DP IB Environmental Systems & Societies (ESS): HL

Your notes

4.1 Water Systems

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Hydrological Cycle

Water on Earth

- The **hydrosphere** includes all Earth's water, such as oceans, rivers, lakes and atmospheric moisture
  - Fresh water only makes up a small fraction (approximately 2.5% by volume) of the Earth's water storages
  - Of this fresh water, approximately 69% is stored in glaciers and ice sheets and 30% is stored as groundwater
  - The remaining 1% of freshwater is in rivers, lakes and the atmosphere
- All water is part of the **hydrological cycle**

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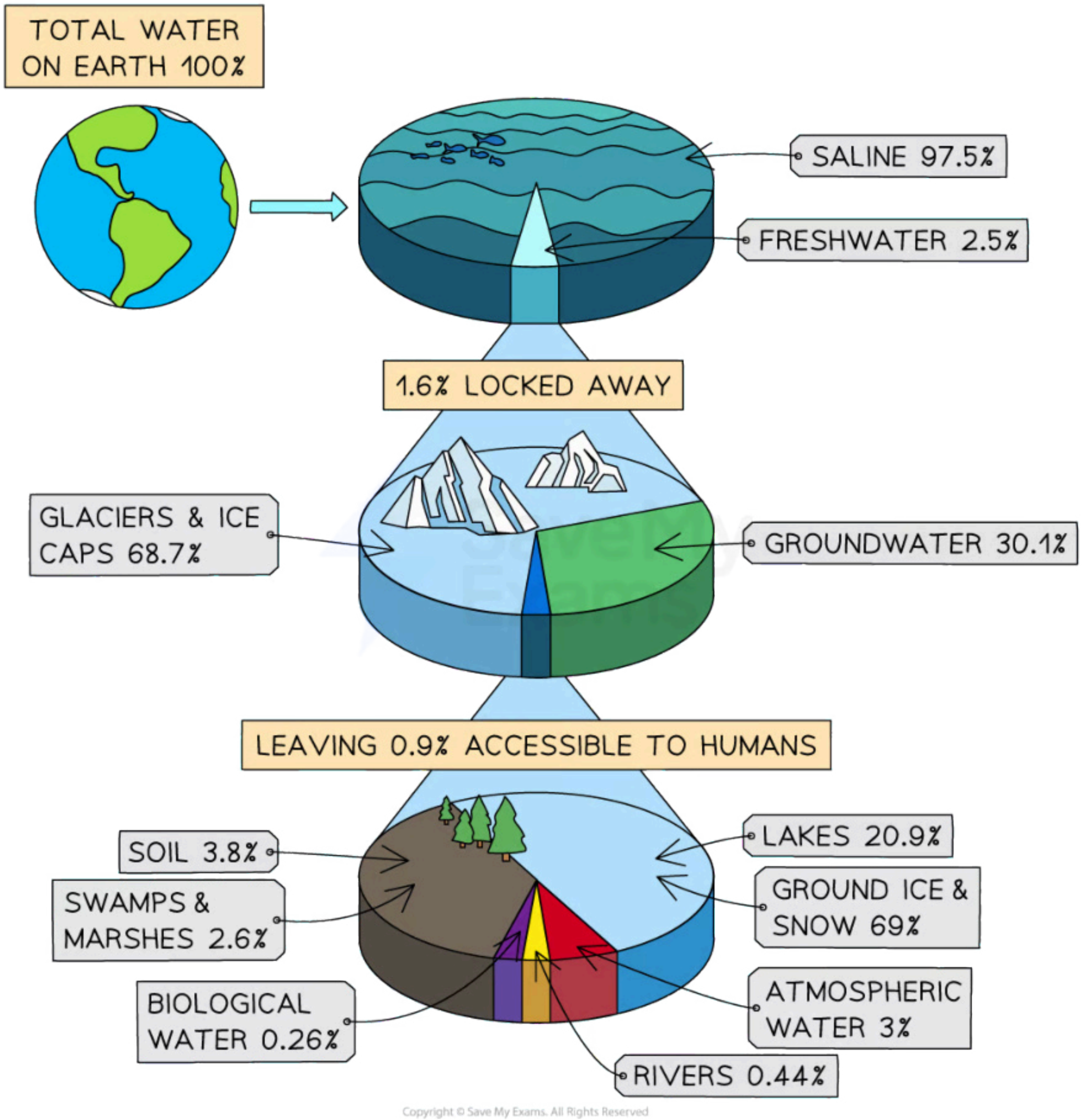

Comparison of the world's freshwater stores

Driving forces of the hydrological cycle

- **Gravity** and **solar radiation** both influence the movement of water in the hydrosphere
  - The Sun's heat causes water to evaporate from oceans, lakes, and rivers
  - Water vapour cools and condenses into clouds, releasing heat

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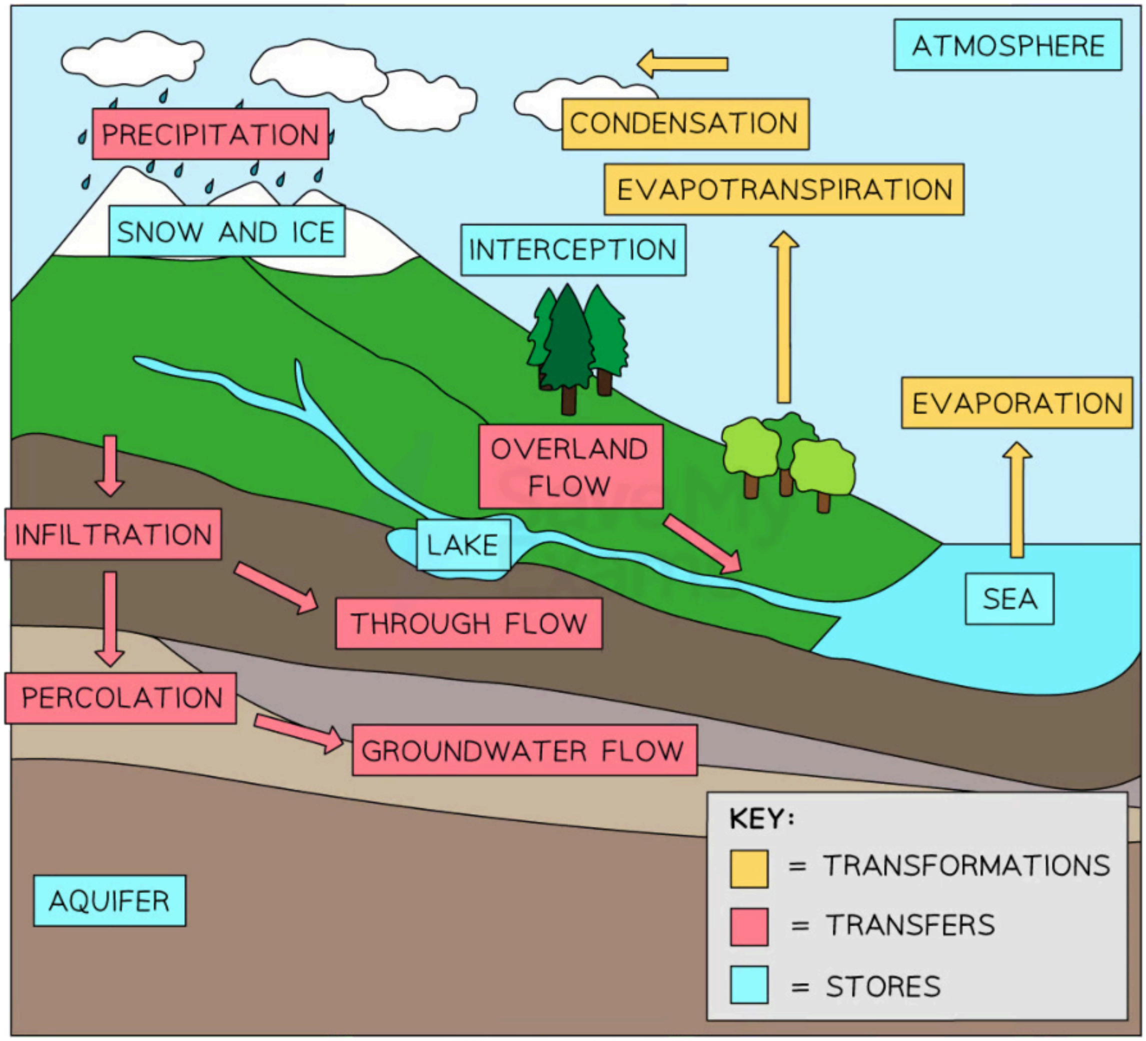
- Gravity pulls condensed water back to Earth via the process of precipitation (rain, snow, sleet, or hail).
- Gravity causes water to flow over land into rivers and streams (runoff) and drain through soil
- Rivers flow downhill due to gravity, moving water from inland back to the oceans

Components of the hydrological cycle

- The global hydrological cycle is a **closed system**
- Within the hydrological cycle, there are **stores** and **flows**
- The hydrological cycle is a series of processes in which water is **constantly recycled** through the system
  - The cycle also shapes landscapes, transports minerals and is essential to life on Earth
- The main **stores** occurring within the hydrological cycle are:
  - Oceans
  - Glaciers and ice caps
  - Groundwater and **aquifers**
  - Surface freshwater (rivers and lakes)
  - Atmosphere
- The main **flows** occurring within the hydrological cycle are:
  - **Transformations**: processes where the state or form of water changes, e.g.
    - Evaporation (the sun evaporates surface water into vapour)
    - Condensation (water vapour condenses and precipitates)
  - **Transfers**: movements of water from one location to another without changing state, e.g.
    - Water runs off the surface into streams and reservoirs or beneath the surface as ground flow
- These flows **move** the water on Earth from one **store** to another (river to ocean or ocean to atmosphere)



The hydrological cycle

Flows in the hydrological cycle

- Flows in the hydrological cycle include the following:

Flows in the Hydrological Cycle

Flow	Type	Description

Evaporation	Transformation	The process by which liquid water changes into a gaseous state (water vapour) and enters the atmosphere from water bodies such as oceans, lakes, and rivers
Transpiration	Transformation	The process by which plants absorb water from the soil through their roots and release it as water vapour through tiny openings called stomata in their leaves
Evapotranspiration	Transformation	The combined process of water vaporisation from the Earth's surface (evaporation) and the release of water vapour by plants (transpiration)
Sublimation	Transformation	The direct transition of water from a solid state (ice or snow) to a vapour state without melting first
Condensation	Transformation	The process by which water vapour in the atmosphere transforms into liquid water, forming clouds or dew, as a result of cooling
Melting	Transformation	The process by which solid ice or snow changes into liquid water due to an increase in temperature
Freezing	Transformation	The process by which liquid water changes into a solid state (ice or snow) due to a decrease in temperature
Advection	Transfer	The wind-blown movement of water vapour or condensed/frozen water droplets (clouds)
Precipitation	Transfer	The process of water falling from the atmosphere to the Earth's surface in the form of rain, snow, sleet, or hail
Surface run-off	Transfer	The movement of water over the Earth's surface typically occurs when the ground is saturated or impermeable, leading to excess water
Infiltration	Transfer	The process of water seeping into the soil from the surface, entering the soil layers and becoming groundwater

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Percolation	Transfer	The downward movement of water through the soil and underlying rock layers, eventually reaches aquifers or groundwater reservoirs
Streamflow	Transfer	The movement of water in streams, rivers, or other water bodies, driven by gravity and the slope of the land, ultimately leads to oceans or lakes
Groundwater flow	Transfer	The movement of water through the pores and spaces in underground soil and rock layers, often moving towards rivers, lakes or oceans

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EXAMINER TIP

Remember that percolation and infiltration are not the same. Percolation happens **after** the water has infiltrated the soil.

Human Impacts on the Hydrological Cycle

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Human Impacts on the Hydrological Cycle

- Human activities have significant impacts on the hydrological cycle
  - They alter the natural processes of **surface run-off** and **infiltration**
- These activities include:
  - Agriculture (specifically irrigation)
  - Deforestation
  - Urbanisation

Agricultural irrigation has a significant impact on the hydrological cycle (photo by Przemyslaw Stroinski on Unsplash)

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Impact of agriculture and irrigation

- Irrigation is the process of artificially supplying water to crops
  - It has a direct impact on the hydrological cycle by modifying the water **distribution** and **availability** in a region
- Increased irrigation leads to:
  - **Artificially high evapotranspiration** rates
  - This is because more water is supplied to plants than would occur naturally
  - This results in increased atmospheric moisture levels
  - This can lead to localised **increases in precipitation** downwind of irrigated areas, altering rainfall patterns in the region
- Excessive irrigation can also result in **increased surface run-off**
  - Water is applied faster than the soil can absorb it
  - This causes water to flow over the soil surface, carrying sediments, fertilisers, and pesticides
  - This leads to **water pollution** and **nutrient imbalances**

Impact of deforestation

- Deforestation refers to the clearing or removal of forests
  - This is primarily for agriculture, logging or urban development purposes
- Forests play a crucial role in the hydrological cycle
  - They act like natural **sponges**
  - They absorb rainfall and facilitate infiltration
    - This helps to **recharge groundwater** and maintain stream flows
- When forests are cleared, **surface runoff increases** significantly
  - Without the tree canopy and vegetation to intercept and slow down rainfall, more water reaches the ground surface
  - This leads to higher surface runoff rates

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- Deforestation also **reduces evapotranspiration** rates
  - As trees are removed, there is less transpiration and evaporation occurring
  - This results in reduced moisture release into the atmosphere
- Overall, deforestation disrupts the balance between surface run-off and infiltration
  - This can lead to **increased erosion**, reduced groundwater recharge and altered stream flow patterns

Impact of urbanisation

Urbanisation has a significant impact on the hydrological cycle (photo by Chris Gallagher on Unsplash)

- Urbanisation involves the transformation of natural landscapes into urban areas with buildings, roads and infrastructure
- Urban development significantly alters the hydrological cycle by:
  - Replacing permeable surfaces (such as soil and vegetation) with **impermeable surfaces** (concrete, asphalt)
    - Impermeable surfaces **prevent infiltration**

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        - This leads to **reduced groundwater recharge**
        - Instead of infiltrating into the soil, rainfall quickly becomes surface run-off
        - This results in **increased flooding** and diminished water availability during dry periods
- Urban areas typically have efficient drainage systems designed to quickly remove excess water
    - This further accelerates surface run-off
    - This can **overload natural water bodies** and cause downstream flooding
- Urban areas often experience higher temperatures due to the urban heat island effect
    - This effect is caused by the concentration of buildings and paved surfaces
    - It can lead to increased evaporation rates
    - This can alter local precipitation patterns

Steady State of Water Bodies

- Understanding the steady state of a water body involves analysing the **balance** between **inputs** and **outputs**
    - This balance ensures that the water level remains **constant over time**

Flow diagrams of inputs and outputs

- Flow diagrams visually represent the water inputs and outputs for a water body
- **Inputs**: e.g.
    - **Precipitation**: rain, snow, or other forms of water falling directly into the water body
    - **Surface run-off**: water flowing over the land into the water body
    - **Groundwater Inflow**: water moving into the water body from underground sources
- **Outputs**: e.g.
    - **Evaporation**: water turning into vapour and leaving the water body
    - **River outflow**: water leaving the water body through rivers or streams
    - **Groundwater outflow**: water moving out of the water body into underground aquifers
    - **Agricultural extraction**: water that is extracted for irrigation
- For example, a lake that is at a steady state may have the following inputs and outputs:
    - **Inputs**: river inflow (80 units), rainfall (30 units), groundwater inflow (40 units), surface run-off (30 units)

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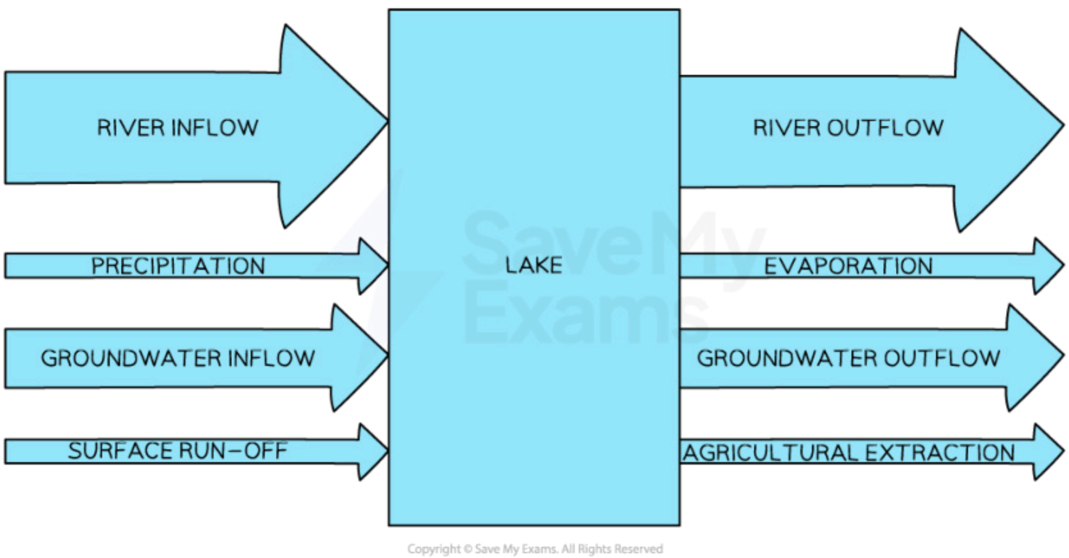
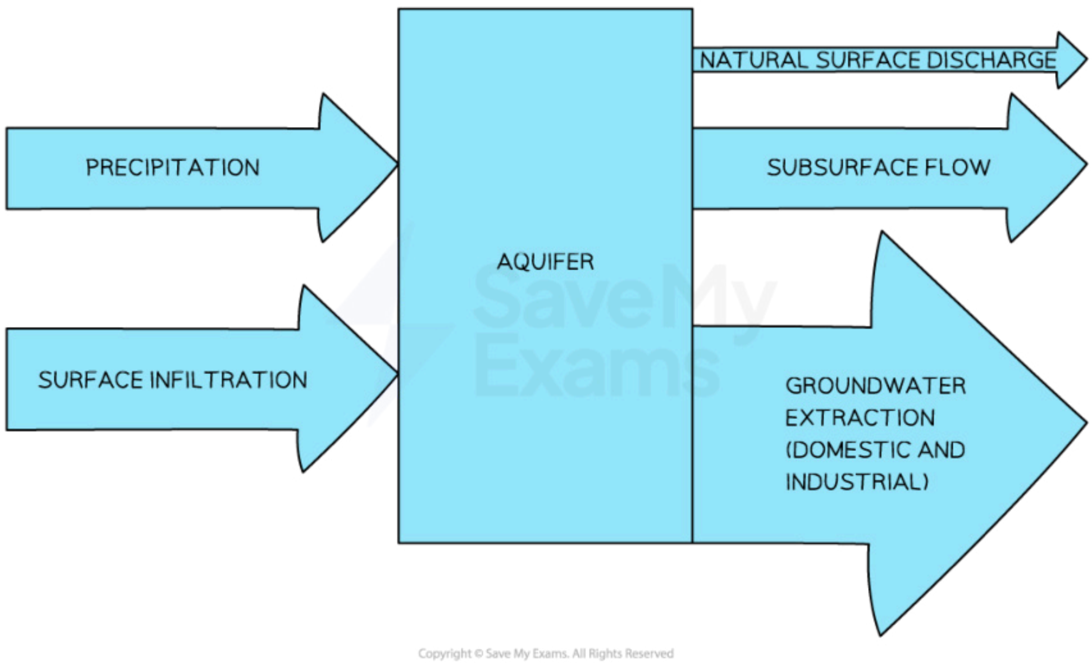
  - **Outputs**: river outflow (80 units), evaporation (30 units), groundwater outflow (40 units), agricultural extraction (30 units)
  - **Steady state**: inputs (180 units) equal outputs (180 units)
- This is an example of **sustainable water harvesting**
  - Sustainable harvesting means taking water from a water body at a rate that does **not exceed** the rate of **natural replenishment**
  - Assessing the total inputs and outputs of a water body can help calculate sustainable rates of water harvesting
  - This ensures the harvested water amount does not disrupt the steady state



Sustainable water harvesting

- If total outputs are greater than total inputs, then the water body will **decrease in size**
  - This may be due to unsustainable water harvesting for **agriculture** or for **domestic** and **industrial purposes,** e.g. water used in drinking, cleaning, heating and cooling systems, and manufacturing processes
  - Water may be extracted faster than it can be naturally replenished
- For example, an aquifer that is being unsustainably harvested (and therefore is not at a steady state) may have the following inputs and outputs:
  - **Inputs**: precipitation (70 units), surface infiltration (80 units)

   - **Outputs**: natural surface discharge (30 units), subsurface flow (70 units), groundwater extraction for domestic and industrial use (150 units)
   - **Steady state disruption**: inputs (150 units) are less than outputs (250 units), causing a **water deficit** of 100 units
- This is why groundwater extraction must be **balanced** with recharge rates—to **prevent aquifer depletion**



Unsustainable water harvesting