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:

Precipitation = Total Runoff + Evapotranspiration +/- 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

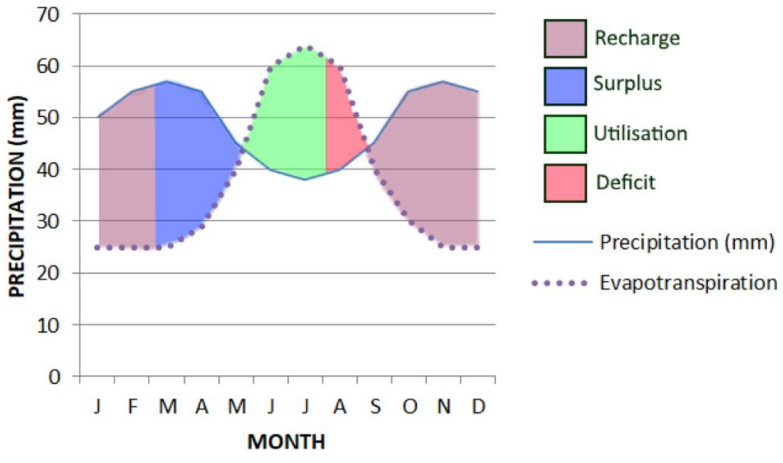
The **soil water budget** shows the annual **balance** between **inputs** and **outputs** in the water cycle. The soil water budget also shows how inputs and outputs impact **soil water storage** and **availability**.

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).

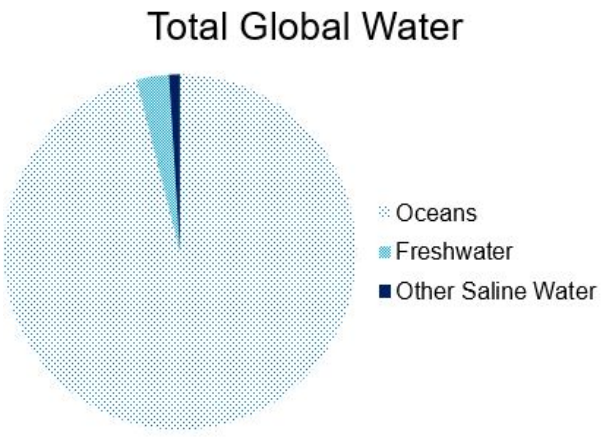
The water is **utilised** in spring and summer, when potential evapotranspiration of plants is highest due to warmer weather.

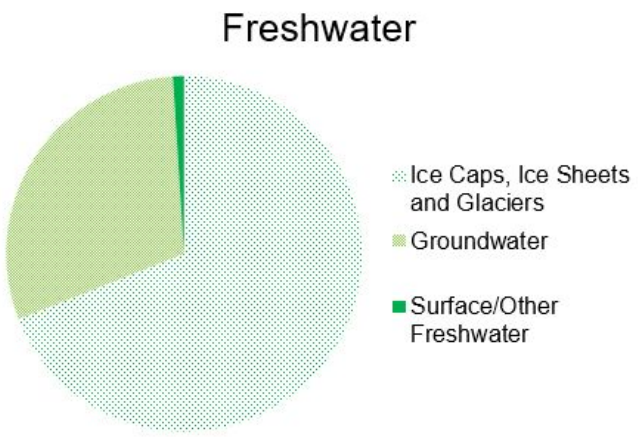
The stores are **depleting** when **evapotranspiration is greater than precipitation**. This can lead to a **deficit** of soil water.

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

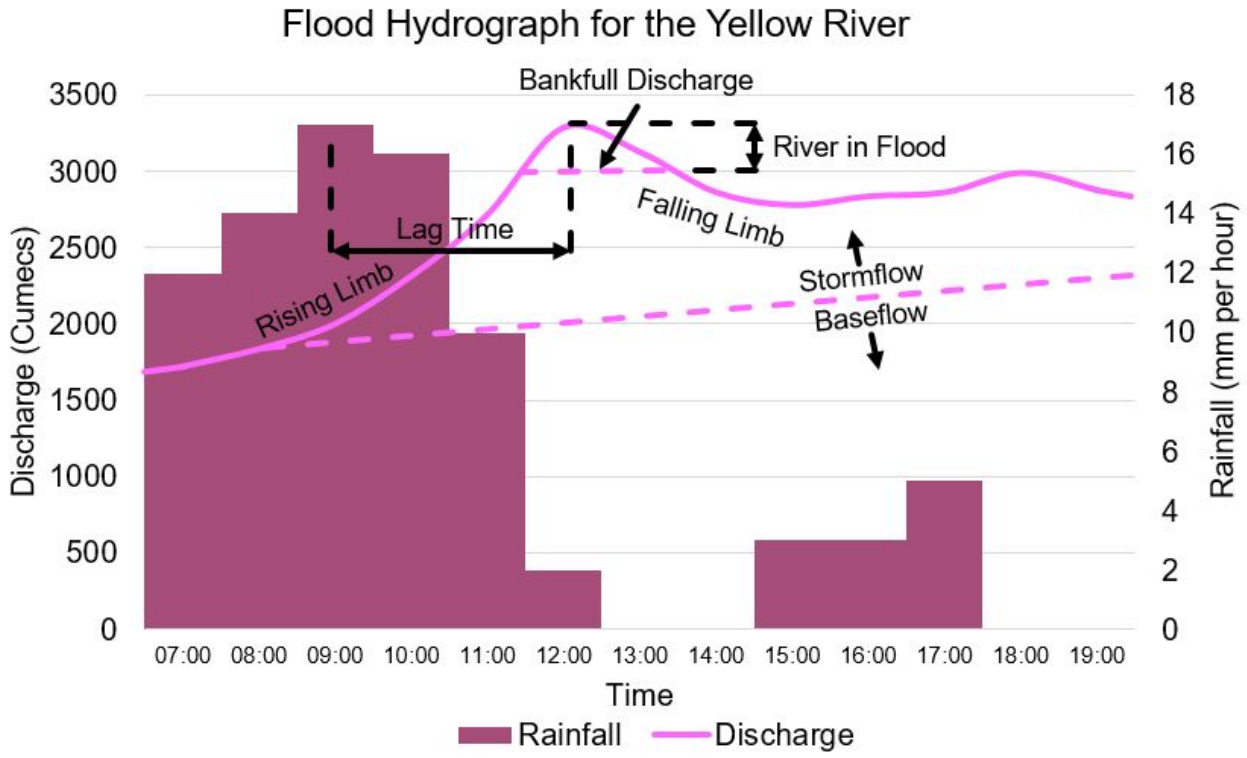
Land Use Change:

- 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:

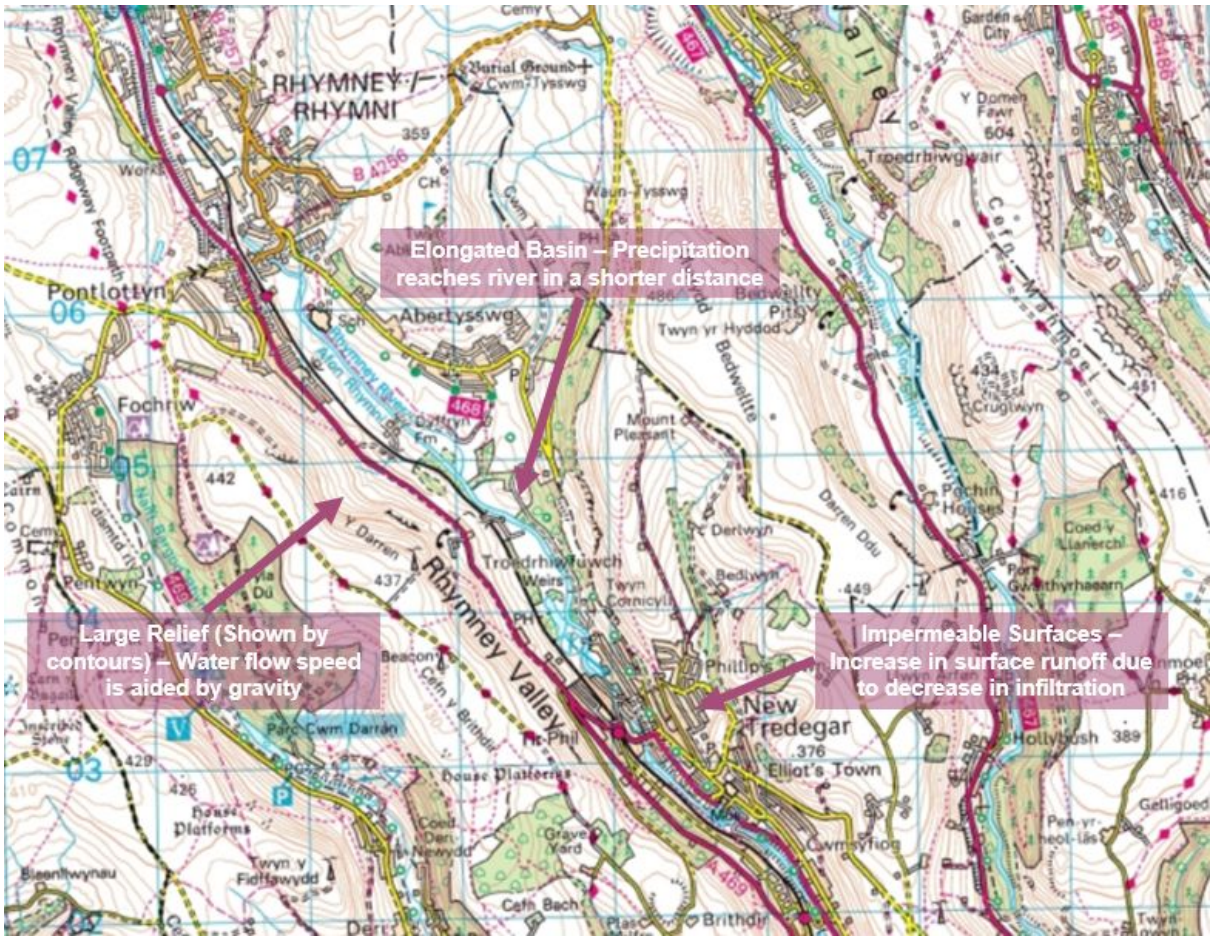
Flashy:

- 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**