In the Name of God

Unit 1: The Hydrologic Cycle

Introduction

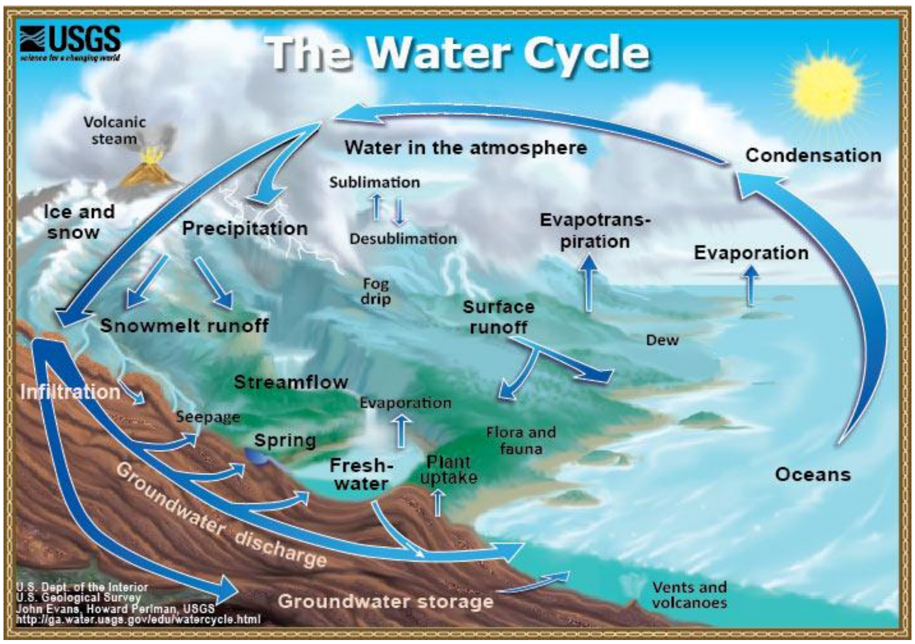
The **water cycle**, also known as the **hydrologic cycle** or **H_2O cycle**, describes the continuous movement of water on, above and below the surface of the Earth. Water can change states among **liquid**, **vapor**, and **solid** at various places in the water cycle. Although the balance of water on Earth remains fairly constant over time, individual water molecules can come and go, in and out of the **atmosphere**. The water moves from one **reservoir** to another, such as from **river** to **ocean**, or from the ocean to the atmosphere, by the physical processes of **evaporation**, **condensation**, **precipitation**, **infiltration**, **runoff**, and **subsurface flow**. In so doing, the water goes through different phases: liquid, solid, and **gas**.

The hydrologic cycle involves the exchange of **heat energy**, which leads to **temperature** changes. For instance, in the process of evaporation, water takes up energy from the surroundings and cools the environment. Conversely, in the process of condensation, water releases energy to its surroundings, **warming** the **environment**. The water cycle figures significantly in the maintenance of life and **ecosystems** on Earth. Even as water in each reservoir plays an important role, the water cycle brings added significance to the presence of water on our planet. By transferring water from one reservoir to another, the water cycle purifies water, replenishes the land with **freshwater**, and transports **minerals** to different parts of the **globe**. It is also involved in reshaping the **geological features** of the Earth, through such processes as **erosion** and **sedimentation**. In addition, as the water cycle also involves **heat exchange**, it exerts an influence on **climate** as well.

Description

The sun, which drives the water cycle, heats water in oceans and seas. Water evaporates as water vapor into the air. Ice and snow can **sublimate** directly into water vapor. **Evapotranspiration** is water transpired from plants and evaporated from the soil. Rising **air currents** take the vapor up into the atmosphere where cooler temperatures cause it to condense into **clouds**. Air currents move water vapor around the globe, cloud particles collide, grow, and fall out of the sky as precipitation. Some precipitation falls as **snow** or **hail**, sleet, and can accumulate as **ice caps** and

glaciers, which can store frozen water for thousands of years. Most water falls back into the oceans or onto land as **rain**, where the water flows over the ground as **surface runoff**. A portion of runoff enters rivers in **valleys** in the **landscape**, with **streamflow** moving water towards the oceans. Runoff and **groundwater** are stored as freshwater in **lakes**. Not all runoff flows into rivers, much of it soaks into the ground as **infiltration**. Some water infiltrates deep into the ground and replenishes **aquifers**, which store freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as groundwater **discharge**. Some groundwater finds openings in the land surface and comes out as freshwater **springs**. Over time, the water returns to the ocean, where our water cycle started. The figure below shows the story of water.



Processes

Many different process lead to movements and phase changes in water:

1- **Precipitation**: Precipitation is condensed water vapor that falls to the Earth's surface. Most precipitation occurs as rain, but also includes snow, hail, **fog drip**, **graupel**, and **sleet**. Approximately 505,000 km^3 (121,000 cu mi) of water falls as precipitation each year, 398,000 km^3 (95,000 cu mi) of it over the oceans.

2- **Canopy interception:** The precipitation that is intercepted by **plant foliage**, eventually evaporates back to the atmosphere rather than falling to the ground.

3- **Snowmelt:** The runoff produced by melting snow.

4- **Runoff:** The variety of ways by which water moves across the land. This includes both surface runoff and channel runoff. As it flows, the water may seep into the ground, evaporate into the air, become stored in lakes or reservoirs, or be extracted for agricultural or other human uses.

5- **Infiltration:** The flow of water from the ground surface into the ground. Once infiltrated, the water becomes soil moisture or groundwater.

6- **Subsurface flow:** The flow of water underground, in the **vadose zone** and aquifers. Subsurface water may return to the surface (e.g. as a spring or by being **pump**ed) or eventually seep into the oceans. Water returns to the land surface at lower elevation than where it infiltrated, under the **force of gravity** or gravity induced pressures. Groundwater tends to move slowly, and is replenished slowly, so it can remain in aquifers for thousands of years.

7- **Evaporation:** The transformation of water from liquid to gas phases as it moves from the ground or bodies of water into the overlying atmosphere. The source of energy for evaporation is primarily solar radiation. Evaporation often implicitly includes transpiration from plants, though together they are specifically referred to as evapotranspiration. Total annual evapotranspiration amounts to approximately 505,000 km^3 (121,000 cu mi) of water, 434,000 km^3 (104,000 cu mi) of which evaporates from the oceans.

8- **Sublimation:** The state change directly from solid water (snow or ice) to water vapor.

9- **Advection:** The movement of water — in solid, liquid, or vapor states — through the atmosphere. Without advection, water that evaporated over the oceans could not precipitate over land.

10- **Condensation:** The transformation of water vapor to liquid water droplets in the air, creating clouds and fog.

11- **Transpiration:** The release of water vapor from plants and soil into the air. Water vapor is a gas that cannot be seen.

Residence times

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 (see lake retention time)	50 to 100 years
Rivers	2 to 6 months
Atmosphere	9 days

The **residence time** of a reservoir within the hydrologic cycle is the average time a water molecule will spend in that reservoir (*see adjacent table*). It is a measure of the average age of the water in that reservoir.

Groundwater can spend over 10,000 years beneath Earth's surface before leaving. Particularly old groundwater is called fossil water. Water stored in the soil remains there very briefly, because it is spread thinly across the Earth, and is readily lost by evaporation, transpiration, stream flow, or groundwater **recharge**. After evaporating, the residence time in the atmosphere is about 9 days before condensing and falling to the Earth as precipitation.

The major **ice sheets** - **Antarctica** and **Greenland** - store ice for very long periods. Ice from Antarctica has been reliably dated to 800,000 years before present, though the average residence time is shorter.

In hydrology, residence times can be estimated in two ways. The more common method relies on the principle of conservation of mass and 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 (or how long it would take the reservoir to empty from full if no water were to enter).

An alternative method to estimate residence times, which is gaining in popularity for dating groundwater, is the use of **isotopic techniques**. This is done in the subfield of isotope hydrology.

Changes over time

The water cycle describes the processes that drive the movement of water throughout the **hydrosphere**. However, much more water is "in storage" for long periods of time than is actually moving through the cycle. The storehouses for the vast majority of all water on Earth are the oceans. It is estimated that of the 332,500,000 mi^3 (1,386,000,000 km^3) of the world's water supply, about 321,000,000 mi^3 (1,338,000,000 km^3) is stored in oceans, or about 95%. It is also estimated that the oceans supply about 90% of the evaporated water that goes into the water cycle.

During colder climatic periods more ice caps and glaciers form, and enough of the global water supply accumulates as ice to lessen the amounts in other parts of the water cycle. The reverse is true during warm periods. During the last ice age glaciers covered almost one-third of Earth's land mass, with the result being that the oceans were about 400 ft (122 m) lower than today. During the last global "**warm spell**," about 125,000 years ago, the seas were about 18 ft (5.5 m) higher than they are now. About three million years ago the oceans could have been up to 165 ft (50 m) higher.

The scientific consensus expressed in the 2007 Intergovernmental Panel on Climate Change (IPCC) Summary for Policymakers is for the water cycle to continue to intensify throughout the 21st century, though this does not mean that precipitation will increase in all regions. In **subtropical land areas** — places that are already relatively dry — precipitation is projected to decrease during the 21st century, increasing the probability of **drought**. The drying is projected to be strongest near the **poleward margins of the subtropics** (for example, the Mediterranean Basin, South Africa, southern Australia, and the Southwestern United States). Annual precipitation amounts are expected to increase in **near-equatorial regions** that tend to be wet in the present climate, and also at **high latitudes**. These large-scale patterns are present in nearly all of the climate model simulations conducted at several international research centers as part of the 4th Assessment of the IPCC. There is now ample evidence that increased **hydrologic variability** and change in climate has and will continue have a profound impact on the water sector through the hydrologic cycle, **water availability**, **water demand**, and **water allocation** at the global, regional, **basin**, and local levels.

Glacial retreat is also an example of a changing water cycle, where the **supply of water** to glaciers from precipitation cannot keep up with the loss of water from melting and sublimation. Glacial retreat since 1850 has been extensive.

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**

Effects on climate

The water cycle is powered from solar energy. 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**.

Aquifer **drawdown** or **overdrafting** and the pumping of **fossil water** increases the total amount of water in the hydrosphere that is subject to transpiration and evaporation thereby causing accretion in water vapour and cloud cover which are the primary absorbers of **infrared radiation** in the Earth's atmosphere. Adding water to the system has a forcing effect on the whole earth system, an accurate estimate of which **hydrogeological** fact is yet to be quantified.

Effects on biogeochemical cycling

While the water cycle is itself a **biogeochemical cycle**, flow of water over and beneath the Earth is a key component of the cycling of other biogeochemicals. 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. The dead zone at the outlet of the Mississippi River is a consequence of **nitrates** from fertilizer being carried off agricultural fields and funnelled down the river system to the Gulf of Mexico. Runoff also plays a part in the **carbon cycle**, again through the transport of eroded **rock** and **soil**.

Slow loss over geologic time

The **hydrodynamic wind** within the upper portion of a planet's atmosphere allows light chemical elements such as **Hydrogen** to move up to the **exobase**, the lower limit of the **exosphere**, where the gases can then reach escape velocity, entering outer space without impacting other particles of gas. This type of gas loss from a planet into space is known as planetary wind. Planets with hot lower atmospheres could result in **humid** upper atmospheres that accelerate the loss of hydrogen.

Top 10 Scientific Journals related to Water Sciences

1- *Water Resources Research*
2- *Water Resources Development*
3- *Journal of the American Water Resources Association (Water Resources Bulletin)*
4- *Water Research*
5- *Water Science and Technology*
6- *Journal of Hydrology*
7- *Hydrological Processes*
8- *Hydrological Sciences Journal*
9- *Journal of Spatial Hydrology*
10- *Hydrology and Earth System Sciences*