HYDROLOGY - 1

An Introduction and the Hydrologic Cycle

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Origin and Definition of Hydrology

Origin

The term Hydrology is from Greek

- *Hydōr*: means ***water***
- *Logos*: means ***study*** or ***science***

Definition

- *"**Hydrology** is the science that deals with the processes governing the depletion and replenishment of the water resources of the land areas of the Earth."* Chow, 1964

"***Water is the driving force of all nature***" Leonardo da Vinci

Significant Facts about Water

- Approximately 70% of the human body is composed of water
- Surface area of Earth is 510,100,000 Km^2 (197,000,000 $miles^2$)

  Mean radius = 6371.0 Km = 3959 miles
  Equatorial radius = 6378.1 Km
  Polar radius = 6356.8 Km

  - ✓ **Saltwater** (69.05%) = 352,200,000 Km^2
  - ✓ **Land** (29.17%) = 148,800,000 Km^2
  - ✓ **Freshwater** (1.78%) = 9,100,000 Km^2

"We forget that the water cycle and the life cycle are one"
Jacques-Yves Cousteau

- Oceans contain 96.5% of the water on and in the Earth (saltwater). Almost 1.0% is saline water in the groundwater and lakes. Therefore freshwater accounts for only a 2.5% of the total water of the Earth which incidentally sustains life in our planet. For practical reasons, Hydrology does not cover all studies of oceans (***Oceanography***), and is not concerned with the medical uses of water (***Medical Hydrology***). Chow, 1964.
- So ***Hydrology*** deals mainly with that 2.5% of the waters of the Earth, their occurrence, circulation and distribution, their chemical and physical properties, and their reactions with the environment.

Interesting Aspect on Hydrology

Sources of Earth's Water

Water Resources	Water Volume (Km³)	Water Volume (acre-ft)	Percentage (%) Total	Percentage (%) Freshwater	Percentage (%) Surface Water
Oceans, Seas and Bays	1,338,000,000	1.08476E+15	96.56	X	X
Glaciers and Polar Ice	24,064,000	1.95095E+13	1.74	69.29	X
Groundwater	23,400,000	1.89712E+13	1.69	–	X
Fresh	10,530,000	8.53704E+12	0.76	30.32	X
Saline	12,870,000	1.04342E+13	0.93	X	X
Lakes	176,400	1.43014E+11	0.0127	–	–
Fresh	91,000	73,776,894,100	0.0065	0.26	87.01
Saline	85,400	69,236,777,540	0.0062	X	X
Soil Moisture	16,500	13,377,129,150	0.0012	0.05	X
Atmosphere	12,900	10,458,482,790	0.0009	0.04	X
Swamps and Marshes	11,470	9,299,131,597	0.0008	0.03	10.96
Rivers	2,120	1,718,758,412	0.0002	0.006	2.03
Biological Water	1,120	908,023,312	0.0001	0.003	X
TOTAL	1,385,684,510	1.12342E+15	100.00	100.00	100.00

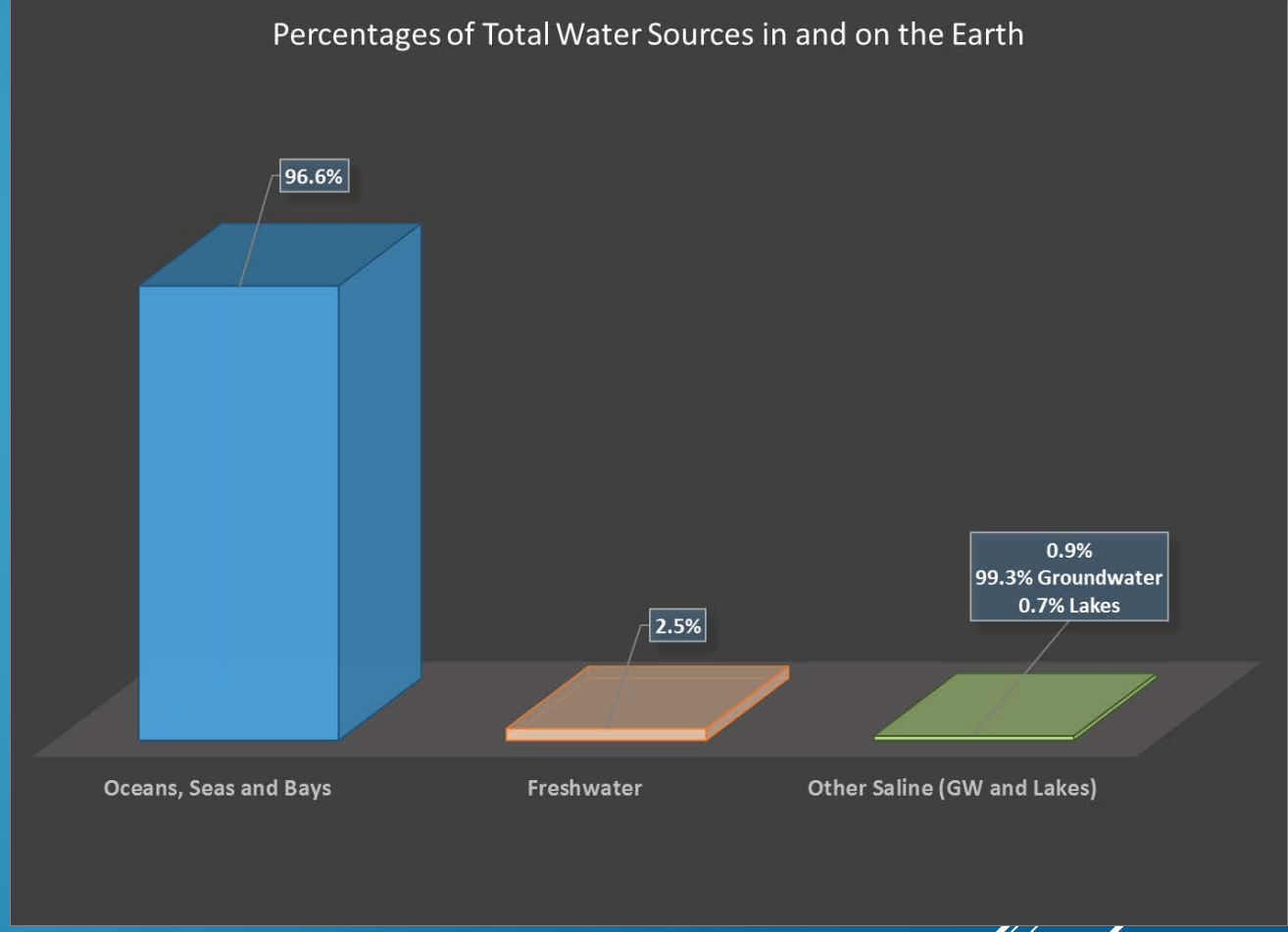
96.6%
0.9%
2.5%

69.3%
30.3%
0.3%
0.1%

87%
11%
2%

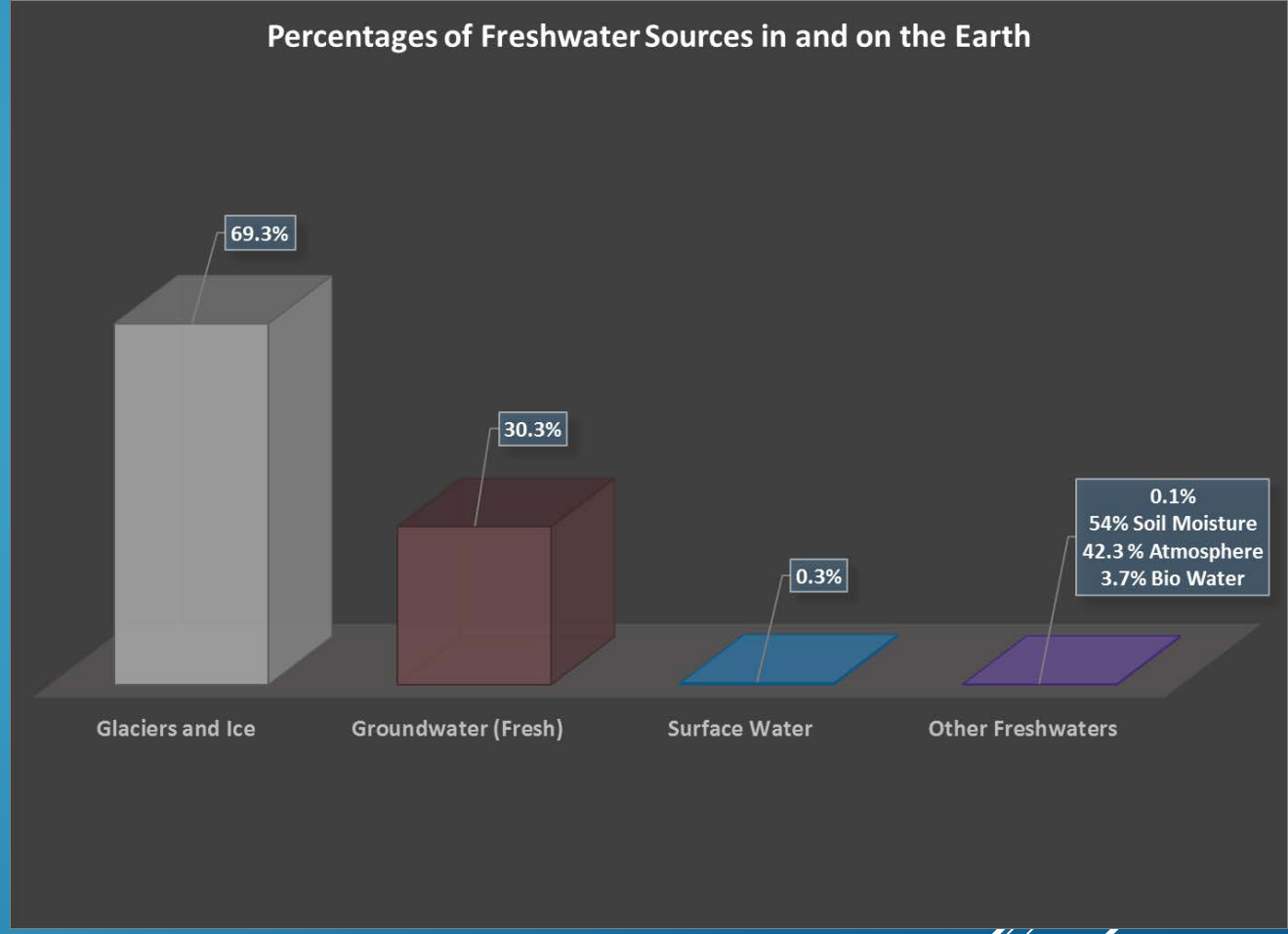
Sources of Earth's Water

- The ***total water*** in the Earth is estimated as 1.39×10^9 Km^3 (1.12×10^{15} acre-ft) in three major sources
  - ✓ **Saltwater** in ***oceans***, ***seas*** and ***bays*** accounts for 1.34×10^9 Km^3 (1.08×10^{15} acre-ft)
  - ✓ **Freshwater** consists of 3.47×10^7 Km^3 (2.82×10^{13} acre-ft)
  - ✓ **Saline water** in ***groundwater*** and ***lakes*** (99.3% and 0.7%, respectively) accounts for 1.3×10^7 Km^3 (1.05×10^{13} acre-ft)



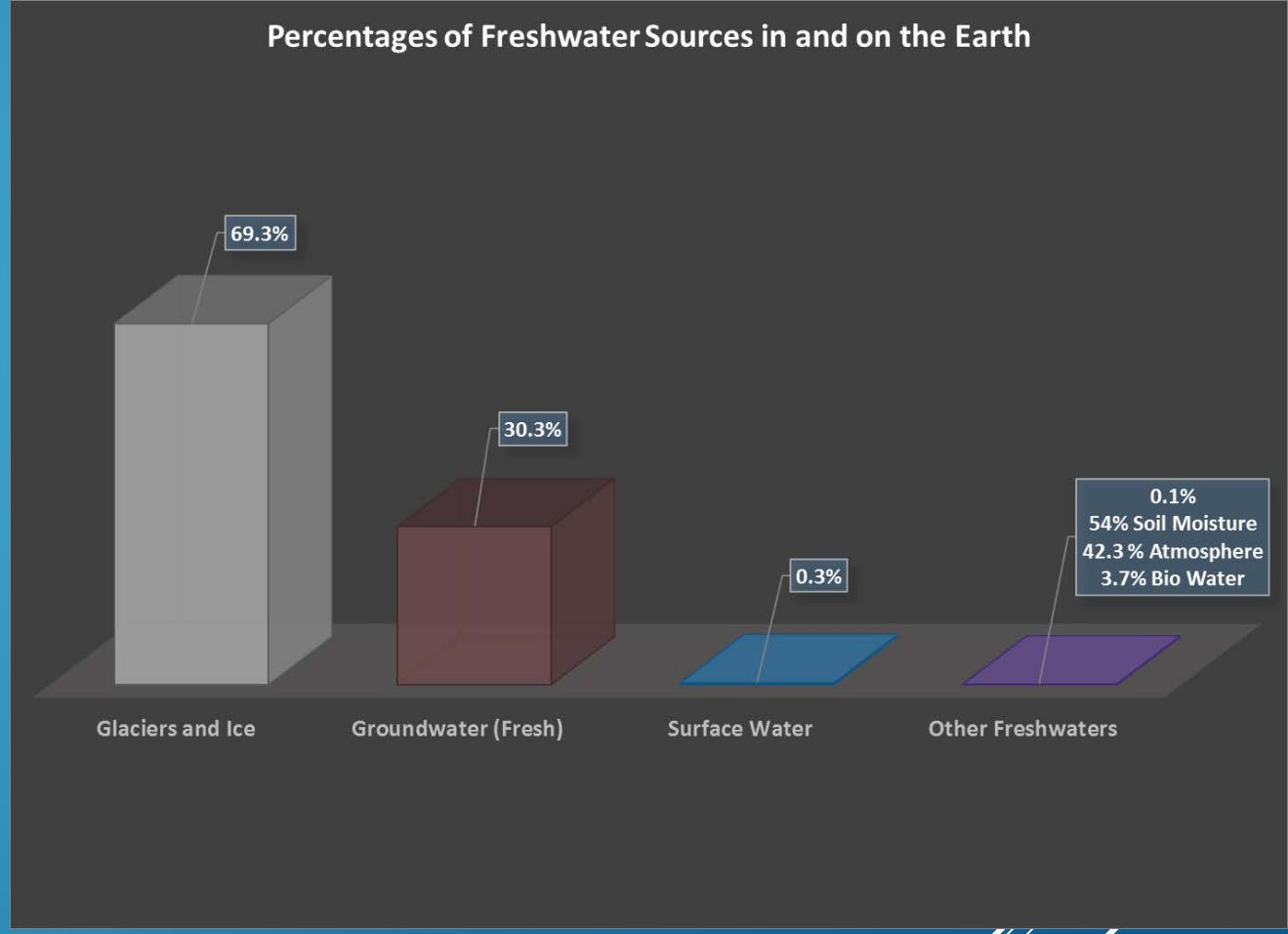
Sources of Earth's Freshwater

- ***Freshwater*** in the Earth is estimated as 3.47×10^7 Km^3 (2.82×10^{13} acre-ft) and only accounts for 2.5% of Earth's total water. It is contained in four major sources
  - ✓ **Glaciers, Ice Caps** and **Polar Ice** is part of the freshwater contained on the surface of the Earth and accounts for 2.41×10^7 Km^3 (1.95×10^{13} acre-ft)



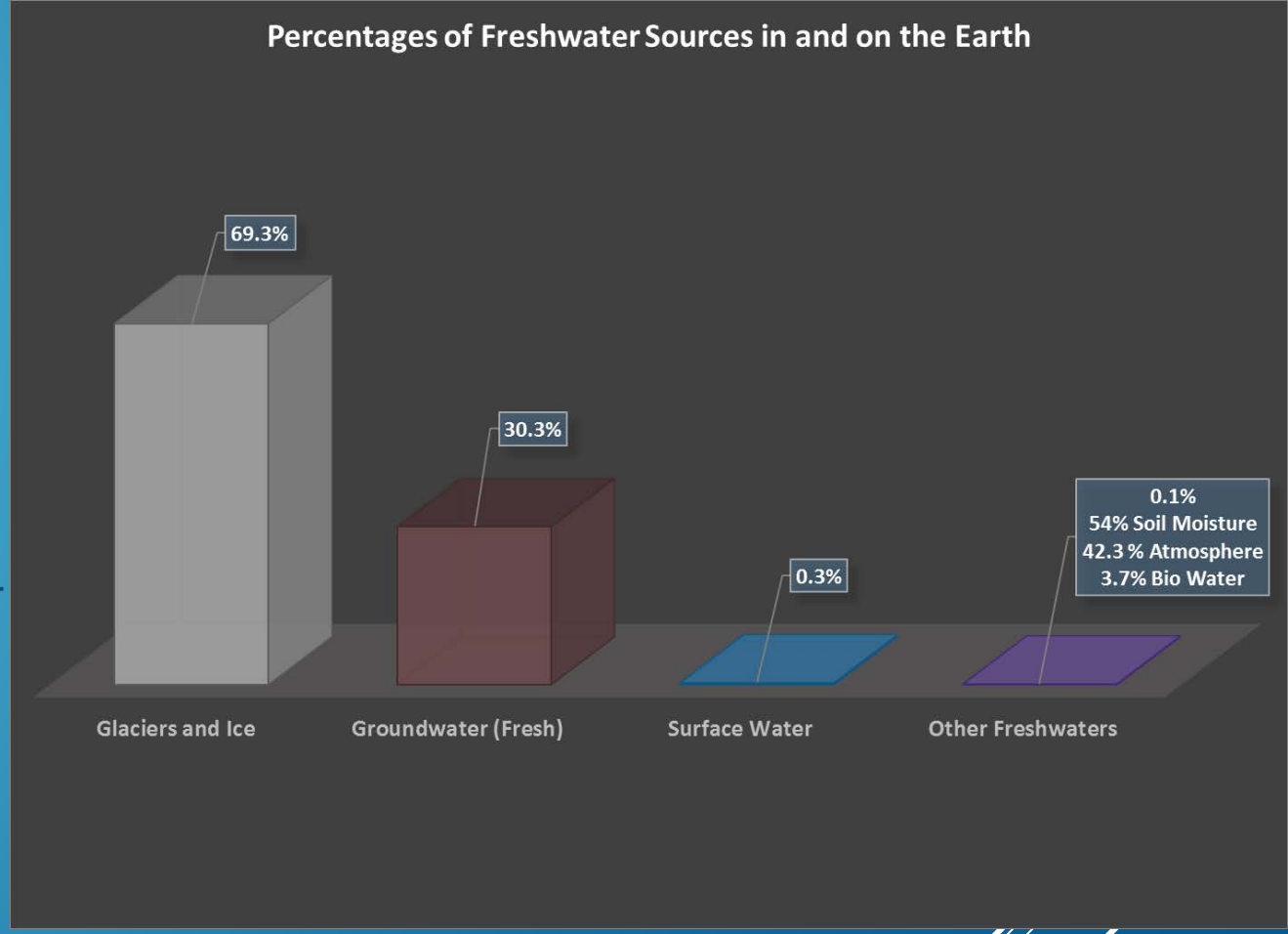
Sources of Earth's Freshwater

- ✓ **Groundwater** is part of the freshwater that exists underneath the surface of the Earth (from 200 to 600 m deep) and forms the surficial and deep aquifers . It accounts for $1.05x10^7$ Km^3 ($8.54x10^{12}$ acre-ft)
- ✓ **Surface Water** is contained over the surface of the Earth in streams or lakes. It accounts for $1.05x10^5$ Km^3 ($8.48x10^{10}$ acre-ft) that represents only 0.3% of the freshwater and less than 0.01% of the total water in the Earth



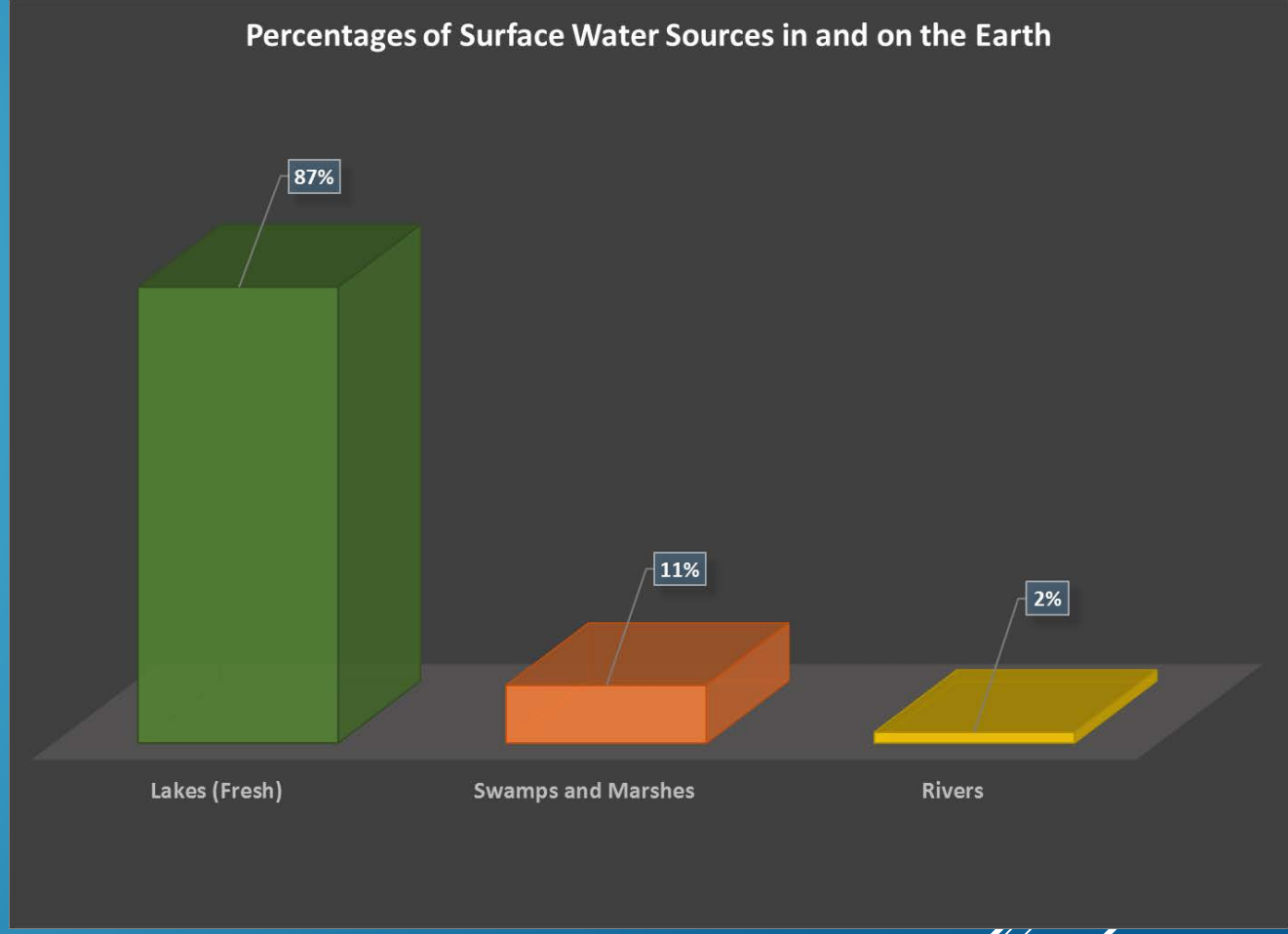
Sources of Earth's Freshwater

- **Other Freshwaters** account roughly for 30,520 Km^3 ($2.47x10^{10}$ acre-ft). It includes three principal components: **Soil Moisture, Atmosphere** and **Biological Water** with approximate contributions of 54%, 42% and 4%, respectively. **Soil Moisture** is the water that remains in the upper layer of the soil and can eventually recharge the aquifer, be absorbed by vegetation or crops and/or evaporate into the atmosphere. The water in the **Atmosphere** results mainly from the oceans' and surface water's evaporation. **Bio Water** includes the water in living species of the flora and fauna



Sources of Earth's Surface Water

- ***Surface Water*** in the Earth is estimated as 1.05×10^5 Km^3 (8.48×10^{10} acre-ft) and barely represents 0.01% of the total water and 0.3% of the Freshwater in the Earth with the following distribution:
  - ✓ **Lakes** (freshwater) provide the largest contribution with 91,000 Km^3 (7.38×10^{10} acre-ft)
  - ✓ **Swamps** and **Marshes** account for 11,470 Km^3 (9.3×10^9 acre-ft)
  - ✓ **Rivers** have a minor contribution of 2,120 Km^3 (1.72×10^9 acre-ft)



Significant Water Aspects in the Earth

- Of the 510 million Km^2 of the Earth about **69%** is occupied by ***Saltwater*** and **1.8%** by ***Freshwater***
- Based on volume, **96.6%** of the Earth's water is ***Saltwater*** in oceans, seas and bays and **0.9%** is ***Saline water*** in lakes and groundwater (0.7% and 99.3%, respectively). Therefore ***Freshwater*** accounts for only **2.5%** of the Earth's water
- The estimated ***Freshwater*** capacity of the Earth is $3.47x10^7$ Km^3 ($2.82x10^{13}$ acre-ft) of which 69.3% is locked up in ice in formations of ***Glaciers*** and ***Ice Caps***. The second source is ***Groundwater*** with a 30.3%. It follows ***Surface Waters*** with 0.3% and ***Other Freshwaters*** 0.1%
- Most of human water supply is obtained from ***Rivers, Lakes*** and ***Groundwater*** (0.006%, 0.26% and 30.3% of ***Freshwater***, respectively)

Significant Water Aspects in the Earth

- Even though the minor contribution of ***Freshwater*** on the Earth's water, its importance in Hydrology is crucial as it will be described
- Also high relevance in Hydrology is that of ***Surface Water,*** in spite of its minimum contribution to the Earth's water (less than 0.01% of the total and 0.3% of the ***Freshwater***). This is due to the conveyance and storage properties of its sources (e.g., ***Rivers, Lakes, Marshes)*** over the processes of the Hydrologic Cycle
- The source of water in the soil (***Soil Moisture***) is quite important in Hydrology even though it slightly represents 0.0012% of the Earth's water. It is associated with initial abstractions (infiltration), surface water/groundwater interactions, water available for crops and vegetation and aquifer or groundwater recharge

Significant Water Aspects in the Earth

- Despite the relatively small water content in the ***Atmosphere*** (12,900 Km^3 =$1.05x10^{10}$ acre-ft) which does not even represent a 0.001% of the Earth's water, its importance to Hydrology is remarkable. ***Atmosphere*** is considered to be the driving force of the Hydrologic Cycle. Unpredictability of atmospheric motion together with the rapid recycling of water through the atmosphere (i.e., it is estimated that a water particle resides for an average of 8 days before it precipitates again), create considerable uncertainty in weather patterns and random fluctuations in precipitation

The Hydrologic Cycle

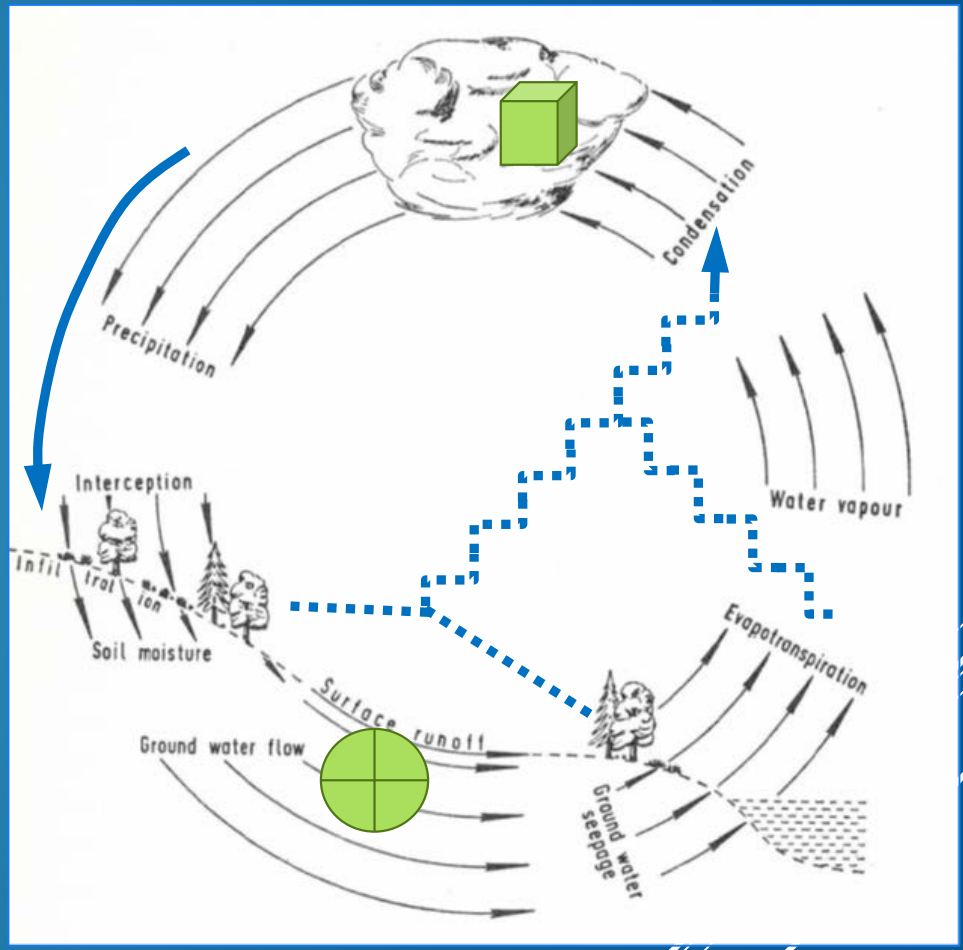
- The Hydrologic Cycle (***HC***) is the central focus of Hydrology which can be seen as the scientific examination and appraisal of the whole continuum of a hydrologic, or water, cycle
- The ***HC*** consists of numerous processes that describe the different paths through which the water, in nature and in its three phases (liquid, solid and gaseous), circulates and is transformed
- The ***HC*** has no beginning or end, and its processes occur continuously in the earth system composed of:

The Hydrologic Cycle

- ✓ **Atmosphere** is the gaseous envelope above the Earth's surface
- ✓ **Hydrosphere** consists of the waterbodies that cover the surface of the Earth
- ✓ **Lithosphere** is the crust and uppermost solid layer of the Earth below the Hydrosphere

The activities of water extend through these three parts of the earth system about 15 Km (9.3 miles) up into the atmosphere and for an average of 1.0 Km (0.62 miles) down into the lithosphere, the crust of the Earth. Groundwater to a depth of 200 to 600 m is freshwater, and below this depth is typically saline

- Atmospheric moisture in transportation and storage
  - ✓ Cloud formation and rain clouds
- Precipitation: rain, snow, hail, sleet
- Surface processes and disposition
  - ✓ Abstractions: interception, transpiration, depression storage, evaporation, infiltration
  - ✓ Generation of surface runoff and groundwater flow
- Evaporation from oceans, surface water, soils; and evapotranspiration from crops and vegetation



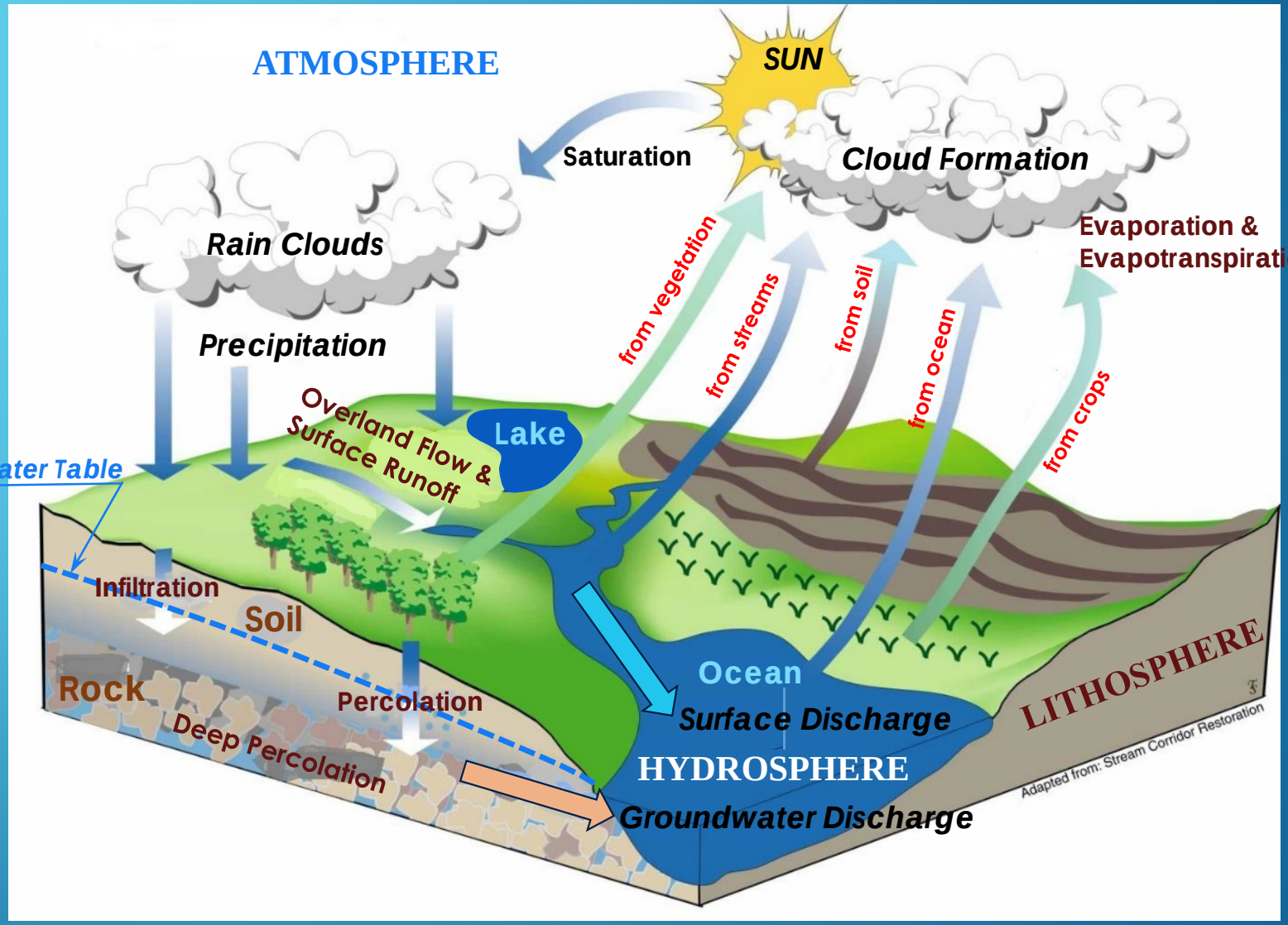
Simplified Hydrologic Cycle

Processes in the Hydrologic Cycle

- As previously stated, Hydrology attempts to quantify water on the Earth and in the various processes or components of the ***HC*** as well as the interactions between those processes which are of unsteady nature. The ***HC*** is fueled by solar energy, driven by gravity and proceeds continuously in the presence or absence of human activity
- Atmospheric moisture as water vapor (from ocean and land evaporation) *circulates* and *forms* rain clouds.
- It *precipitates* to the Earth, either on land or in the oceans (crust of the Lithosphere or Hydrosphere, respectively), mainly as rain or snow

- Part of that precipitation is *intercepted* by trees and vegetation; is *retained* and *stored* in land depressions; *evaporates* prior to reaching the hydrosphere or land surface; is *conveyed* as overland flow and stream flow; *infiltrates* into soils; *percolates* into deeper layers; *recharges* surficial aquifers and groundwater; *discharges* into streams; and eventually *flows out* into oceans
- Water mostly from oceans *evaporates* and *rises* within the atmosphere as water vapor and *forms* clouds from condensation
- As conditions are favorable for water molecules to rapidly combine into a droplet (saturation) that is too heavy to be suspended in air, it falls to the ground as precipitation… All repeats again, and the ***HC*** continues its endless path

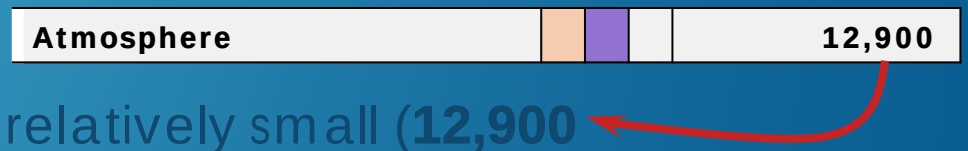
Processes in the Hydrologic Cycle



Graphic Depiction of Hydrologic Cycle

Quantitative Hydrologic Cycle

- Even though the ***HC*** undergoes a series of complex processes (i.e., evaporation, interception, infiltration, depression storage, precipitation, percolation and runoff); the knowledge acquired from research allows us to quantitatively evaluate its components
- There is a continuous change in the sources or components of the ***HC***, however stationary estimates of water distribution can be obtained by analyzing average conditions (i.e., long-period records)
- While the water content in the atmosphere is relatively small (**12,900 Km^3 = $1.04x10^{10}$ acre-ft**), large quantities of water pass through it



Water Resources	Water Volume		Percentage		
	(Km^3)	(acre-ft)	Total	Freshwater	Surface Water
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TOTAL	1,385,684,510	1.12342E+15	100.00	100.00	100.00

Quantitative Hydrologic Cycle

- The annual (volumetric) precipitation on land surface is 9.2 times greater than the moisture content in the atmosphere or **119,000 Km^3**, which is equal to an average annual precipitation of **800 mm** (Vol/Area x 10^6 mm/Km = [119,000 Km^3] /[148.8x10^6 Km^2]*10^6 mm/Km) or **31 in**

$12{,}900\ Km^3 \times 9.2 = 119{,}000\ Km^3$

- The annual precipitation on the oceans is about **458,000 Km^3** that represents 35.5 times the moisture content in the atmosphere. This indicates more atmospheric activity over the oceans and corresponds to an average annual precipitation of **1268 mm** (Vol/Area x 10^6 mm/Km = [458,000 Km^3]/ [361.3x10^6 Km^2]*10^6 mm/Km) or **50 in**

$12{,}900\ Km^3 \times 35.5 = 458{,}000\ Km^3$

458,000 Km^3 + 119,000 Km^3 = 577,000 Km^3

- The annual (volumetric) evaporation for average conditions (over a long period of time) tends to equal the annual precipitation (**577,000 Km^3/year**) with 87.5% coming from oceans and 12.5% from land. The average annual evaporation from the oceans is approximately **505,000 Km^3/year** equal to **1398 mm/year** (Vol/Area x 10^6 mm/Km = [505,000 Km^3/year] /[361.3x10^6 Km^2]*10^6 mm/Km) or **55 in/year** and from land is **72,000 Km^3/year** equal to **484 mm/year** (Vol/Area x 10^6 mm/Km = [72,000 Km^3/year] /[148.8x10^6 Km^2]*10^6 mm/Km) or **19 in/year**

Quantitative Hydrologic Cycle

Quantitative Hydrologic Cycle

- The average annual runoff from land that discharges into the oceans would be the difference between the precipitation and evaporation (over land and from land, respectively). It is **47,000 Km^3**
- Of the average annual runoff that discharges into the oceans, 95.3% belongs to rivers or surface water and 4.7% to groundwater. Therefore the average annual discharge from rivers is **44,800 Km^3** and from groundwater is **2200 Km^3**
- With all the average calculations and assuming a long period of time, it is possible to develop a global annual water balance (or water budget) that can be summarized in the following table representing the water resources of the Earth

119,000 Km^3 – 72,000 Km^3 = 47,000 Km^3

47,000 Km^3 x 0.953 = 44,800 Km^3

47,000 Km^3 x 0.047 = 2200 Km^3

Water Resources of the Earth

Water Resources	Unit	Oceans	Land
Area	(Km^2)	**361,300,000***	**148,800,000**
Precipitation	(Km^3/yr)	**458,000**	**119,000**
	(mm/yr)	**1268**	**800**
	(in/yr)	**50**	**31**
Evaporation	(Km^3/yr)	**505,000**	**72,000**
	(mm/yr)	**1398**	**484**
	(in/yr)	**55**	**19**
Runoff to Oceans	(Km^3/yr)	—	**47,000**
	(mm/yr)	—	**316**
	(in/yr)	—	**12**
from Rivers	(Km^3/yr)	—	**44,800**
from Groundwater	(Km^3/yr)	—	**2200**

12,900 Km^3 x 35.5

12,900 Km^3 x 9.2

577,000 Km^3

458,000/361,300,000 x 10^6

119,000/148,800,000 x 10^6

577,000 Km^3 x 0.875

577,000 Km^3 x 0.125

505,000/361,300,000 x 10^6

72,000/148,800,000 x 10^6

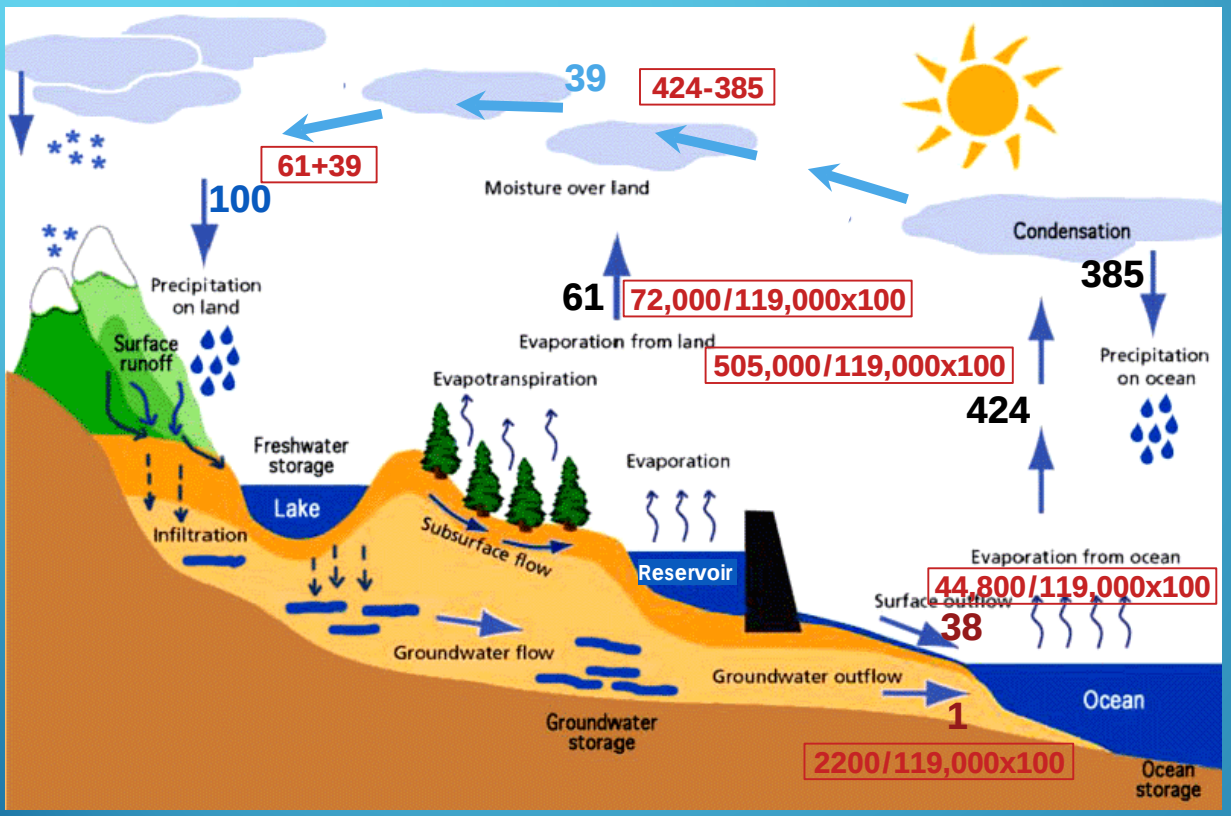
119,000 – 72,000

47,000/148,800,000 x 10^6

47,000 Km^3 x 0.953

47,000 Km^3 x 0.047

*** it also includes freshwater**



- Quantitative values for a ***HC*** (annual average) can be obtained from the previous table
- Assuming an arbitrary value of **100** units for the ***Precipitation on land*** (119,000 Km^3/119,000 Km^3x100)
- The ***Precipitation on ocean*** will be **385** units (458,000 Km^3/119,000 Km^3x100)
- Applying the same procedure, the units of all hydrologic components are estimated

Quantitative Hydrologic Cycle

Hydrologic Cycle: Conclusion

- The concept of the ***HC*** may seem to be simple, however all the processes acting on it are extremely intricate creating phenomena that to be evaluated require of significant knowledge of physics, chemistry, statistics and biology. Even so, it may never be totally understood. Without perfect knowledge, those phenomena have to be simplified by means of the ***systems*** concept and applying meaningful assumptions
- The global ***HC*** can be represented by a system that is comprised of three subsystems: atmospheric water system, surface water (hydrosphere) system and subsurface water (lithosphere) system. Each of them contains several processes or components

Hydrologic Cycle: Conclusion

- Hydrology of a region is defined by its weather patterns and by factors such as topography, geology and vegetation. Natural and mainly anthropogenic factors affect the natural water environment altering the dynamic equilibrium of the flora and fauna and the safety and health of humankind.
- As an example, it is known that mainly because the burning of fossil fuels, the amount of carbon dioxide (CO_2) in the atmosphere is increasing. This produces significant warming of the earth and far-reaching effects in global hydrology (i.e., sea level rise)

Residence Time (T_r)

- An important concept in hydrology and considerably valuable for water quality analysis is the *Residence Time* (T_r). It is defined as the average time for a water molecule to pass through any hydrologic system. This definition implies that a T_r can be estimated for a large subsystem of the hydrologic cycle of the Earth (or ***Global HC***) or a relative small hydraulic work (e.g., pond for a small community to retain water and improve water quality)
- *Residence Time* (T_r) is calculated by dividing the volume of water V_w in storage by the flow discharge Q,

$$T_r = \frac{V_w}{Q}$$

Residence Time (T_r)

- The flow discharge values in the previous equation are averages of quantities that may have significant spatial variation
- An interesting and useful application of this concept on a large scale problem would be to estimate T_r for the global atmospheric moisture. From the Table of ***Sources of Earth's Water***, V_w***=12,900 Km³*** (Water Volume in Atmosphere) and from the Table of ***Water Resources of the Earth***, ***Q=577,000 Km³/yr*** (458,000 and 119,000 Km^3/yr, precipitation on oceans and land, respectively), so

$$T_r = \frac{12{,}900 Km^3}{577{,}000 Km^3 / yr} = 8.16 days$$

Residence Time (T_r)

- This relatively very low *Residence Time* T_r for water moisture in the atmosphere is one reason why weather conditions cannot be predicted with reasonable accuracy more than a few days in advance
- Weather forecasting is however a more site-specific exercise that requires of changes in barometric pressure, current weather state, and sky condition being analyzed by computer-based models. The chaotic nature of atmosphere, excessive computational requirements, errors involved in measuring initial conditions, and incomplete understanding of its processes make forecasting a more difficult task as its range increases

Questions?

Thank you!