The Hydrologic Cycle

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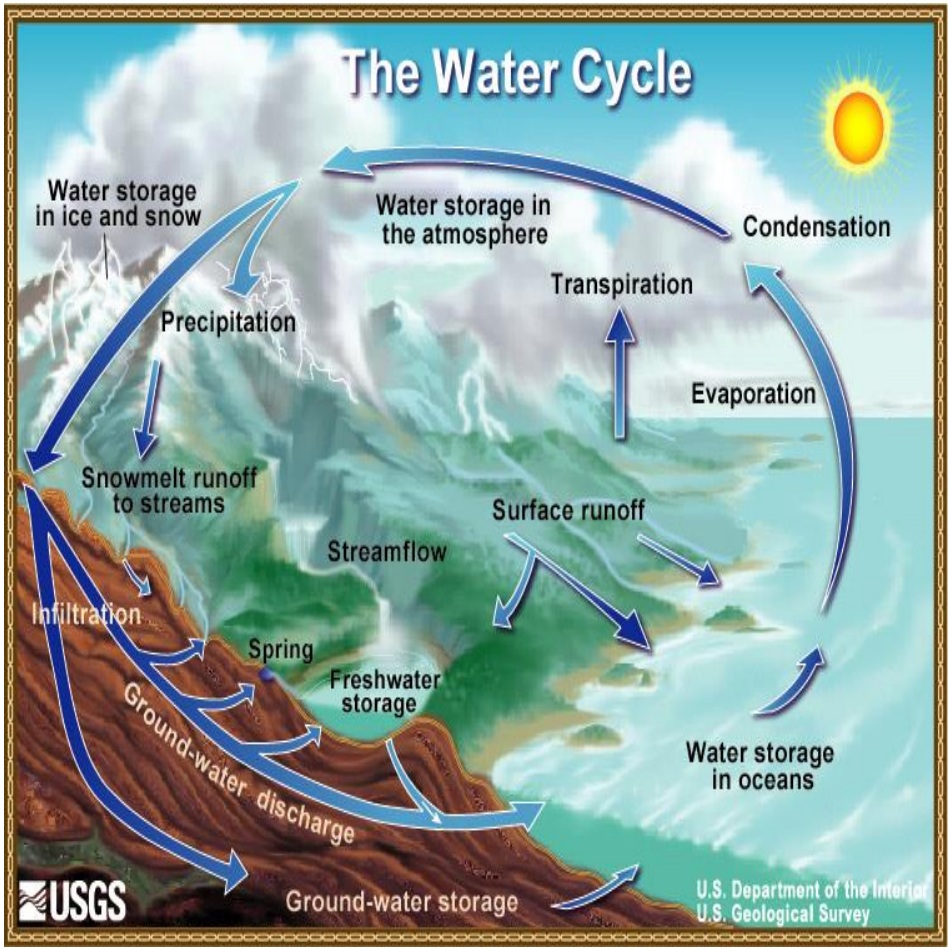

- The water on earth stays consistent, it is believed to have been consistent throughout the life of the planet
- There are five processes by which water moves throughout each of the earth's spheres
  - *condensation*
  - *precipitation*
  - *infiltration*
  - *runoff*
  - *evapotranspiration*

Table 1. The distribution of water across the globe

Location	Volume (10^3 km^3)	% of total volume in hydrosphere	% of freshwater	Volume recycled annually (km^3)	Renewal period (years)
Ocean	1,338,000	96.5	-	505,000	2,500
Ground water (gravity and capillary)	23,400[1]	1.7		16,700	1,400
Predominantly fresh ground water	10,530	0.76	30.1		
Soil moisture	16.5	0.001	0.05	16,500	1
Glaciers and permanent snow cover	24,064	1.74	68.7		
Antarctica	21,600	1.56	61.7		
Greenland	2,340	0.17	6.68	2,477	9,700
Arctic Islands	83.5	0.006	0.24		
Mountainous regions	40.6	0.003	0.12	25	1,600
Ground ice (permafrost)	300	0.022	0.86	30	10,000
Water in lakes	176.4	0.013	-	10,376	17
Fresh	91.0	0.007	0.26		
Salt	85.4	0.006	-		
Marshes and swamps	11.5	0.0008	0.03	2294	5
River water	2.12	0.0002	0.006	43,000	16 days
Biological water	1.12	0.0001	0.003		-
Water in the atmosphere	12.9	0.001	0.04	600,000	8 days
Total volume in the hydrosphere	1,386,000	100	-		
Total Fresh water	35,029.2	2.53	100		

[1] Excluding groundwater in the Antarctic estimated at 2 million km^3, including predominantly freshwater of about 1 million km^3.

Source: Shiklomanov, forthcoming

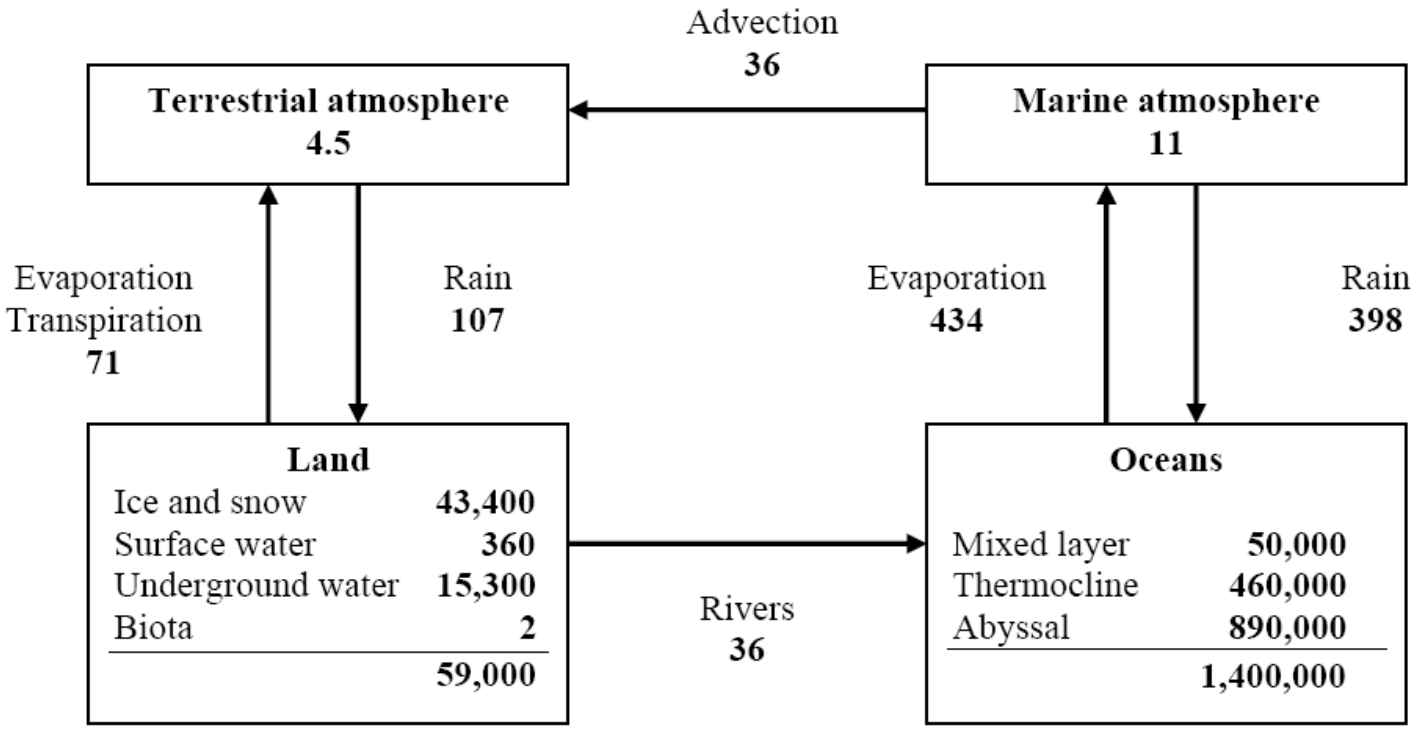

Figure 2. Estimates of global water reservoirs (in 10^{15} kg and 10^{15} kg yr^{-1}) global water cycle fluxes (After Chahine, 1992)

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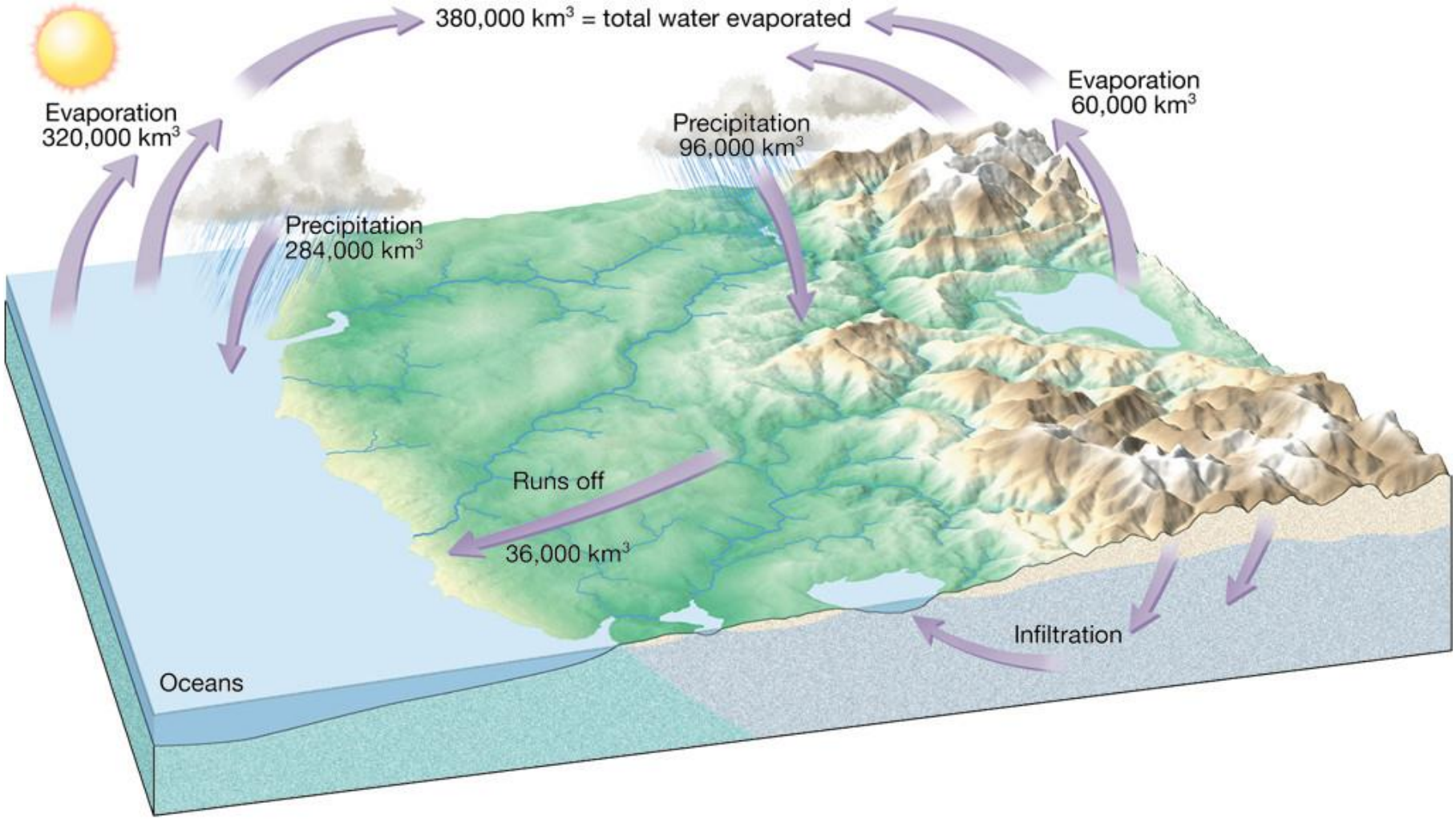

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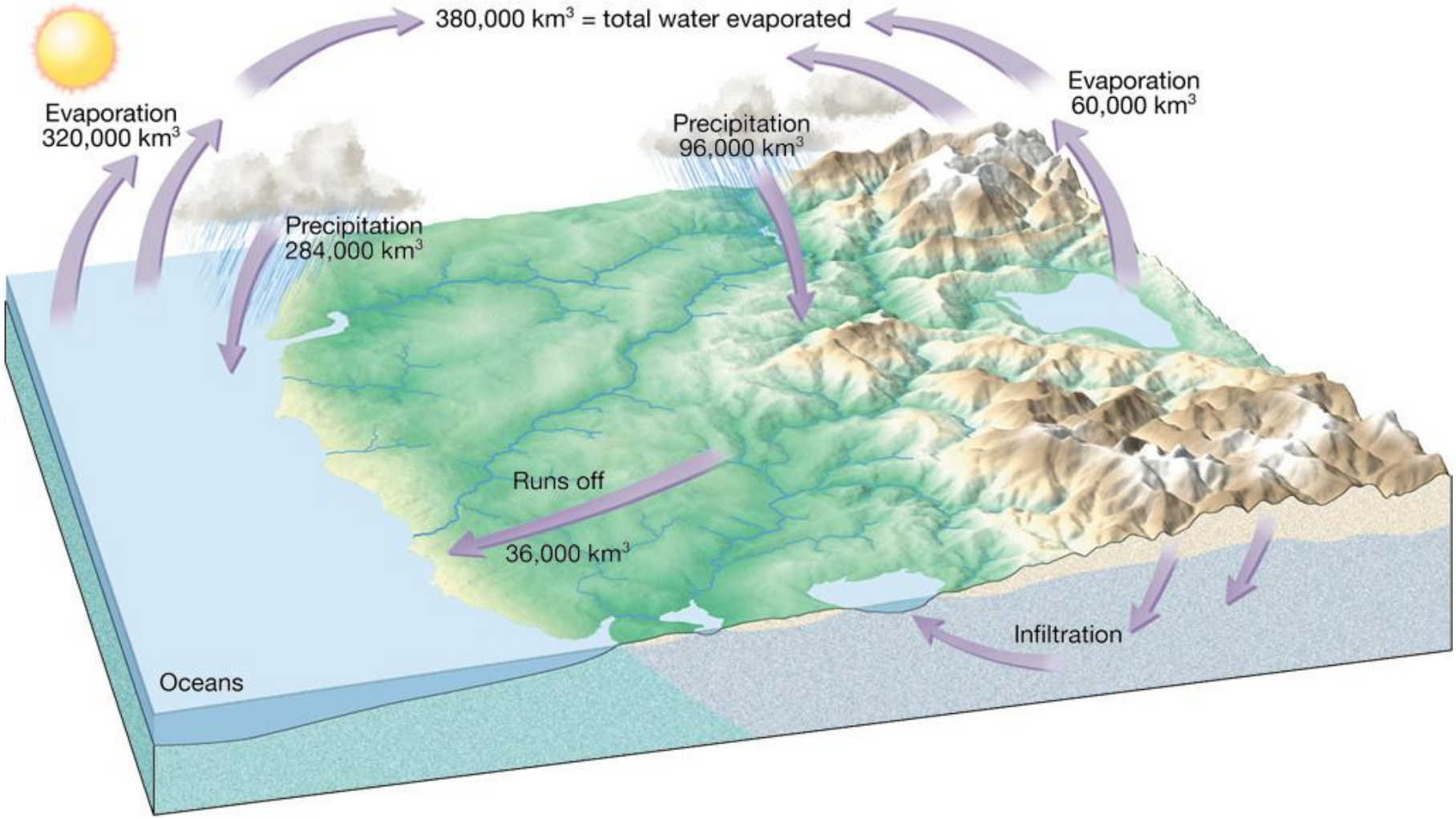


Average reservoir residence times

Reservoir	Average residence time
Antarctica	20,000 years
Oceans	3,200 years
Glaciers	20 to 100 years
Seasonal snow cover	2 to 6 months
Soil moisture	1 to 2 months
Groundwater: shallow	100 to 200 years
Groundwater: deep	10,000 years
Lakes	50 to 100 years
Rivers	2 to 6 months
Atmosphere	9 days

How can calculate residencial time?

1) **Principle of conservation of mass**

Assumes the amount of water in a given reservoir is roughly constant.

With this method, residence times are estimated **by dividing the volume of the reservoir by the rate by which water either enters or exits the reservoir.**

Conceptually, this is equivalent to timing **how long it would take the reservoir to become filled from empty if no water were to leave**

2) **Isotope hydrology** is a field of hydrology that uses isotopic dating to estimate the age and origins of water and of movement within the hydrologic cycle.

Water molecules carry unique fingerprints, based in part on differing proportions of the oxygen and hydrogen isotopes that constitute all water

Air, soil and water contain mostly oxygen 16 (^{16}O). **Oxygen 18 (^{18}O) occurs in approximately one oxygen atom in every five hundred and is a bit heavier than oxygen 16**, as it has two extra neutrons. From a simple energy standpoint this results in a preference for evaporating the lighter ^{16}O containing water and leaving more of the ^{18}O water behind in the liquid state (called fractionation). Thus seawater tends to be richer in ^{18}O and rain and snow relatively depleted in ^{18}O.

Human activities that alter the water cycle include:

- agriculture
- industry
- alteration of the chemical composition of the atmosphere
- construction of dams
- deforestation and afforestation
- removal of groundwater from wells
- water abstraction from rivers
- urbanization

Impact of hydrological cycle

86% of the global evaporation occurs from the oceans, reducing their temperature by evaporative cooling . Without the cooling, the effect of evaporation on the greenhouse effect would lead to a much **higher surface temperature of 67** °C (153 °F), and a warmer planet

Runoff is responsible for almost all of the transport of eroded sediment and phosphorus from land to waterbodies.

The salinity of the oceans is derived from erosion and transport of dissolved salts from the land.

Cultural eutrophication of lakes is primarily due to phosphorus, applied in excess to agricultural fields in fertilizers, and then transported overland and down rivers.

Both runoff and groundwater flow play significant roles in transporting nitrogen from the land to waterbodies.

Table 3, shows a summary of the above problems by the type of water bodies polluted and the extent and reach of the effects.

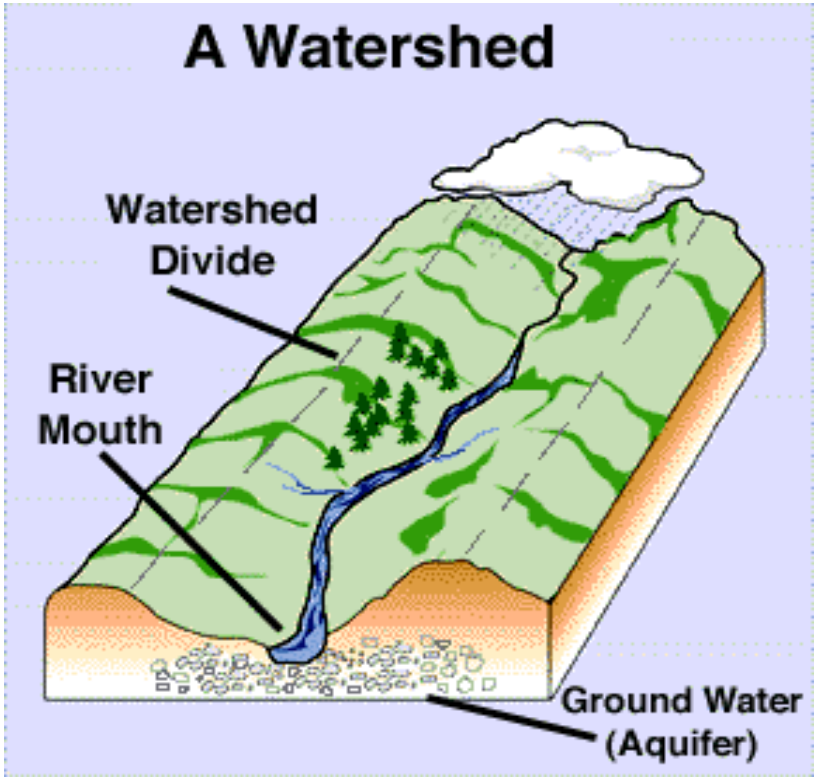
Table 3. The world's major water quality issues

Issue Scale	Water bodies polluted	Sector affected	Time lag between cause and effect	Effects extent
Organic pollution	Rivers++ Lakes + Groundwater +	Aquatic environment	< 1 year	Local to district
Pathogens	Rivers ++ Lakes + Groundwater +	Health ++	< 1 year	Local
Salinization	Groundwater ++ Rivers +	Most uses Aquatic environment Health	1 - 10 years	District to region
Nitrate	Rivers + Lakes + Groundwater ++	Health	> 10 years	District to region
Heavy metals	All bodies	Health Aquatic environment Ocean fluxes	< 1 to > 10 years	Local to global
Organics	All bodies	Health Aquatic environment Ocean fluxes	1 - 10 years	Local to global
Acidification	Rivers ++ Lakes ++ Groundwater +	health Aquatic environment	> 10 years	District to region
Eutrophication	Lakes ++ Rivers +	Aquatic environment Most uses Ocean fluxes	> 10 years	Local
Sediment load (increase and decrease)	Rivers + Lakes	Aquatic environment Most uses Ocean fluxes	1 – 10 years	Regional
Diversion, dams	Rivers + Lakes + Groundwater ++	Aquatic environment Most uses	1 – 10 years	District to region

+ serious on global scale
++ very serious issue on global scale
WHO/UNEP, 1991

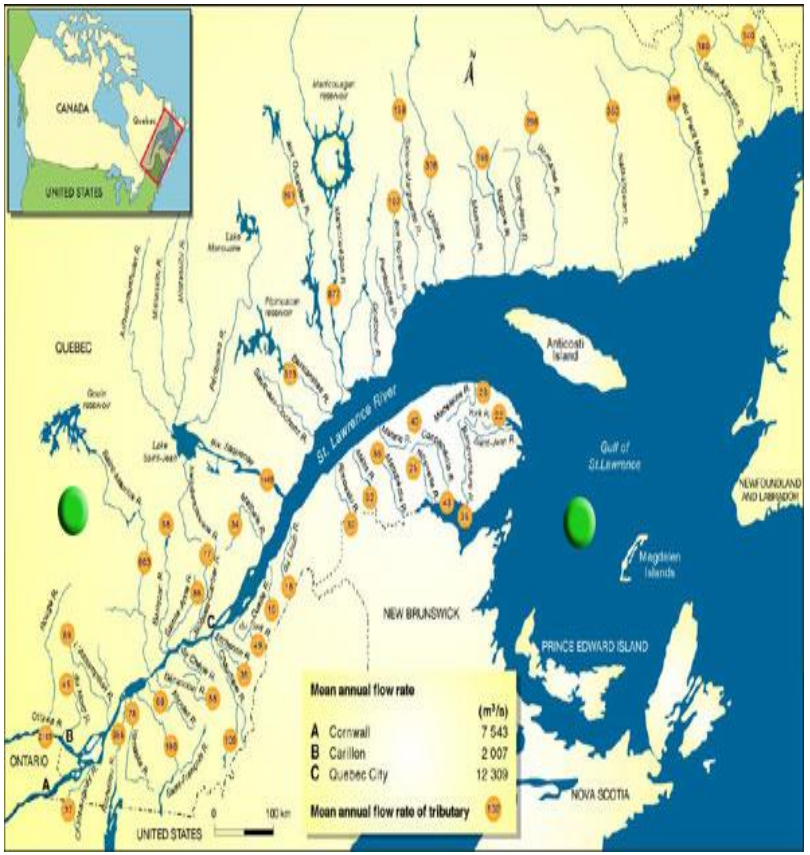
Watershed

- A **watershed** is the area of land where all of the water that is under it or drains off of it goes into the same place



Basin

A basin is a large-scale watershed, such as the St. Lawrence River basin



Cryosphere

- The **cryosphere**, derived from the Greek word *kryo* for "cold" or "too cold", is the term which collectively describes the portions of the Earth's surface where water is in solid form, including sea ice, lake ice, river ice, snow cover, glaciers, ice caps and ice sheets, and frozen ground.

- Its influence on surface energy and moisture fluxes, clouds, precipitation, hydrology, and atmospheric and oceanic circulation.

THE TIDES

- **The alternating rise and fall in sea level with respect to the land, produced by the gravitational attraction of the moon and the sun**
- Tides in Earth's oceans are due to the **differential** of gravitational attraction on different parts of Earth (relative to its center); primarily by the Moon, and secondarily by the Sun.
- The part of the oceans on the side of the Earth facing the Moon (or Sun) feels stronger gravity, and the part of the oceans on the side of the Earth facing away from the Moon (or Sun) feels weaker gravity.
- When the Sun and Moon are in line with the Earth, tides are stronger than average *(spring tides),* and when the Sun and Moon are at right angles to each other, tides are weaker than average (*neap tides*).
- There are also variations in tide strength due to differences in the Earth-Moon and Earth-Sun distances, and the orientations of the orbit planes of the Earth and Moon with each other, and with the Earth's equatorial plane.

Moon Tides

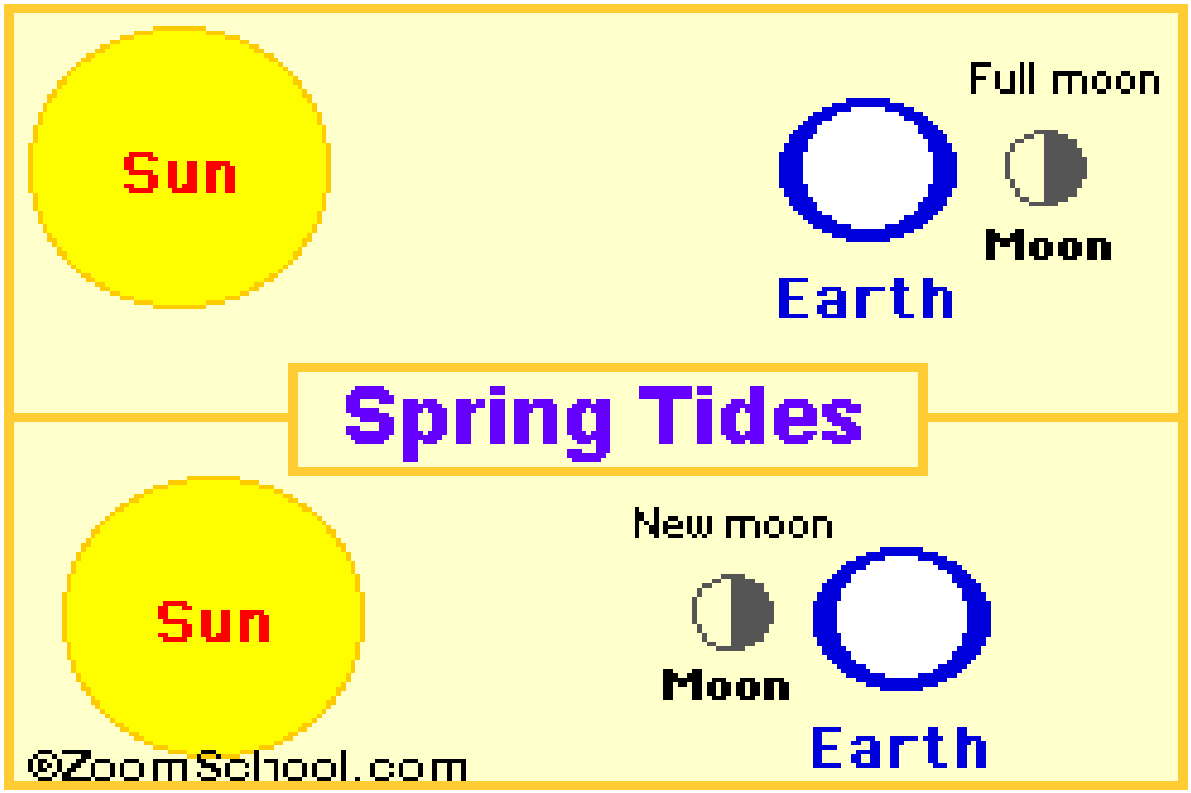
- The alternating rise and fall in sea level with respect to the land, produced by the gravitational attraction of the moon and the sun.
- To a much smaller extent, tides also occur in large lakes, the atmosphere, and within the solid crust of the earth, acted upon by these same gravitational forces of the moon and sun.

- Two type of Tides

1. Spring Tides
2. Neap Tides

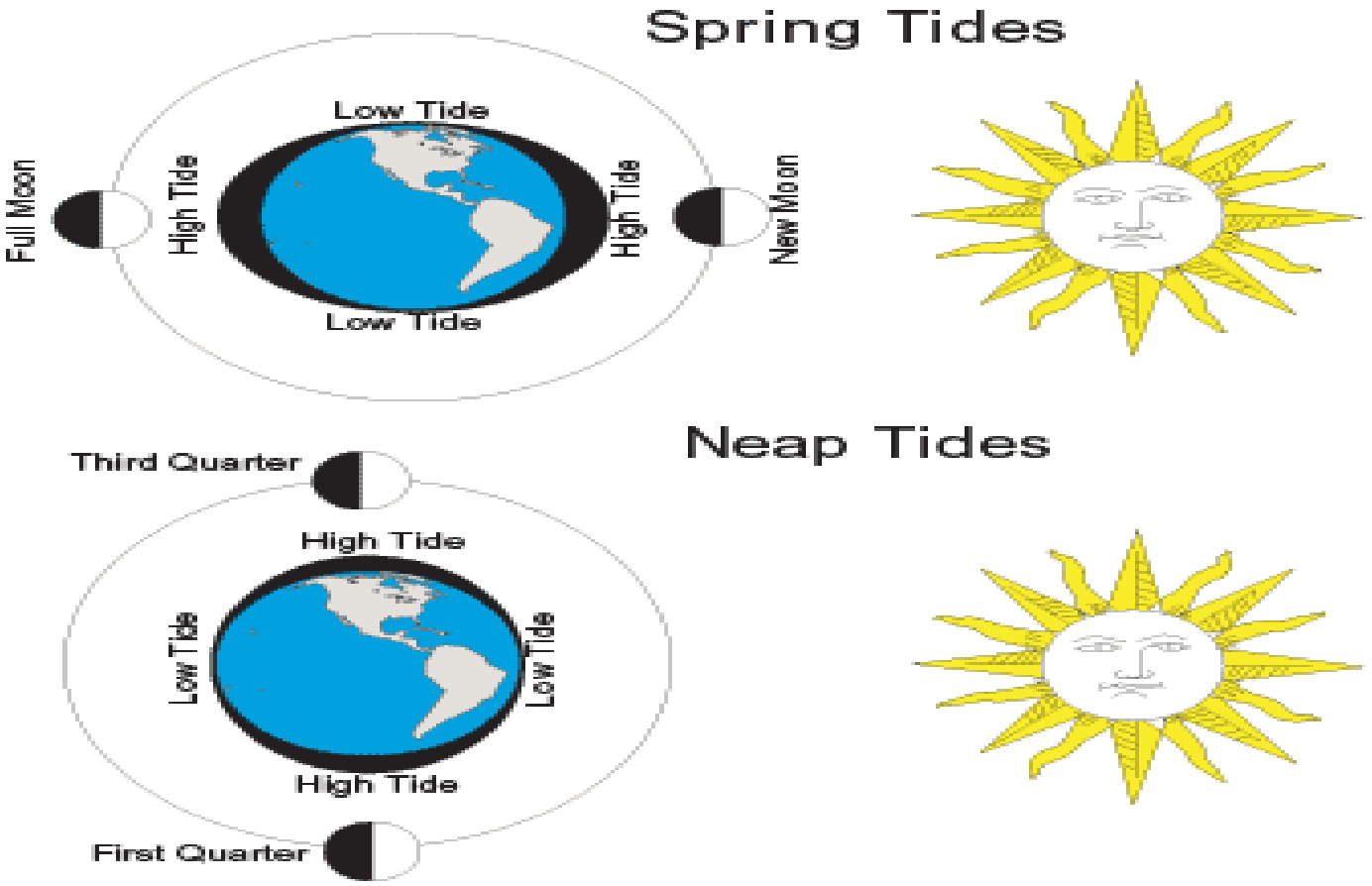
Spring Tides

- Spring tides are especially strong tides.
- They occur when the Earth, the Sun, and the Moon are in a line. The gravitational forces of the Moon and the Sun both contribute to the tides. Spring tides occur during the full moon and the new moon.



Neap Tides

- Neap Tides are weak tides
- When the gravitational pull of the moon and Sun are at right angles to each other. These events are called **neap tides** and they occur during the first and last quarter of the moon.



THE EARTH'S CRYOSPHERE

- Earth's supply of frozen water, the cryosphere, is second only to the oceans in water content.
- The cryosphere consists mainly of the permanent ice caps of Antarctica and Greenland, with much smaller amounts in Arctic and mountain glaciers.
- Major changes in sea level can occur during times of global climate change (global warming), due to associated changes in the water content of the cryosphere.

Permafrost

• Land areas in polar regions, such as Antarctica and Greenland, and the north slopes of Alaska and Siberia, have zones below their surfaces in which ground water remains frozen year-round.

• Regions in which soil water is permanently frozen constitute is known as permafrost

Oceans

- Oceans are responsible for keeping the planet from burning up by the sun's heat and it is the planet's largest source of heat
- The large mass of liquid serves as a buffer for the sun's heat and it keeps earth in a state of homeostasis by not allowing any drastic changes in temperature
- Why would it be important to keep the earth's temperature at a relatively constant state?