## Introduction and the review of water cycle

A basic understanding of the water cycle and the properties of water is critical when working towards protection and sustainable utilisation of water. By appreciating the water cycle it becomes easier for students to understand the complex ways in which various land uses can affect our catchments. Similarly, the concepts learnt about the properties of water will form a good grounding for understandings needed in later lectures. For example, in order to understand how water can get polluted you need to understand that water has the potential to dissolve things and hold them in suspension, similarly it helps to understand how the kinetic energy of flowing water has the power to erode landforms. 97% of the Earth’s water is too salty for consumption and use by humans. Similarly, the majority of the remaining 3% is fresh water and can’t be used as it is locked in glaciers, and icebergs. Accessible freshwater comes from streams, lakes and underground sources. These sources represent less than half of 1%of all water on Earth.

### What is the Water Cycle?

Fresh water is replenished through a continuous cycle involving the evaporation of surface waters, oceans and other moisture. Energy from the sun heats the water, causing it to evaporate and rise as water vapour into the atmosphere. As the water vapour rises it cools and condenses to form clouds. The water cycle is a closed cycle, as there are no new inputs of water from external sources. The Earth's rotation and the different rates at which air masses are heated and cooled create the winds that transport the condensed water vapour. When conditions are favourable, the condensed water vapour will be released as precipitation (rain, snow etc.) which returns to the Earth's surface so the cycle can begin again.

The **water cycle**, also known as the **hydrologic cycle** or the **hydrological cycle**, describes the continuous movement of water on, above and below the surface of the Earth. The mass of water on Earth remains fairly constant over time but the partitioning of the water into the major reservoirs of ice, fresh water, saline water and atmospheric water is variable depending on a wide range of climatic variables. 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 as stated above, condensation, precipitation, infiltration, surface runoff, and subsurface flow. In doing so, the water goes through different forms: liquid, solid (ice) and vapor.

The water cycle involves the exchange of energy, which leads to temperature changes. When water evaporates, it takes up energy from its surroundings and cools the environment. When it condenses, it releases energy and warms the environment. These heat exchanges influence climate. The evaporative phase of the cycle purifies water which then replenishes the land with freshwater. The flow of liquid water and ice transports minerals across the globe. It is also involved in reshaping the geological features of the Earth, through processes including erosion and sedimentation. The water cycle is also essential for the maintenance of most life and ecosystems on the planet. The sun, which drives the water cycle, heats water in oceans and seas. Water evaporates as water vapor into the air. Some ice and snow sublimates directly into water vapor. Evapotranspiration is water transpired from plants and evaporated from the soil. The water molecule H2O has smaller molecular mass than the major components of the atmosphere, nitrogen and oxygen, N2 and O2, hence is less dense. Due to the significant difference in density, buoyancy drives humid air higher. As altitude increases, air pressure decreases and the temperature drops. The lower temperature causes water vapor to condense into tiny liquid water droplets which are heavier than the air, and fall unless supported by an updraft. A huge concentration of these droplets over a large space up in the atmosphere become visible as cloud. Some condensation is near ground level, and called fog.

Atmospheric circulation moves water vapor around the globe; cloud particles collide, grow, and fall out of the upper atmospheric layers 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 water emerging from the ground (groundwater) may be 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 can 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. In river valleys and floodplains, there is often continuous water exchange between surface water and ground water in the hyporheic zone. Over time, the water returns to the ocean, to continue the water cycle.

### Deep Water Recycling

The water cycle through degassing and deep recycling via subduction zones. The long-term exchange of water between the earth's interior and the exosphere and transport of water bound in hydrous minerals.

## Processes

Many different processes lead to movements and phase changes in water

Precipitation

> 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.

Subduction & Mineral hydration

> Sea water seeps into the oceanic lithosphere through fractures and pores, and reacts with minerals in the crust and mantle to form hydrous minerals (such as serpentine) that store water in their crystal structures. Water is transported into the deep mantle via hydrous minerals in subducting slabs. During subduction, a series of minerals in these slabs such as serpentine can be stable at different pressures within the slab geotherms, and may transport significant amount of water into the Earth's interior. As plates sink and heat up, released fluids can trigger seismicity and induce melting within the subducted plate and in the overlying mantle wedge. This type of melting selectively concentrates volatiles and transports them into the overlying plate. If an eruption occurs, the cycle then returns the volatiles into the oceans and atmosphere

Canopy interception

> The precipitation that is intercepted by plant foliage eventually evaporates back to the atmosphere rather than falling to the ground.

Snow melt

> The runoff produced by melting snow.

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.

Infiltration

The flow of water from the ground surface into the ground. Once infiltrated, the water becomes soil moisture or groundwater. A recent global study using water stable isotopes, however, shows that not all soil moisture is equally available for groundwater recharge or for plant transpiration.

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 pumped) 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.

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.

Sublimation

The state change directly from solid water (snow or ice) to water vapor by passing the liquid state.

Deposition

This refers to changing of water vapor directly to ice.

Advection

The movement of water through the atmosphere. Without advection, water that evaporated over the oceans could not precipitate over land.

Condensation

The transformation of water vapor to liquid water droplets in the air, creating clouds and fog.

Transpiration

The release of water vapor from plants and soil into the air.

Percolation

Water flows vertically through the soil and rocks under the influence of gravity.

Plate tectonics

Water enters the mantle via subduction of oceanic crust. Water returns to the surface via volcanism.

The water cycle involves many of these processes.

**The residence time.**

The *residence time* of a reservoir within the hydrologic cycle is the average time a water molecule will spend in that reservoir. 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.

In hydrology, residence times can be estimated in two ways. The more common method relies on the principle of conservation of mass (water balance) 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.

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. 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. Fundamental thermodynamics and climate models suggest that dry regions will become drier and wet regions will become wetter in response to warming. Efforts to detect this long-term response in sparse surface observations of rainfall and evaporation remain ambiguous. We show that ocean salinity patterns express an identifiable fingerprint of an intensifying water cycle. Our 50-year observed global surface salinity changes, combined with changes from global climate models, present robust evidence of an intensified global water cycle at a rate of 8 ± 5% per degree of surface warming. This rate is double the response projected by current-generation climate models and suggests that a substantial (16 to 24%) intensification of the global water cycle will occur in a future 2° to 3° warmer world.

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.

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 - to counteract its impact, water-sensitive urban design can be practiced

**Effects on climate**

The water cycle is powered from solar energy. Most 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 and a warmer planet. Aquifer drawdown or over drafting and the pumping of fossil water increases the total amount of water in the hydrosphere, and has been postulated to be a contributor to sea-level rise.

## 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.

## 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.

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