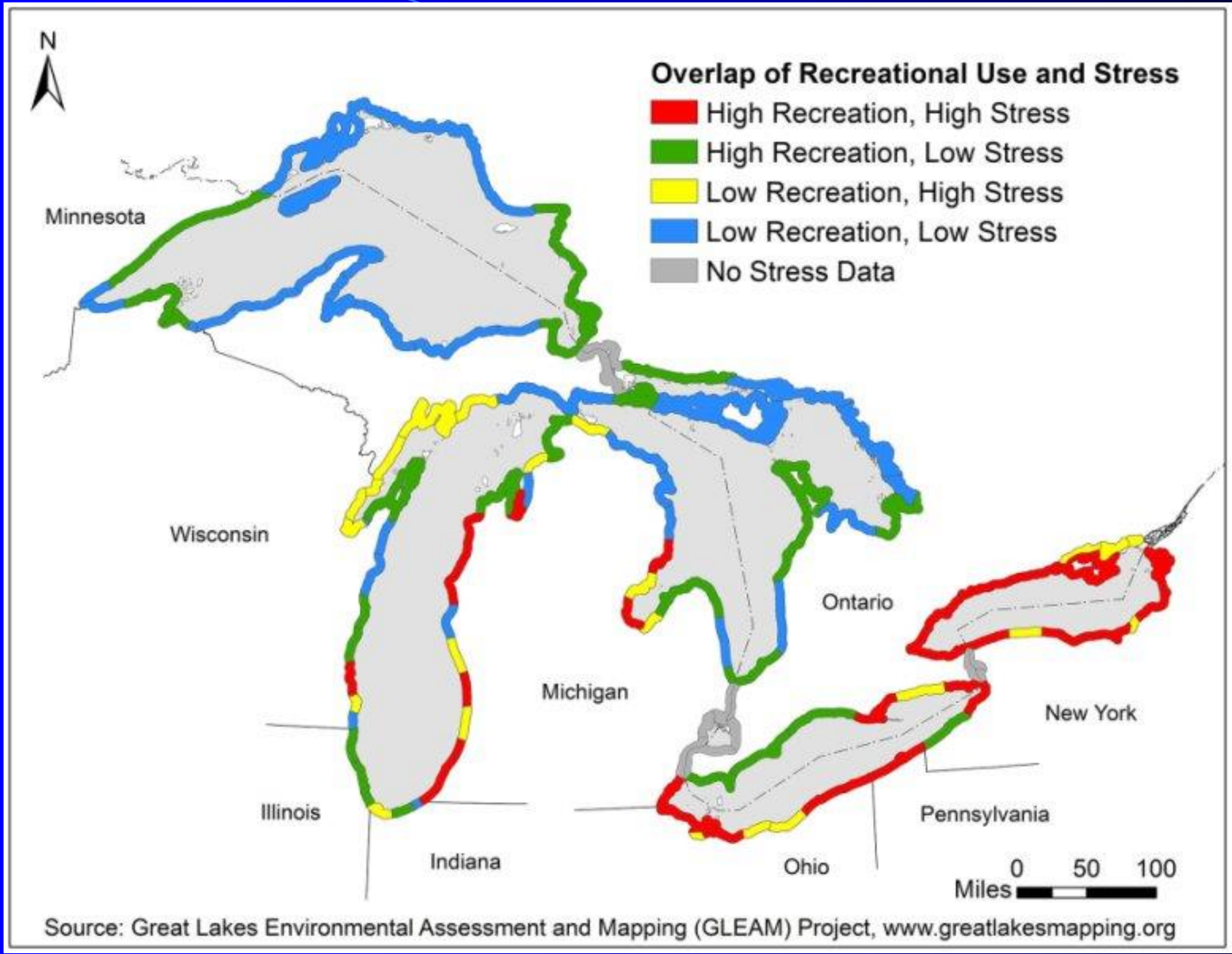
Photic zone is the lighted portion of a lake inhabited by phytoplankton

Seasonal thermal structure of lakes as a function of latitude

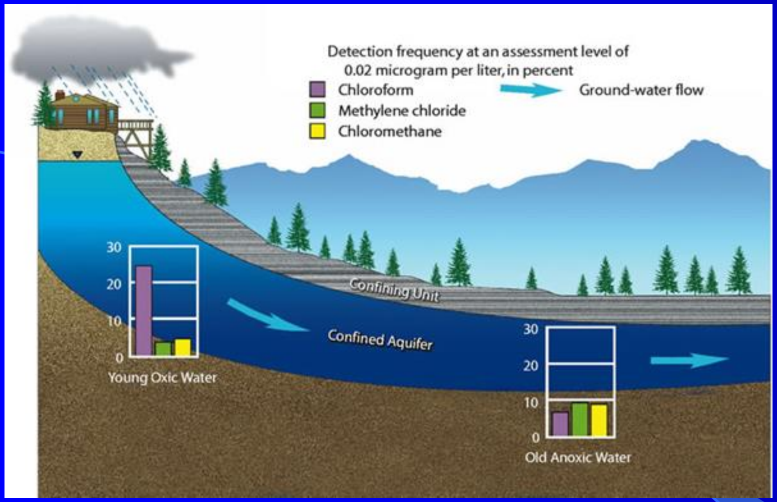


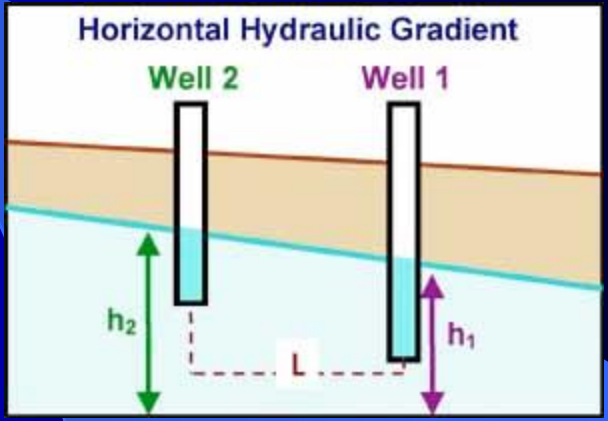
Why do we care about the seasonal variation in temperature = Eutrophication



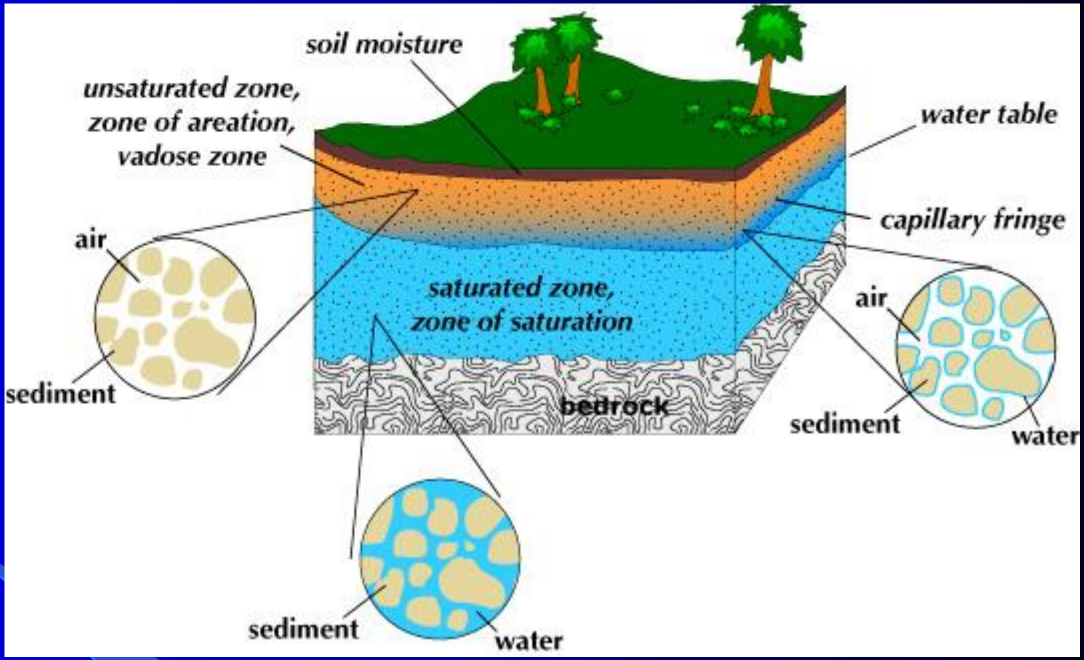

N
Overlap of Recreational Use and Stress
High Recreation, High Stress
High Recreation, Low Stress
Low Recreation, High Stress
Low Recreation, Low Stress
No Stress Data
Minnesota
Wisconsin
Michigan
Ontario
New York
Pennsylvania
Illinois
Indiana
Ohio
0 50 100
Miles
Source: Great Lakes Environmental Assessment and Mapping (GLEAM) Project, www.greatlakesmapping.org

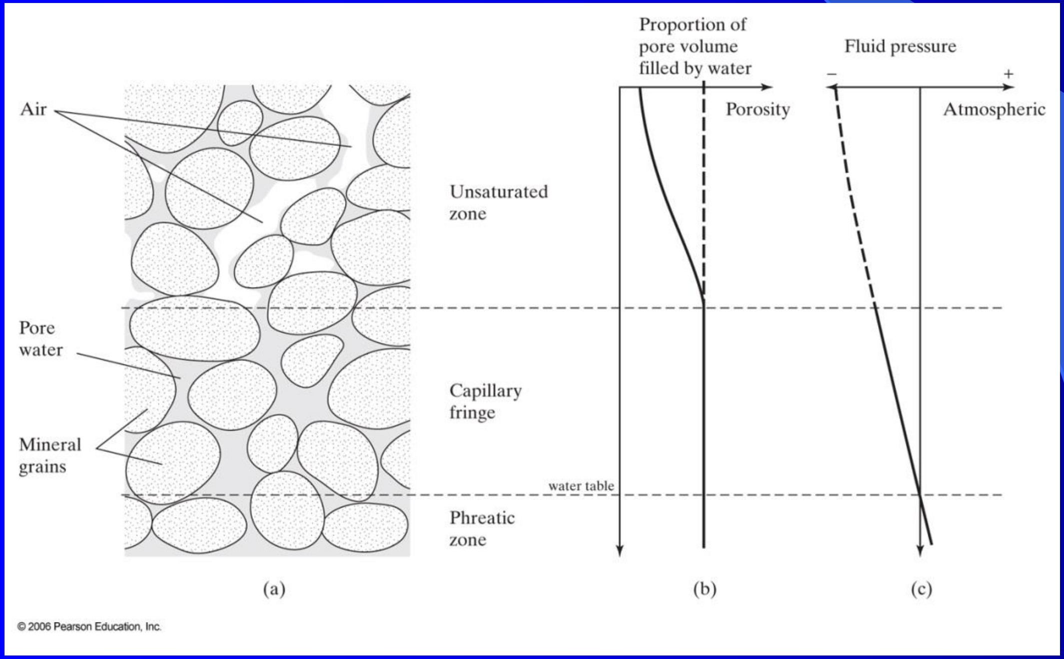
Groundwater



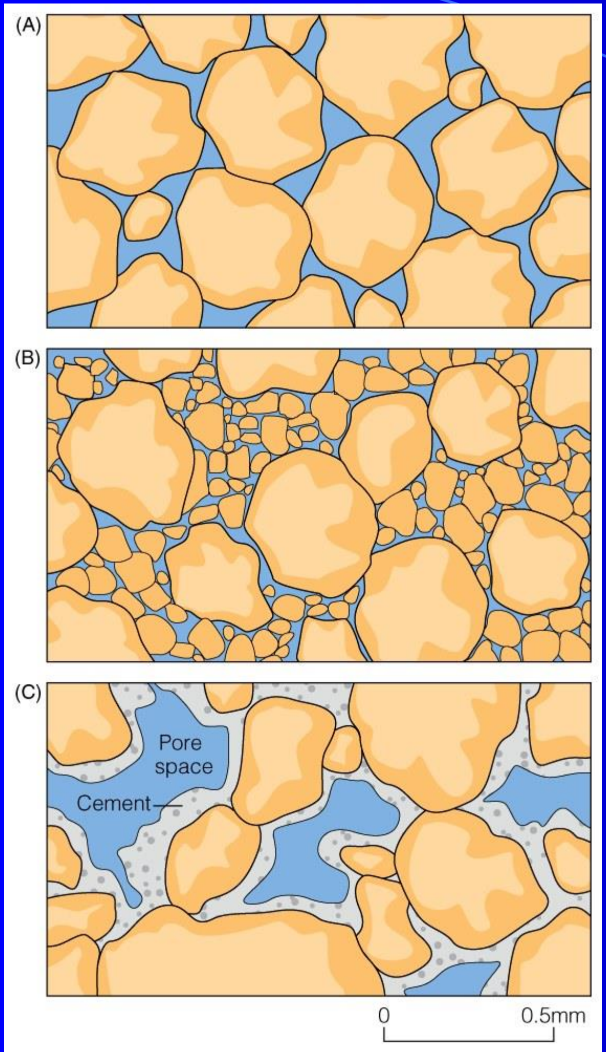


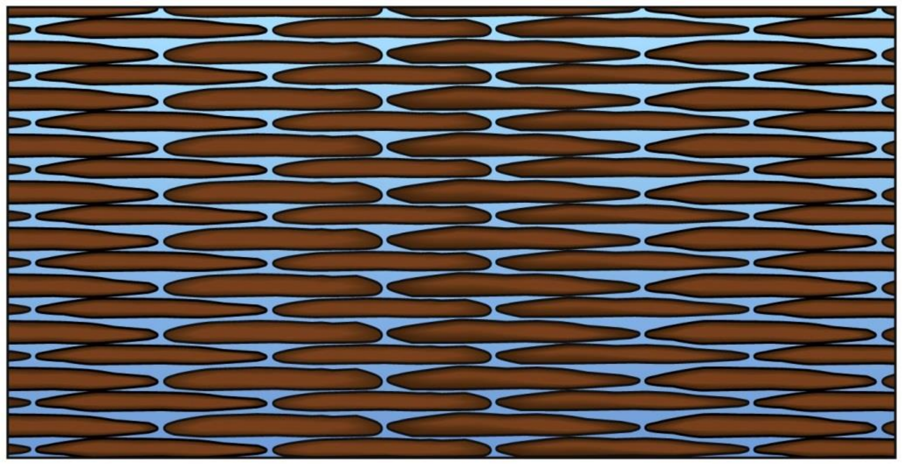
The Water Table



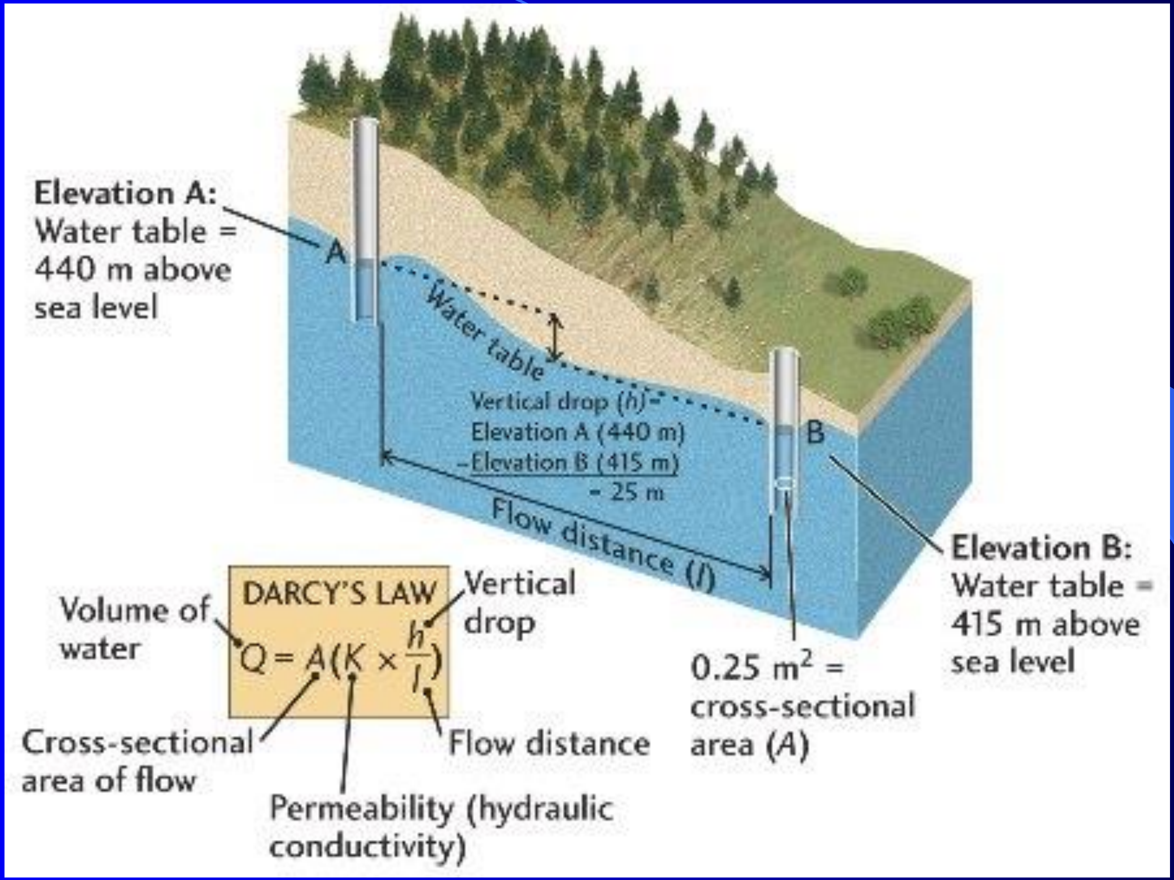


Porosity and permeability

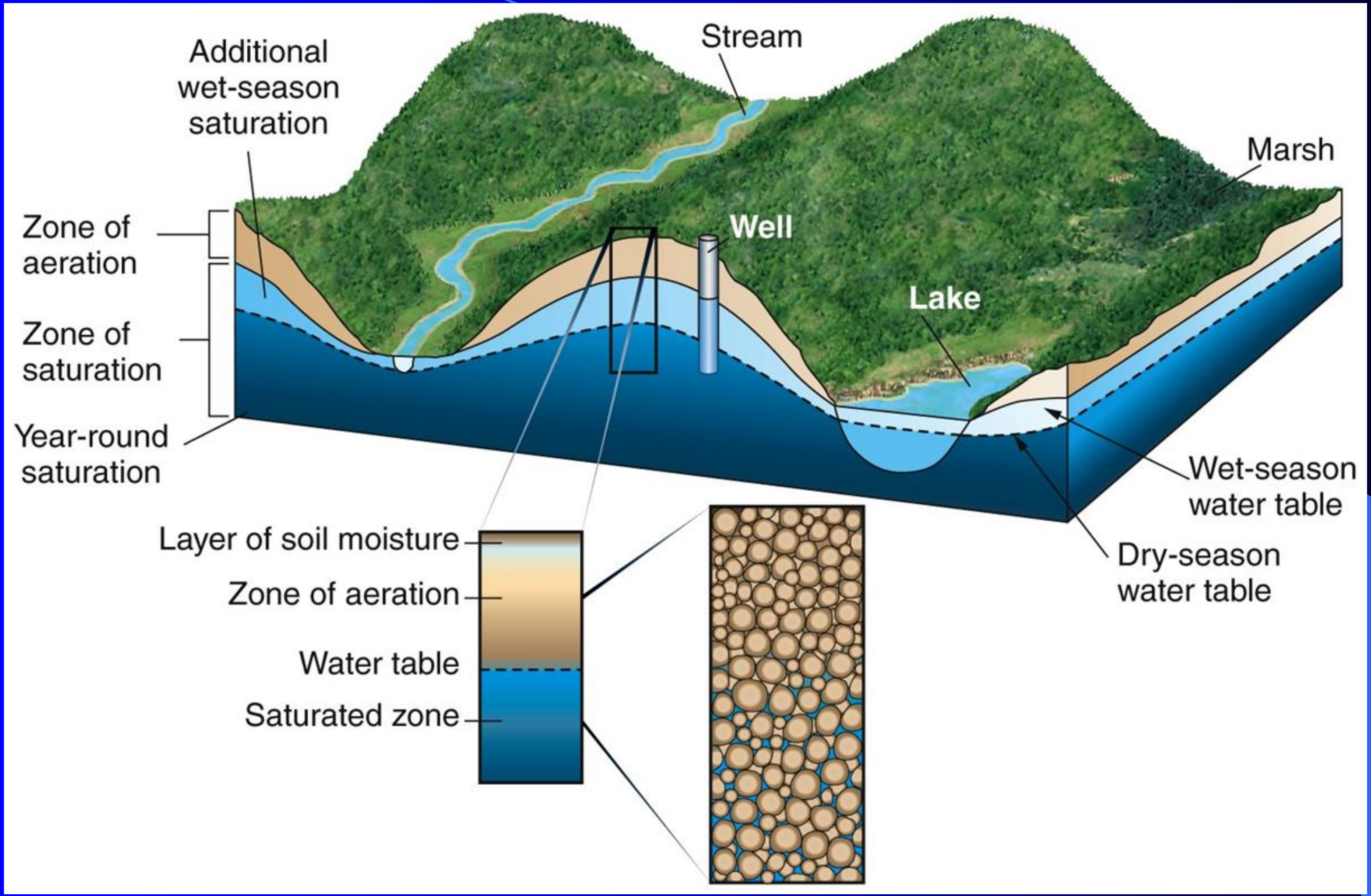




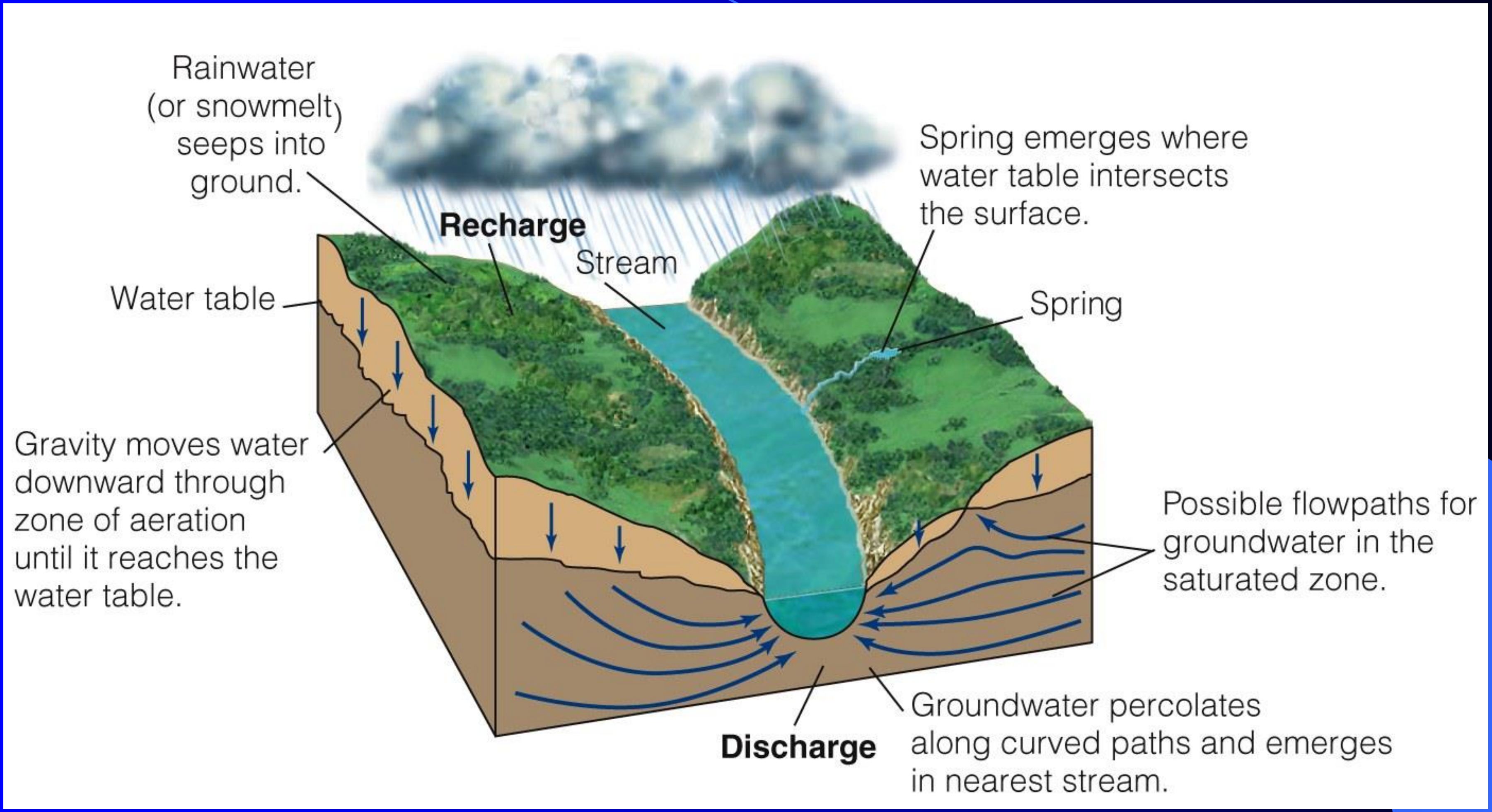
Darcy's Law



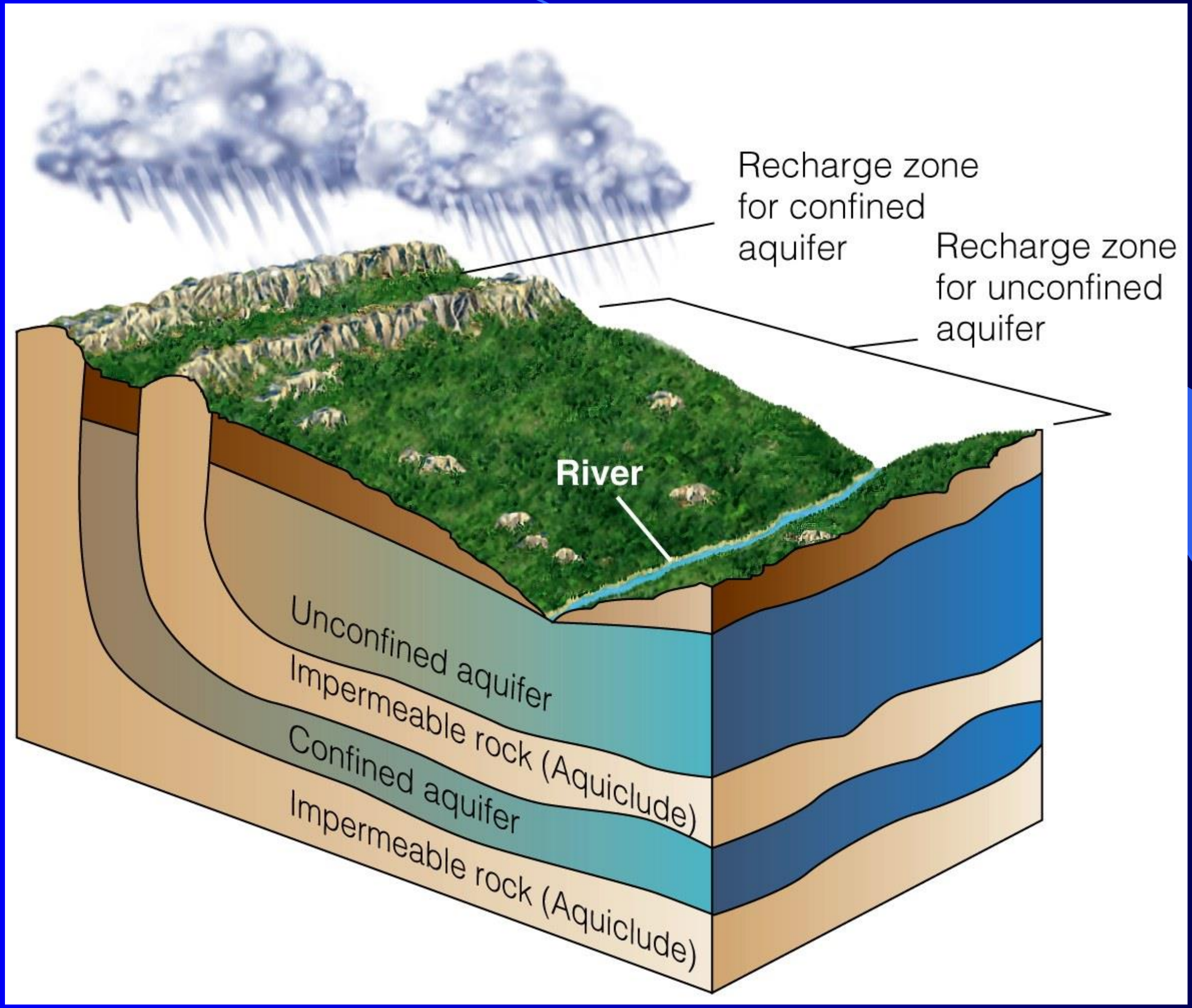
Elevation A:
Water table =
440 m above
sea level
A
Water table
Vertical drop (h) =
Elevation A (440 m)
– Elevation B (415 m)
= 25 m
Flow distance (l)
B
Elevation B:
Water table =
415 m above
sea level
DARCY'S LAW
$Q = A(K \times \frac{h}{l})$
Volume of
water
Vertical
drop
Cross-sectional
area of flow
Permeability (hydraulic
conductivity)
Flow distance
0.25 m² =
cross-sectional
area (A)


Additional wet-season saturation
Stream
Marsh
Zone of aeration
Well
Lake
Zone of saturation
Year-round saturation
Wet-season water table
Dry-season water table
Layer of soil moisture
Zone of aeration
Water table
Saturated zone

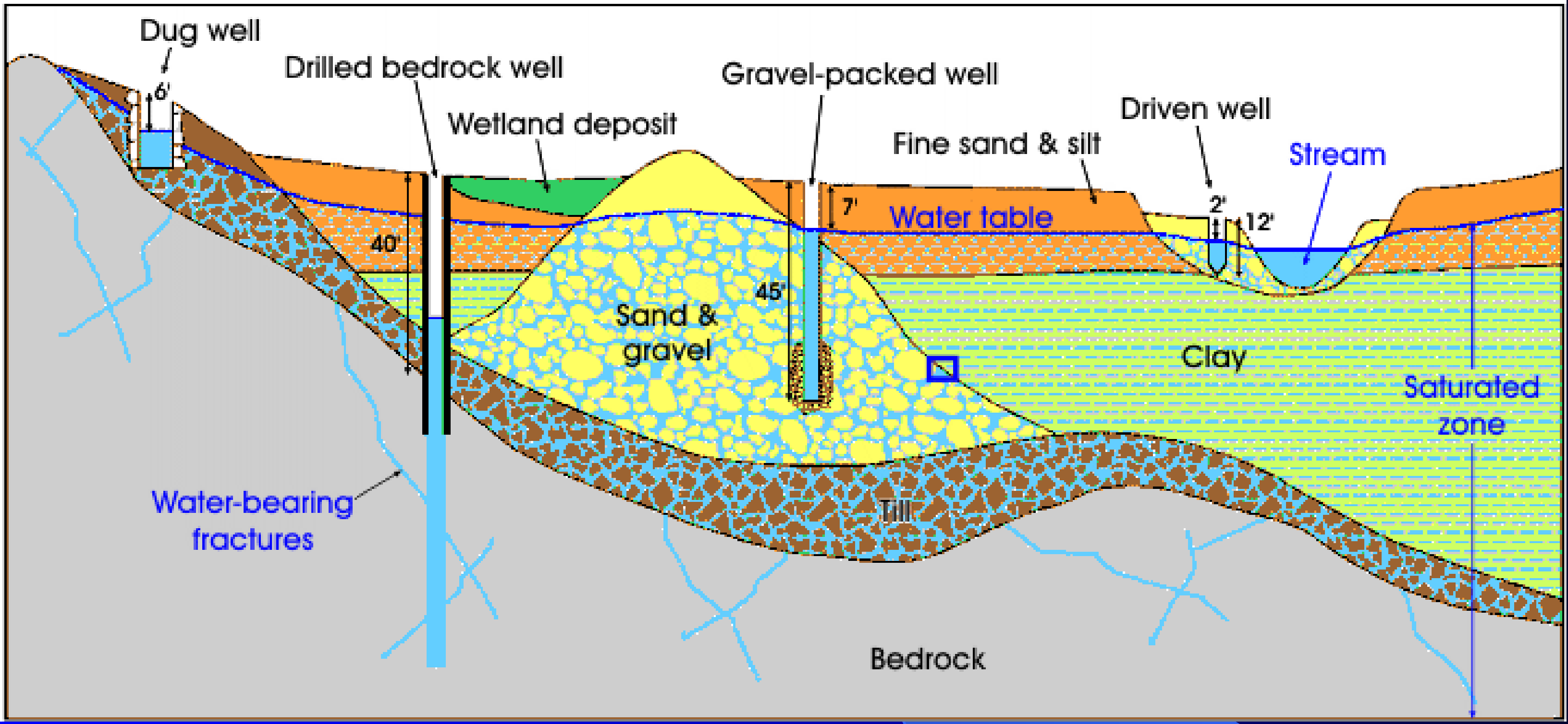
Groundwater Recharge



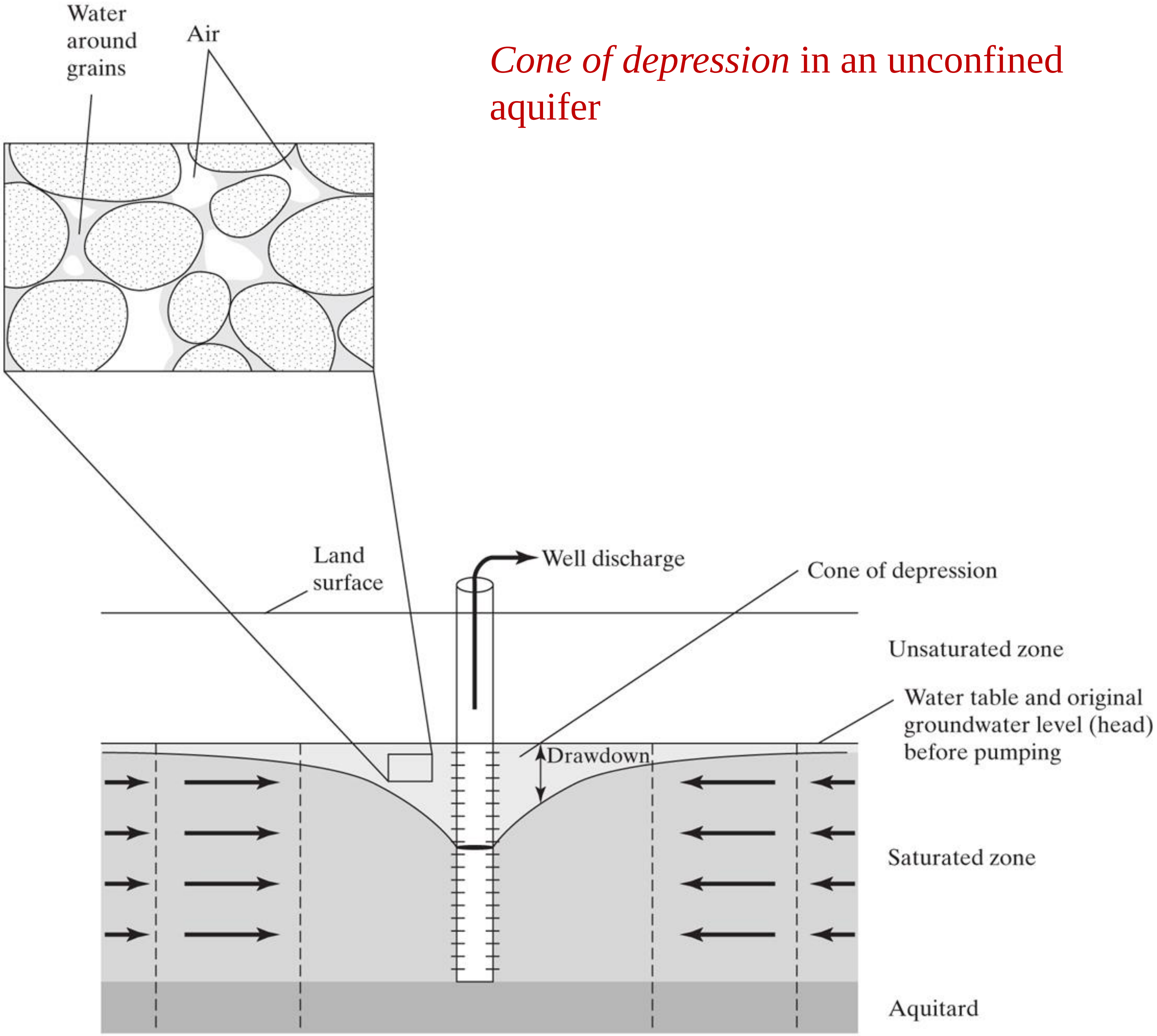
Artesian Aquifer



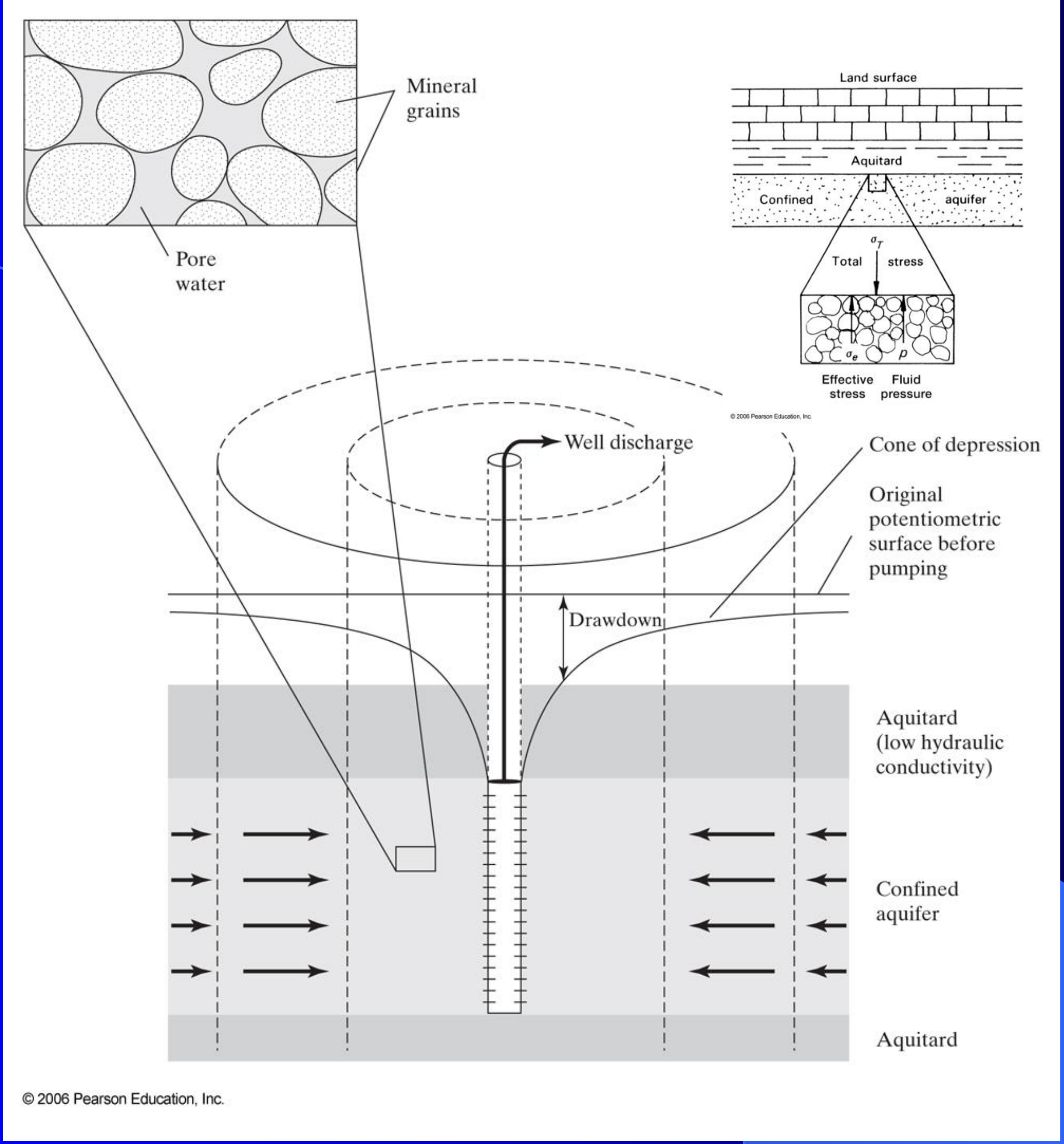
Typical New England Aquifer



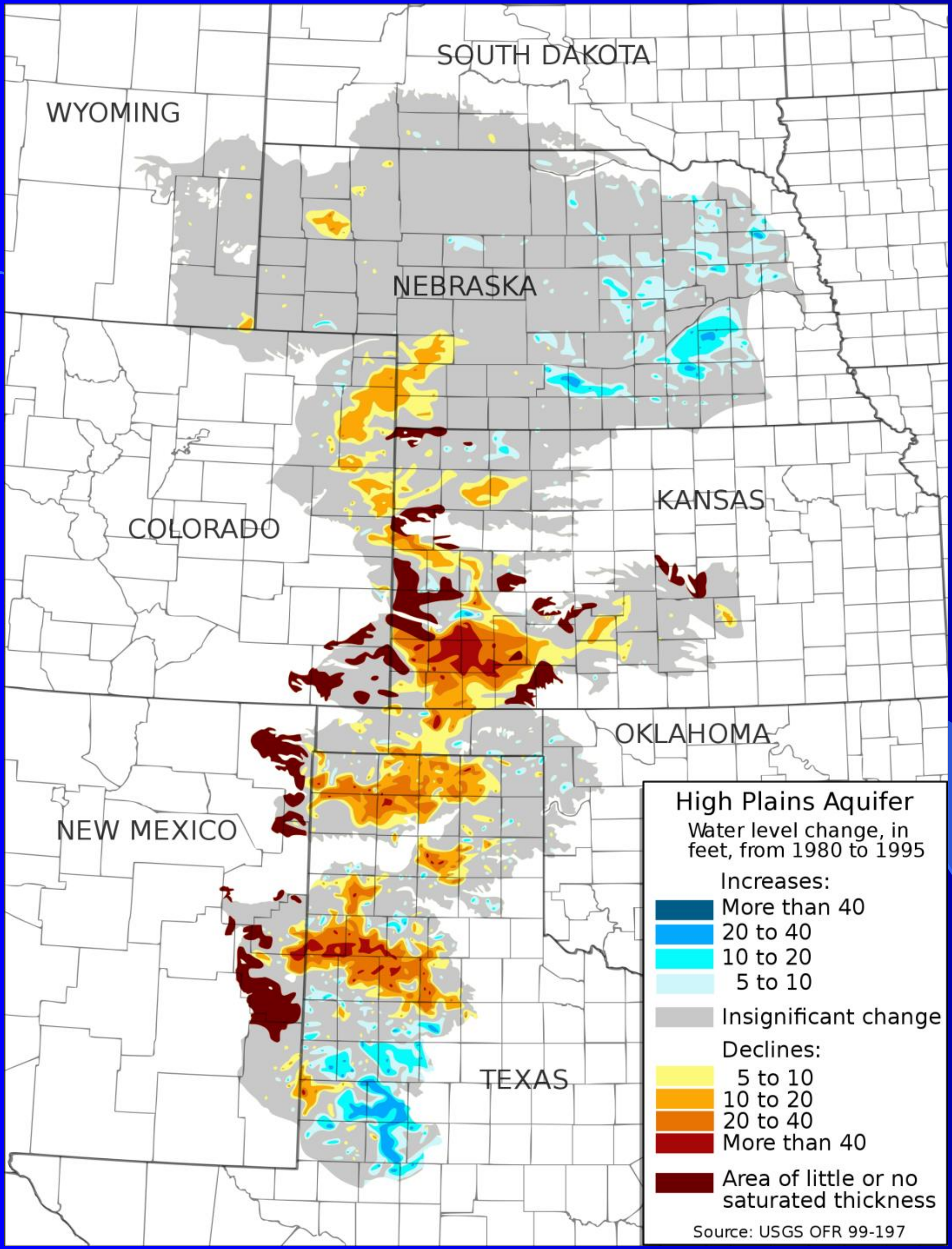
Cone of depression in an unconfined aquifer

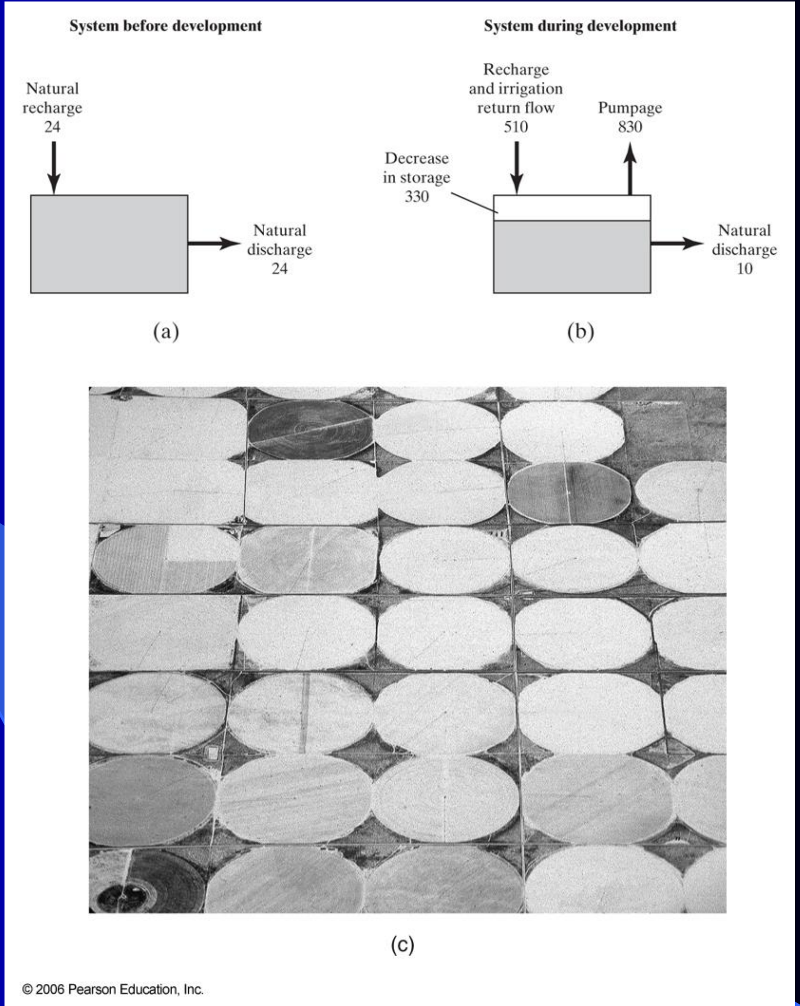


Cone of depression in a confined aquifer and effective stress

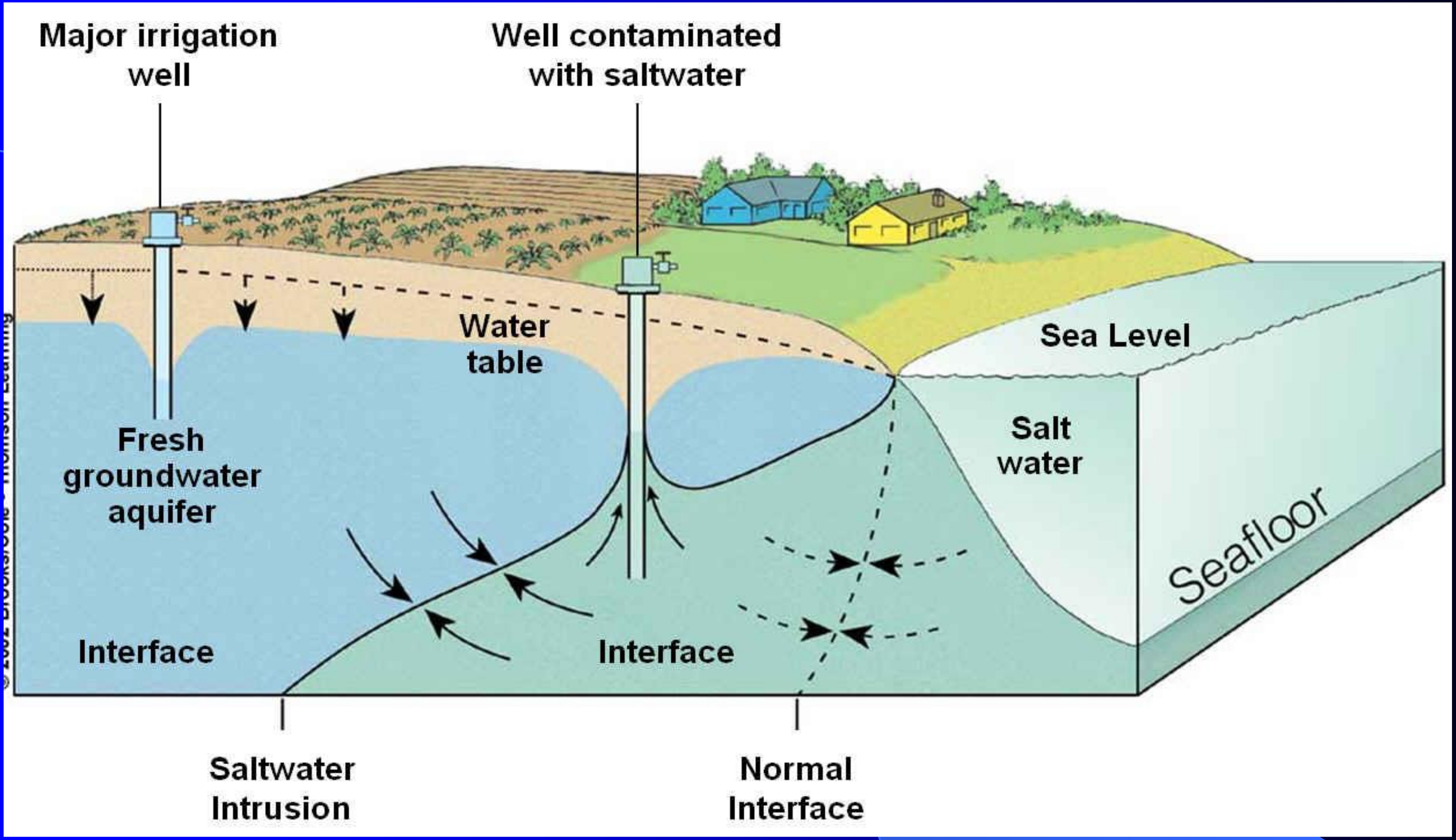


Resource sustainability – withdrawals from the High Plains aquifer

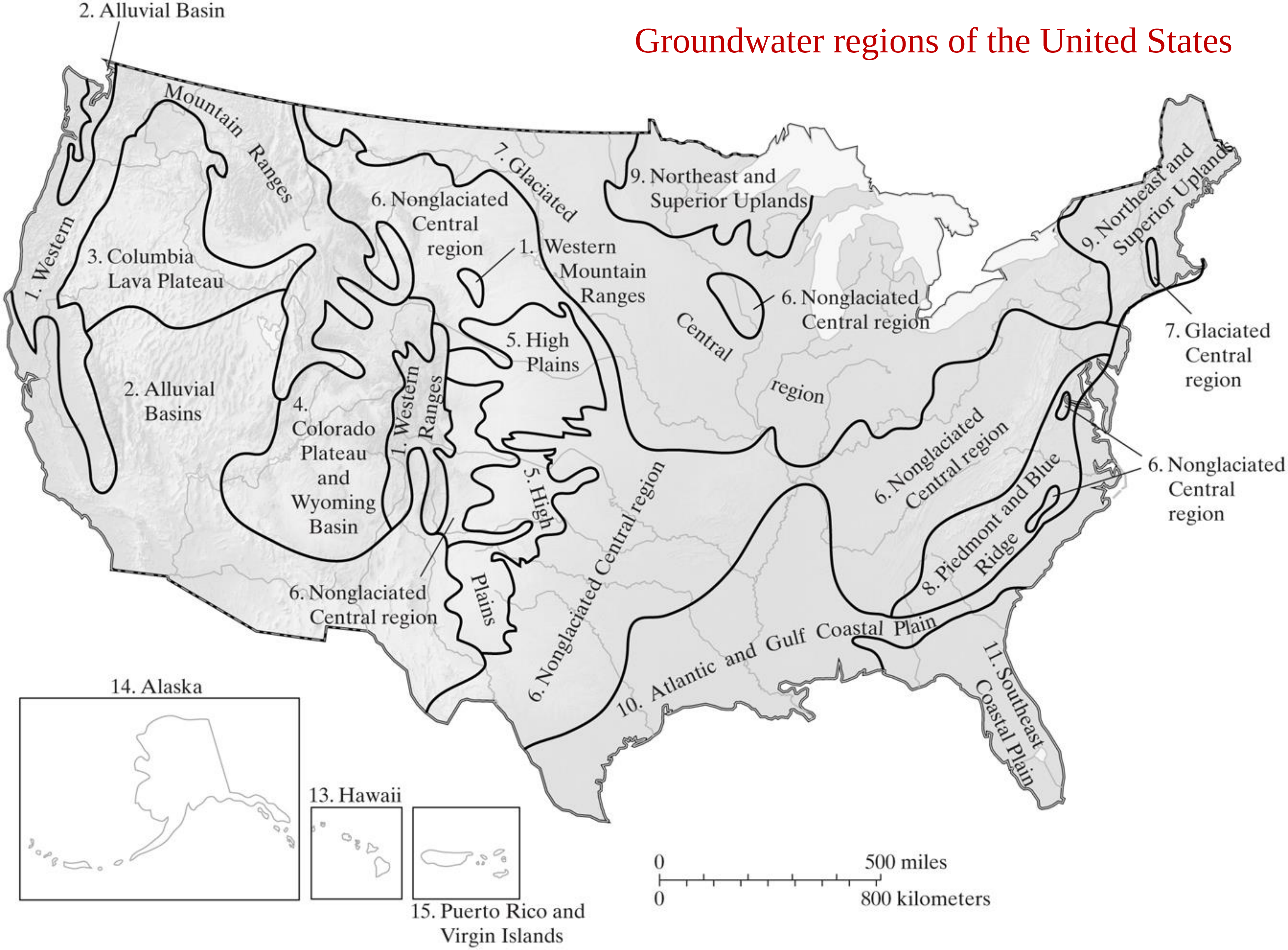




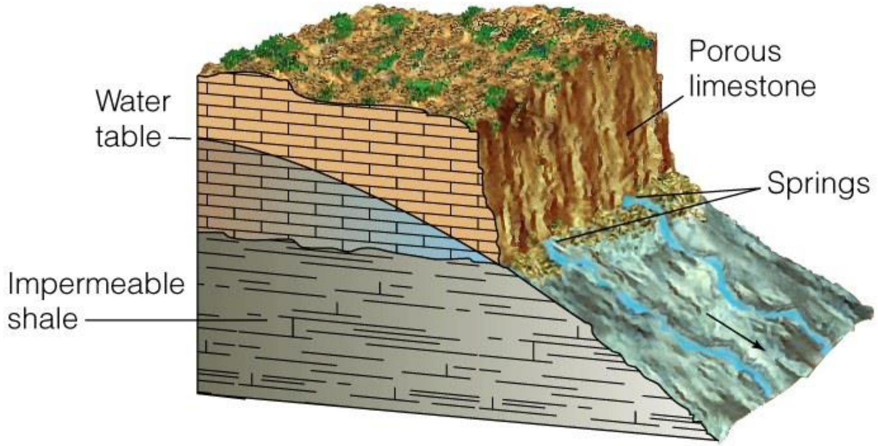
Salt water incursion



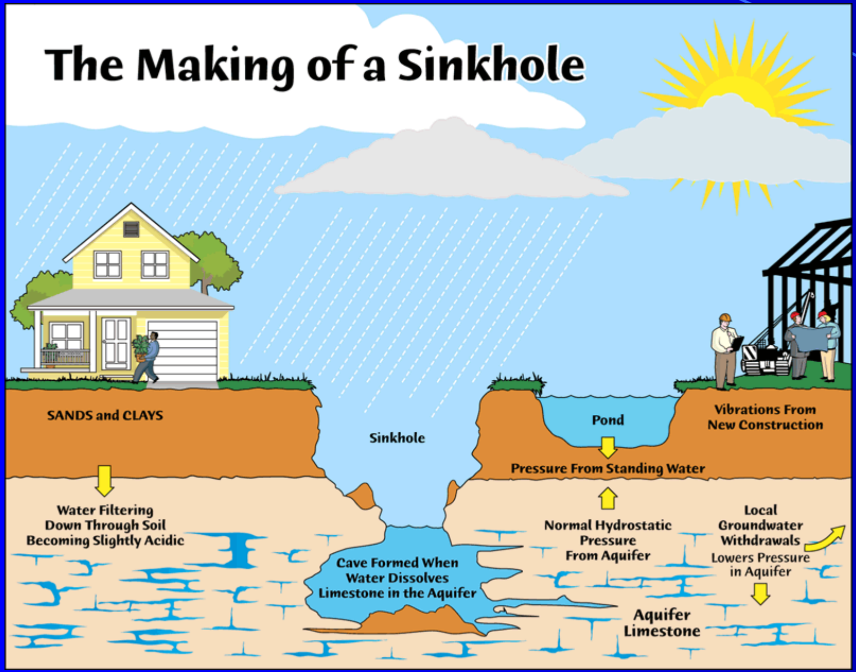
Groundwater regions of the United States



Springs



Sinkholes



The Making of a Sinkhole
SANDS and CLAYS
Sinkhole
Pond
Vibrations From New Construction
Pressure From Standing Water
Water Filtering Down Through Soil Becoming Slightly Acidic
Normal Hydrostatic Pressure From Aquifer
Local Groundwater Withdrawals Lowers Pressure in Aquifer
Cave Formed When Water Dissolves Limestone in the Aquifer
Aquifer Limestone

Photo courtesy of Doug Gouzie, 2006

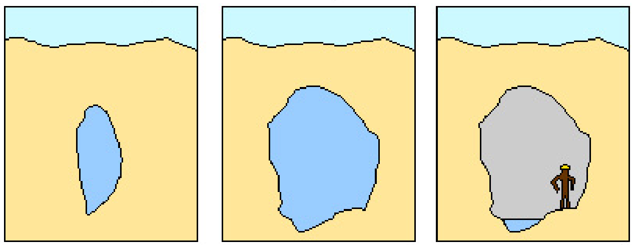
Caves

Caves: subsurface cavities formed by dissolution of rock

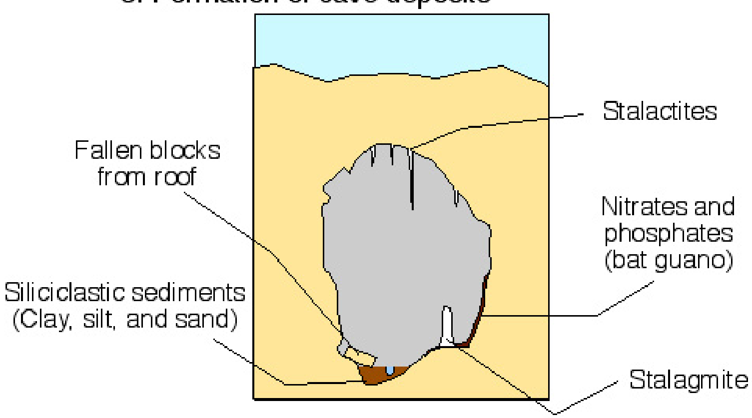
Steps in the Formation of Caves

1. Extensive chemical weathering
   Requirements:
   a. Abundant groundwater
   b. Soluble bedrock (limestone) ((gypsum))

2. Lowering of water table (for an air-filled cave)



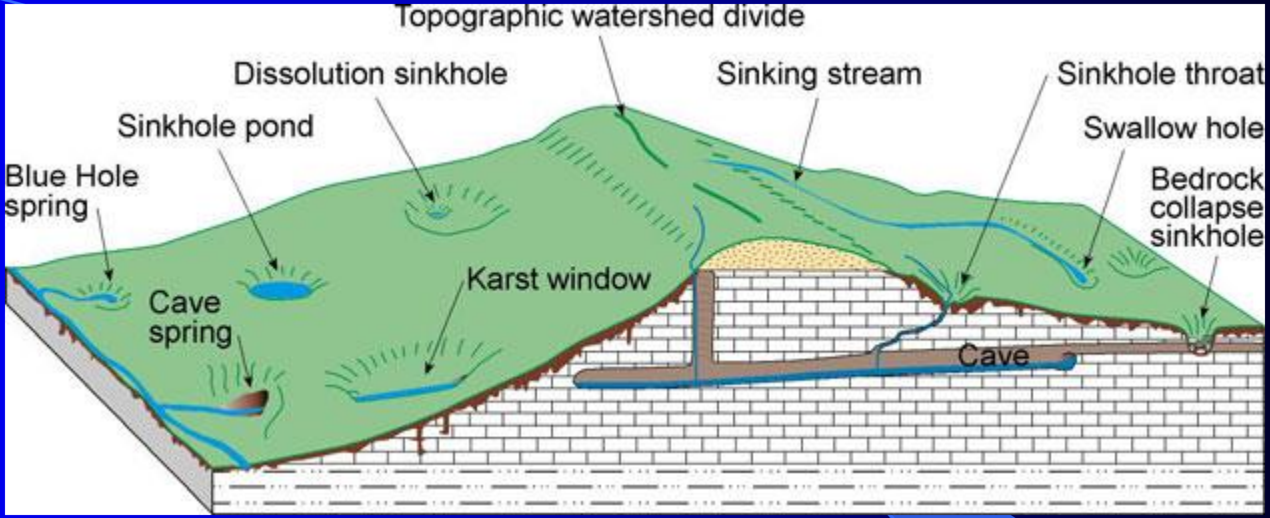
3. Formation of cave deposits



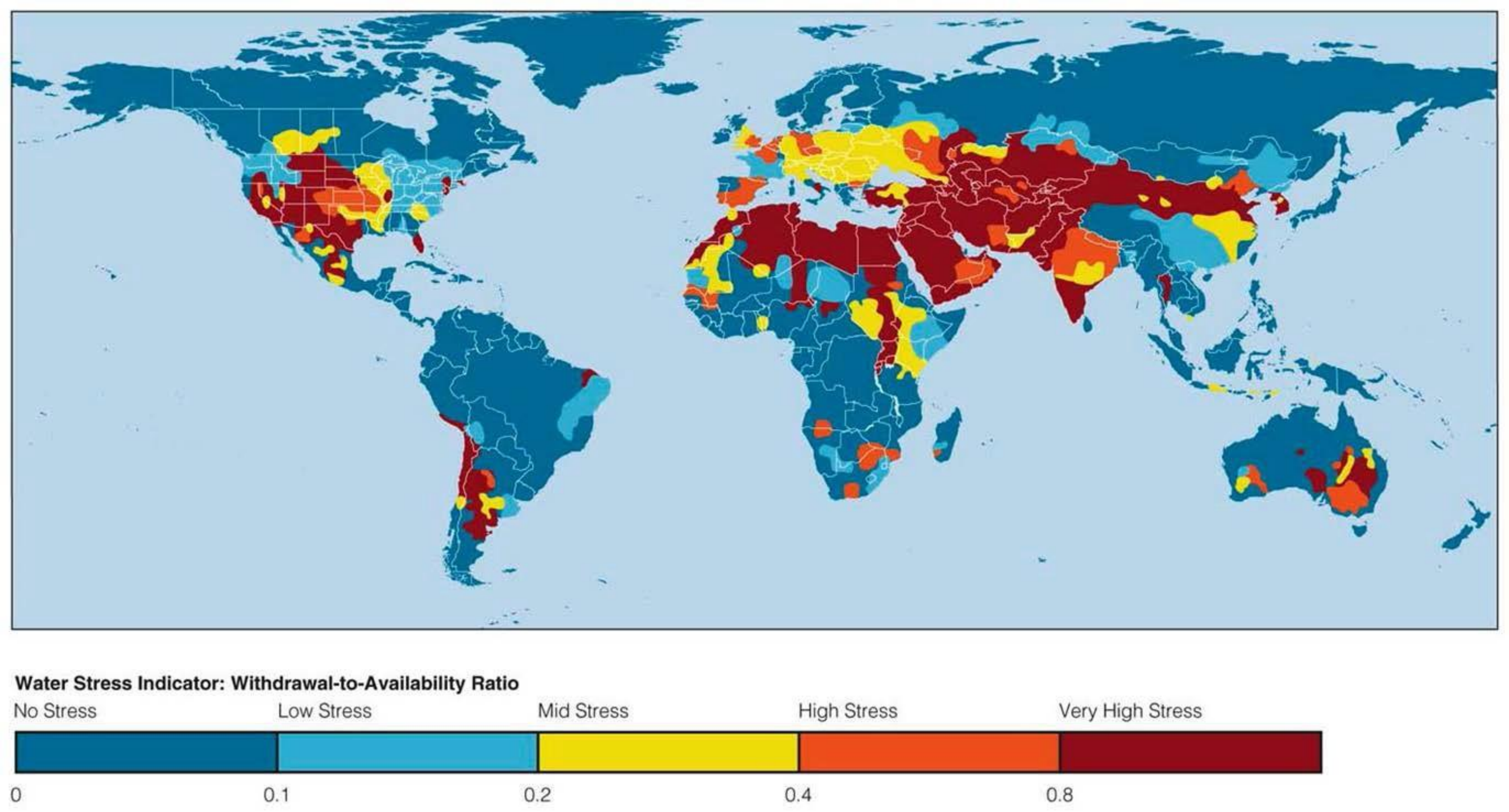
4. More of 1, 2, & 3 in various orders

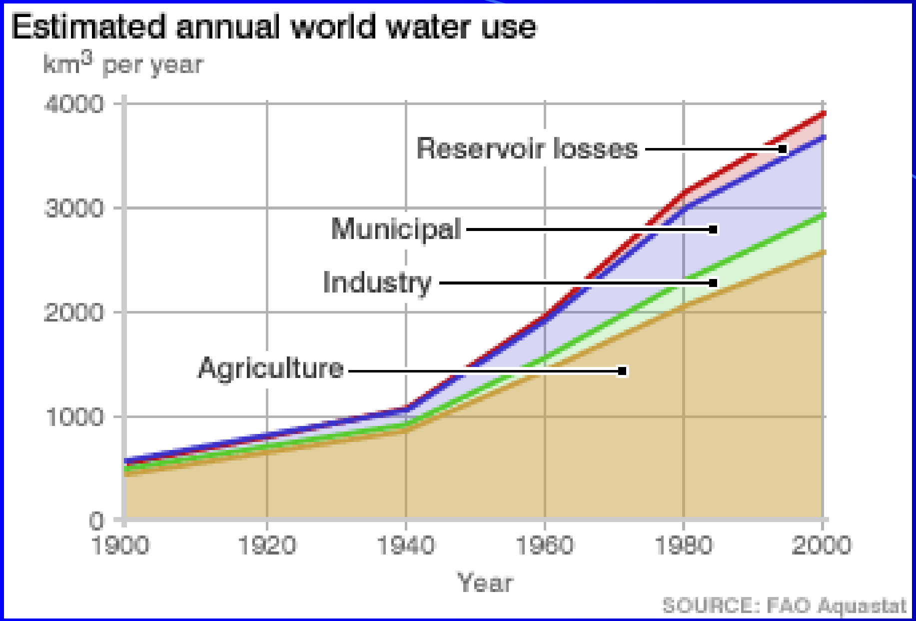
LBR 3/2002

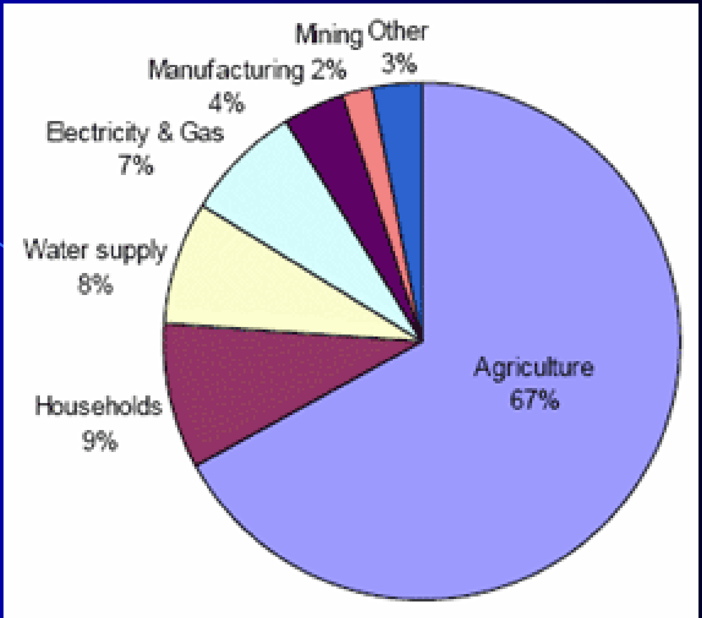
Karst

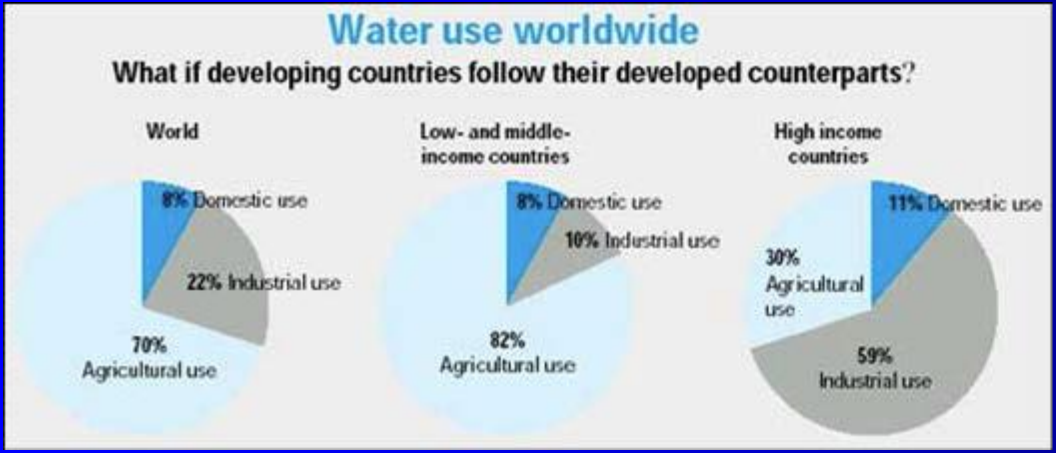

Topographic watershed divide
Dissolution sinkhole
Sinking stream
Sinkhole throat
Sinkhole pond
Swallow hole
Blue Hole spring
Bedrock collapse sinkhole
Cave spring
Karst window
Cave

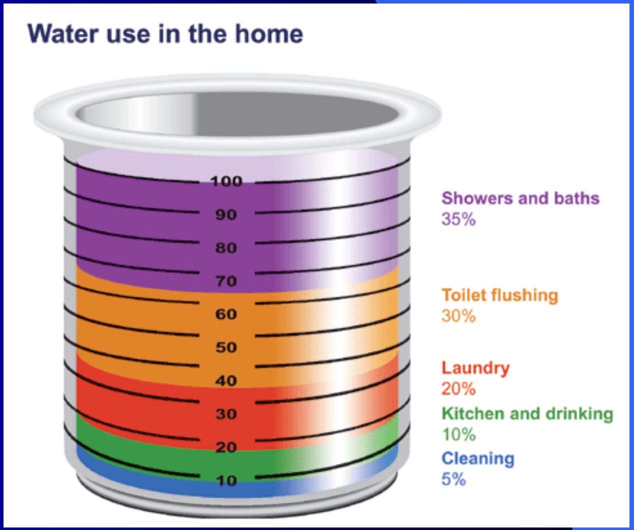
Water Stress Indicator




Estimated annual world water use
km3 per year
4000
3000
2000
1000
0
1900
1920
1940
1960
1980
2000
Year
Reservoir losses
Municipal
Industry
Agriculture
SOURCE: FAO Aquastat


Mining
Other 3%
Manufacturing 2%
4%
Electricity & Gas 7%
Water supply 8%
Households 9%
Agriculture 67%


Water use worldwide
What if developing countries follow their developed counterparts?
World
8% Domestic use
22% Industrial use
70% Agricultural use
Low- and middle-income countries
8% Domestic use
10% Industrial use
82% Agricultural use
High income countries
11% Domestic use
30% Agricultural use
59% Industrial use


Water use in the home
100
90
80
70
60
50
40
30
20
10
Showers and baths 35%
Toilet flushing 30%
Laundry 20%
Kitchen and drinking 10%
Cleaning 5%

[EPA Regulated drinking water contaminants]