

AQA Geography A-Level

3.1.1: Water and Carbon Cycles

Essential Notes

Systems

Systems are composed of:

- **Inputs** - Where matter or energy is added to the system
- **Outputs** - Where matter or energy leaves the system
- **Stores** - Where matter or energy builds up in the system
- **Flows** - Where matter or energy moves in the system
- **Boundaries** - Limits to the system (e.g. watershed)

Open systems are when systems receive inputs and transfer outputs of **energy or matter** with other systems. **Closed systems** are when energy inputs equal outputs. **Dynamic equilibrium** in a system is when **inputs equal outputs** despite changing conditions. **Positive feedback** occurs when a chain of events **amplifies** the impacts of the original event, whereas **negative feedback** refers to a chain of events that **nullifies** the impacts of the original event, leading to **dynamic equilibrium**.

On a **local scale** the carbon and water cycles are both **open systems**, but on a **global scale**, they are **closed systems**. Each of these systems contains **flows/transfers, inputs, outputs and stores/components**.

The Water Cycle: Local Scale

In a **local drainage basin system**, water may be lost as an **output** through **evapotranspiration and runoff**, but more water may be gained as an **input** through **precipitation**. As the inputs and outputs are not balanced, it is an **open system**.

Inputs:

- Precipitation

Outputs:

- Evapotranspiration - The combined return of water to the atmosphere from evaporation and transpiration (plants)
- Streamflow - Water that flows through streams and into the ocean or as tributaries to other rivers

Stores:

- Groundwater - Water stored in the pore spaces of rocks
- Soil Water
- Rivers
- Interception - Water stored temporarily by trees etc, before it reaches the ground
- Surface

Flows:

- Infiltration - Water moving from above ground into the soil.
- Percolation - Water moves from the ground or soil into porous rock or rock fractures.
- Throughflow - Flow of water through the soil
- Surface Runoff
- Groundwater Flow - Flow of water through the rocks
- Streamflow
- Stemflow - Flow of water that has been intercepted by plants or trees, down a stem, leaf, branch or other part of a plant

The **water balance** is used to express the process of **water storage and transfer** in a drainage basin system and uses the formula:

$$\text{Precipitation} = \text{Total Runoff} + \text{Evapotranspiration} \pm \text{Storage}$$

It is important to use the water balance in your answers and to know what the balance is affected by, as it could be applied to explain **droughts or floods**.

The water cycle is impacted on a local scale by:

- **Deforestation** - Less interception.
Soil less able to store water
- **Storm Events** - Increases runoff and water storage
- **Seasonal Changes** - More interception in spring; Snow reduces flows; Hot weather reduces precipitation
- **Agriculture** - Pastoral (Livestock) ground trampled so less infiltration; Arable (Crops) - Ploughing increases infiltration. Ditches increase runoff
- **Urbanisation** - Impermeable surfaces increase runoff

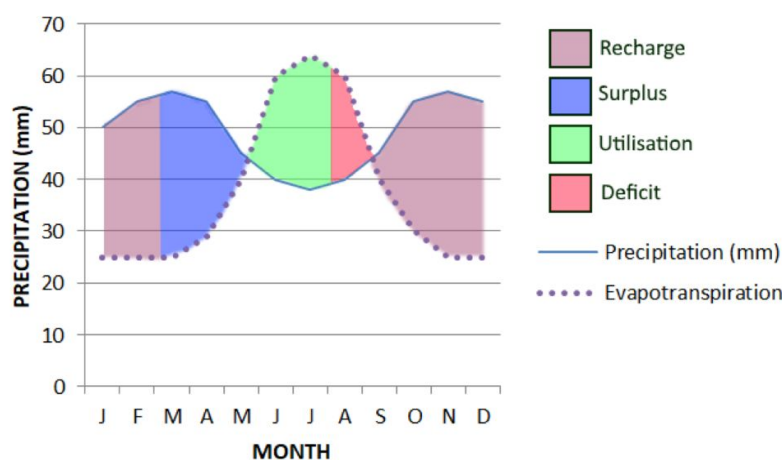
The **soil water budget** shows the annual **balance** between **inputs** and **outputs** in the water cycle. The soil water budget also shows how inputs and outputs impact **soil water storage and availability**.

There is a **surplus** of water in the winter months, after **recharge** of soil water in autumn. Soil water is **recharged** in autumn because the **inputs** of precipitation **exceed** the outputs of evapotranspiration (because it rains more and it is cooler).

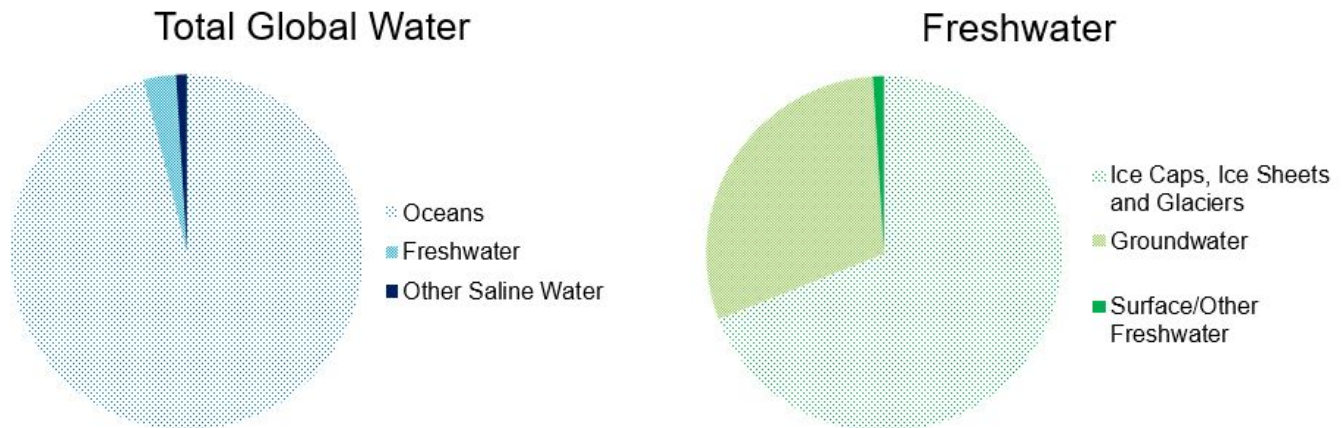
The water is **utilised** in spring and summer, when potential evapotranspiration of plants is highest due to warmer weather.

The stores are **depleting** when **evapotranspiration is greater than precipitation**. This can lead to a **deficit** of soil water.

Maximum storage of water in the soil is **field capacity**. The water budget is dependent on **type, depth and permeability of the soil and bedrock**.



The Water Cycle: Global Scale



Water can be stored in four areas:

- **Hydrosphere** - Any liquid water
 - **Lithosphere** - Water stored in the crust and upper mantle
 - **Cryosphere** - Any water that is frozen
 - **Atmosphere** - Water vapour
- **Aquifers** are underground water stores and on a global scale they are unevenly distributed.
 - **Shallow groundwater aquifers** can store water for up to **200 years**, but **deeper fossil aquifers**, formed during wetter climatic periods, may last for **10,000 years**.
 - From accumulation to ablation/calving, **glaciers** may store water for **20-100 years**, which may feed **lakes** that store water for **50-100 years**.
 - **Seasonal snow cover** and **rivers**, both store water for **2-6 months**
 - **Soil water** acts as a more temporary store, holding water for **1-2 months**.

The Water Cycle: Changes over Time

Natural Processes

Seasonal Changes:

- Less precipitation, more evaporation in summer because of higher temperatures
- Reduced flows in winter as water is stored as ice
- Reduced interception in winter, when deciduous trees lose their leaves
- Increased evapotranspiration in summer; deciduous trees have their leaves/higher temperatures

Human Impacts

Farming Practices:

- Ploughing breaks up the surface, increasing infiltration
- Arable farming (crops) can increase interception and evapotranspiration
- Pastoral (animal) farming compacts soil, reducing infiltration and increasing runoff

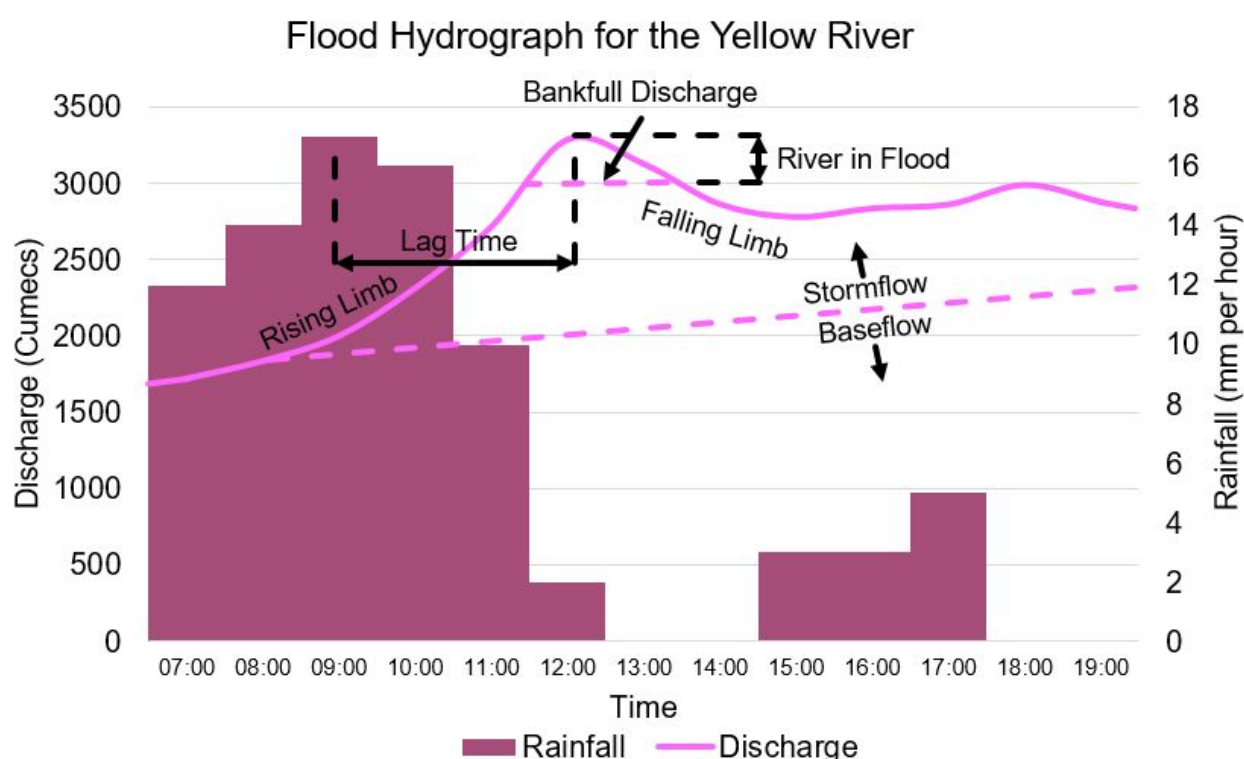
Land Use Change:

- Deforestation (e.g. for farming) reduces interception, evapotranspiration and but infiltration increases (dead plant material in forests usually prevents infiltration)
- Construction reduces infiltration and evapotranspiration, but increases runoff

Water Abstraction (water removed from stores for human use):

- This reduces the volume of water in surface stores (e.g. lakes).
- Water abstraction increases in dry seasons (e.g. water is needed for irrigation)
- Human abstraction from aquifers as an output to meet water demands is often greater than inputs to the aquifer, leading to a decline in global long-term water stores

Flood Hydrographs



A **flood hydrograph** is used to represent **rainfall** for the drainage basin of a river and the **discharge** of the same river on a graph. The key components are labelled above. Numerous factors affect whether the flood hydrograph will be:

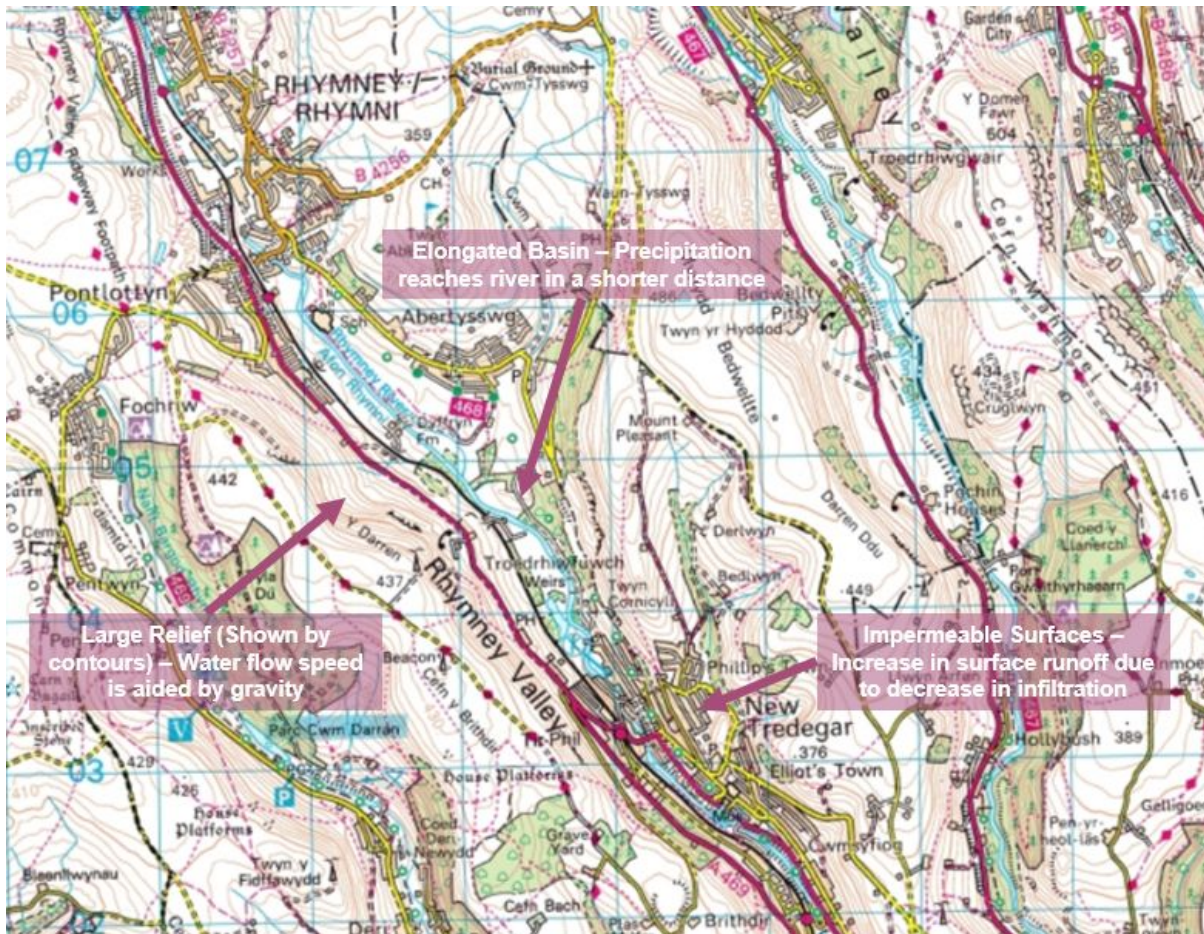
Flashy:

- Short lag time
- Steep rising and falling limb
- Higher flood risk
- High peak discharge

Subdued:

- Long lag time
- Gradually rising and falling limb
- Lower flood risk
- Low peak discharge

Some of the factors which would **increase** surface runoff of a river and therefore act to create a flashy hydrograph are shown on the OS Map, and others are listed below:



- **Pastoral Farming** - Ground trampled so less interception
- **Deforestation** - Less interception
- **High Rainfall Intensity** - Higher discharge potential
- **Antecedent Rainfall** - Increased surface runoff as ground is saturated
- **Impermeable Underlying Geology** - Decreased infiltration
- **High Drainage Density** - Many tributaries to main river

The Carbon Cycle: Local Scale

The carbon cycle occurs on a **local scale** in a plant, or sere such as the **lithosere**, which is a **vegetation succession** that occurs on **bare rock**. Over time a soil builds up on the rock from **decaying organic matter**. The **climatic climax** (final stage of a vegetation succession) is achieved when the **ecosystem** can develop no further. E.g. when a **woodland** is formed.

The Carbon Cycle: Global Scale

Transfers:

- **Photosynthesis** - Living organisms convert **Carbon Dioxide** from the atmosphere and **Water** from the soil, into **Oxygen** and **Glucose** using **Light Energy**. This removes CO₂ from the atmosphere
- **Respiration** - The opposite of photosynthesis
- **Combustion** (Burning fossil fuels, wildfires etc.) - Releases CO₂ into the atmosphere
- **Decomposition** - When living organisms die, they are **broken down by decomposers** which **respire**, returning CO₂ into the atmosphere. Some carbon is also **returned to the soil**
- **Diffusion** - The **oceans can absorb CO₂** from the atmosphere, but this harms aquatic life by causing **coral bleaching**
- **Weathering and Erosion** - Rock particles broken down and transferred to the ocean, where the carbon is used by marine organisms to create shells
- **Burial and Compaction** - Sea shell fragments become **compacted over time** to form **limestone** and organic matter may form **fossil fuels**
- **Carbon Sequestration** - Transfer of carbon from the atmosphere and can be both **natural and artificial**

Main Carbon Stores (In order of magnitude):

- **Marine Sediments and Sedimentary Rocks** - Lithosphere - Long-term
- **Oceans** - Hydrosphere - Dynamic
- **Fossil Fuel Deposits** - Lithosphere - Long-term but currently dynamic
- **Soil Organic Matter** - Lithosphere - Mid-term
- **Atmosphere** - Dynamic
- **Terrestrial Plants** - Biosphere - Mid-term but very dynamic

The **lithosphere** is the **main store of carbon**, with global stores **unevenly distributed**. For example, the **oceans** are larger in the **southern hemisphere**, and **storage in the biosphere** mostly occurs on land. **Terrestrial plant storage** is focussed in the **tropics** and the **northern hemisphere**.

The Carbon Cycle: Changes Over Time

Natural Processes

Wildfires: Transfer carbon from **biosphere** to **atmosphere** as CO₂ is released through burning. Can encourage the growth of plants in the long term

Volcanic Activity: Carbon stored within the earth is released during **volcanic eruptions**, mainly as CO₂ gas

Human Impacts

Fossil Fuel Use - Combustion transfers CO₂ to the atmosphere from a **long-term carbon sink**

Deforestation - Often used to clear land for farming/housing, rapidly releases carbon stored in plants using **slash and burn** techniques and interrupting the forest carbon cycle

Farming Practices - **Arable farming** releases CO₂ as animals respire. **Ploughing** can release CO₂ stored in the soil. Farm machinery such as tractors may release CO₂.

The **Carbon Budget** is the balance between carbon **inputs and outputs** to a store at any scale:
E.g. The carbon budget in the atmosphere has **inputs from respiration and combustion**, but **outputs including the oceans/photosynthesis**

Carbon Source - A store that **emits more carbon than it absorbs**:
E.g. a damaged rainforest

Carbon Sink - A store that **absorbs more carbon than it emits**:
E.g. a virgin rainforest

The Enhanced Greenhouse Effect

The **Enhanced Greenhouse Effect** is the process that is currently causing global warming as abnormally **high levels of greenhouse gases** are being produced by humans, **trapping radiation from the sun**, causing global warming and leading to climate change. It is important that you discuss the **Enhanced Greenhouse Effect** when assessing human impacts on the global climate, not the **Greenhouse Effect**, which is a natural process

Impact of the Carbon Cycle on Regional Climates

Tropical Rainforests:

- **High rates of photosynthesis and respiration** in forests lead to **greater humidity, cloud cover and precipitation**
- **Deforestation reduces photosynthesis and respiration**, further **reducing humidity and cloud cover and decreasing precipitation**

Oceans:

- **Warmer oceans** cause **more plankton growth** and through plankton **chemical production**, cause **clouds** to potentially form

Feedback Loops

Positive Feedback:

- **Wildfires** are more likely in hotter and drier climates due to global warming, which release large quantities of CO₂ into atmosphere, which in turn then increases the warming effect
- **Ice reflects radiation from the sun**, reducing surface warming. As **sea temperatures rise and ice melts**, the warming effect is amplified as there is **less ice to reflect the radiation**. Further melting occurs and the process continues
- Higher temperatures are **thawing the permafrost releasing CO₂ and methane** (which has 20 times the warming effect of CO₂), causing warming on a local and global scale. The higher temperatures cause more permafrost to melt, causing further gas releases and further warming

Negative Feedback:

- **Increased photosynthesis** by plants and rising global temperatures allows **vegetation to grow in new areas**, e.g. where permafrost has melted. New vegetation absorbs CO₂ from the atmosphere, decreasing the warming effect

- Higher temperatures and more CO₂ cause a **greater carbon fertilisation in plants**, so they absorb more CO₂, reducing the levels of CO₂ and the rates of warming and then the carbon fertilisation, if temperatures decline. The process repeats
- **Phytoplankton photosynthesise to gain energy** and warmer oceans and more sunlight due to climate change boost this and the **production of a chemical by the plankton which causes cloud formation**. Increased cloud cover decreases warming by the sun and more photosynthesis reduces CO₂ levels, reducing the levels of warming. The plankton grow less quickly and less of the chemical is increased decreasing cloud cover. The cycle continues

Tropical Rainforests: Interrelationships between the Cycles

Natural Rainforest Water Cycle:

- Precipitation falls
- **75% intercepted by trees** and through stem flow **35% reaches the ground** and infiltrates the soil and another **35% is used by plants** and through transpiration returns to the atmosphere
- **25% evaporates** almost immediately and returns to the atmosphere

Deforested Rainforest Water Cycle:

- Precipitation falls
- **Most reaches the ground immediately** with **little vegetation to intercept the rainfall**, leading to **high surface runoff**, with higher flooding risk
- **Less evapotranspiration**, so the atmosphere is **less humid and rainfall decreases**

Natural Rainforest Carbon Cycle:

- Trees suited to humid and warm conditions, which promotes photosynthesis
- They absorb large amounts of oxygen from the atmosphere acting as an important **carbon sink**
- Decomposition and respiration releases CO₂ back to the atmosphere and soil, where carbon is stored

Deforested Rainforest Carbon Cycle:

- Lack of trees so **photosynthesis is reduced**
- **Fires** to clear land leads to CO₂ being released into the atmosphere. **Forests become a carbon source** instead of a carbon sink
- **Lack of life** until new plants grow
- **Low rates of decomposition** occurs in this environment

Relationships Between the Two Cycles:

- Rain that forms over intact tropical rainforest may fall over deforested land due to wind, causing erosion, with **soil and ash flowing into rivers**, increasing the carbon content of rivers. The **water** leaves the rainforest cycle as an **output through streamflow** due to **reduced interception and increased surface runoff**
- Alternatively there is **reduced rainfall in the intact forest**, as there is **less evapotranspiration** in the deforested area, causing **drought periods** and the **intact rainforest to deteriorate**
- Deforestation on **peatlands** and the **digging of drainage channels** reduces water storage. The organic peat matter is no longer preserved underwater and **decomposes quickly**, releasing CO₂ into the atmosphere. **Weathering and erosion increase** speeding up decomposition. There is a greater wildfire risk from the hotter temperatures

- **Blocking drainage ditches** in peatland rainforests, helps restore the natural environment, by **increasing soil water storage and decreasing runoff**. This can **raise the water table** and decrease the flood risk. However, a managed forest is often **less effective at sequestering CO₂** than a virgin forest

Mitigating Climate Change

Global Intervention - Paris Climate Deal (COP21):

- Aim to limit global temperatures to **2°C above pre-industrial levels**
- Support for developing countries
- Public interaction and awareness schemes
- Meet every 5 years to review and improve goals

Regional Intervention - EU 20-20-20:

- **20% reduction in GHG emissions and commitment to 20% of energy coming from renewable sources and 20% increase in energy efficiency by 2020**
- EU has suggested it will **increase its emissions reduction to 30%** if major GHG producing countries also improve their targets

National Intervention - Climate Change Act 2008 UK:

- **Legally binding target** for the UK to reduce GHG emissions by **80% of 1990 levels by 2050 with a target of 26% by 2020 which has recently increased to 34%**
- Created **national carbon budgets** and the **Independent Committee on Climate Change** to help the government and report on progress that is being made

Local Scale:

- Improving home insulation
- Recycling
- Using energy more wisely and use of **smart meters** and using **public transport** or **car sharing schemes** and **calculating personal carbon footprints**