AQA Geography A-Level

3.1.1: Water and Carbon Cycles

Detailed Notes

Systems

Systems are composed of:

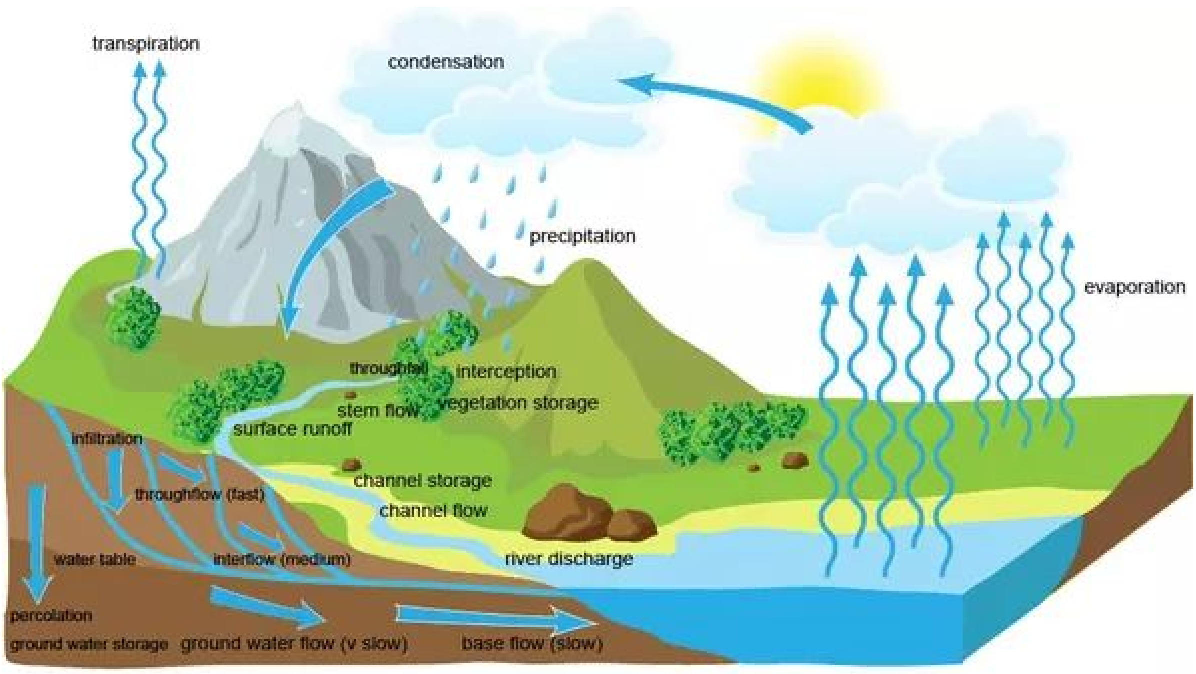
- **Inputs** - Where matter or energy is added to the system
- **Outputs** - Where matter or energy leaves the system
- **Stores** - Where matter or energy builds up in the system
- **Flows** - Where matter or energy moves in the system
- **Boundaries** - Limits to the system (e.g. watershed)

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**. The following **inputs, outputs, flows and stores** drive and cause changes in the water cycle over time. They all have impacts of varying **magnitude** over different lengths of time.



Source: https://xlskoor.blogspot.com/2016/04/drainage-river-system.html

Inputs

Precipitation: Any water that falls to the surface of the earth from the atmosphere including **rain, snow and hail**. Be careful not to confuse rainfall with precipitation, as they have different meanings. There are three types of rainfall:

- **Convectional** - Due to heating by the sun, warm air rises, **condenses** at higher altitudes and falls as rain.
- **Relief** - Warm air is forced upward by a **barrier such as mountains**, causing it to **condense** at higher altitudes and fall as rain.
- **Frontal** - **Warm air rises over cool air** when two bodies of air at different temperatures meet, because the warm air is less dense and therefore lighter. It **condenses** at higher altitudes and falls as rain.

Outputs

Evapotranspiration: Compromised of **evaporation** and **transpiration**. **Evaporation** occurs when water is heated by the sun, causing it to become a **gas** and rise into the atmosphere. **Transpiration** occurs in **plants** when they **respire** through their leaves, releasing water they **absorb** through their roots, which then **evaporates** due to heating by the sun.

Streamflow: All water that enters a **drainage basin** will either leave through the atmosphere, or through streams which drain the basin. These may flow as **tributaries** into other rivers or directly into lakes and oceans.

Flows

Infiltration - This is the process of water moving from above ground into the soil. The **infiltration capacity** refers to how quickly **infiltration** occurs. **Grass crops and tree roots create passages for water to flow** through from the surface into the soil, therefore increasing the i**nfiltration capacity**. If **precipitation falls at a greater rate than the infiltration capacity** then **overland flow** will occur - **Moderate/Fast**

Percolation - Water moves from the ground or soil into **porous rock or rock fractures**. The **percolation rate** is dependent on the **fractures** that may be present in the rock and the **permeability** of the rock - **Slow**

Throughflow - Water moves **through the soil** and into streams or rivers. Speed of flow is dependent on the **type of soil**. **Clay soils** with a **high field capacity** and **smaller pore spaces** have a **slower flow rate**. **Sandy soils drain quickly** because they have a **lower field capacity**, **larger pore spaces** and **natural channels** from animals such as worms. Some sports fields have sandy soils, to reduce the chance of waterlogged pitches, but this may also increase the flood risk elsewhere - **Moderate/Fast**

Surface Runoff (Overland flow) - Water flows above the ground, as **sheetflow** (lots of water flowing over a large area), or in **rills** (small channels similar to streams, that are unlikely to carry water during periods where there is not any rainfall) - **Fast**

Groundwater Flow - Water **moves through the rocks**. Ensures that there is water in rivers, even after long period of dry weather. Jointed rocks such as limestone in **Karst environments** where there are many **underground streams and caves**, may transfer water very rapidly - **Usually slow but variable**

Streamflow - Water that moves through **established channels** - **Fast**

Stemflow - Flow of water that has been intercepted by plants or trees, down a stem, leaf, branch or other part of a plant - **Fast**.

Stores

Soil Water - Water stored in the soil which is **utilised by plants** - **Mid-term**
Groundwater - Water that is stored in the **pore spaces of rock** - **Long-term**
River Channel - Water that is stored in a river - **Short-term**
Interception - Water intercepted by plants on their branches and leaves before reaching the ground - **Short-term**
Surface Storage - Water stored in puddles, ponds, lakes etc. - **Variable**

The **water table** is the **upper level** at which the **pore spaces and fractures in the ground become saturated**. It is used by researchers to **assess drought conditions, health of wetland systems, success of forest restoration programmes** etc.

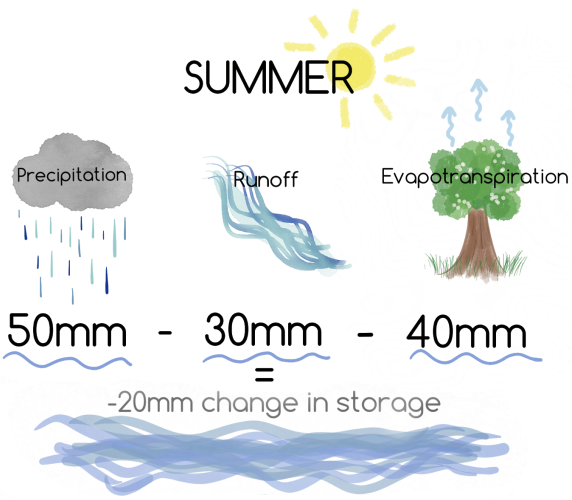
The Water Balance

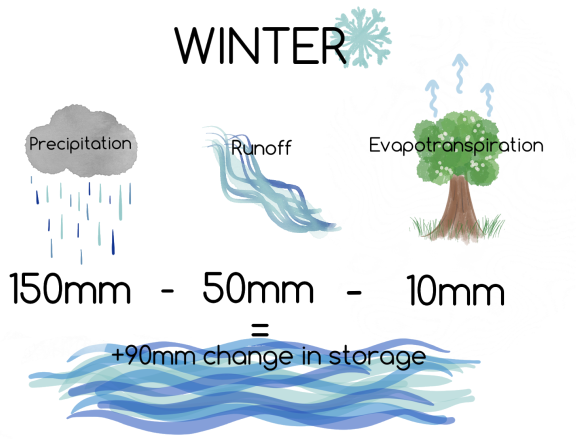
The **water balance** is used to express the process of **water storage and transfer** in a drainage basin system and uses the formula:

Precipitation = Total Runoff + Evapotranspiration +/- (change in) 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 balance of an area will change dependent on **physical factors**, especially during seasonal variations of temperature and precipitation. The amount of precipitation in comparison with the amount of runoff and evapotranspiration affects **change in storage**.





Changes to the Water Cycle

The water cycle is impacted on a local scale by:

- **Deforestation** - There is **less interception by trees** so **surface runoff increases**. The soil is no longer held together by roots, so **soil water storage decreases**. There are fewer plants so **transpiration decreases.**

- **Storm Events** - Large amounts of rainfall quickly **saturate the ground** to its **field capacity**. No more water can **infiltrate** the soil, increasing the **surface runoff**. Storm events are therefore **less effective at recharging water stores than prolonged rainfall**. In 24 hours if 20mm of rain fell evenly this would **infiltrate the soil and percolate into the groundwater stores as well**, with low **surface runoff**. In 1 hour if 20mm of rain fell, there would be **less water infiltrating the soil and percolating into the rocks**, reducing the **replenishment of groundwater stores**, but increasing runoff.

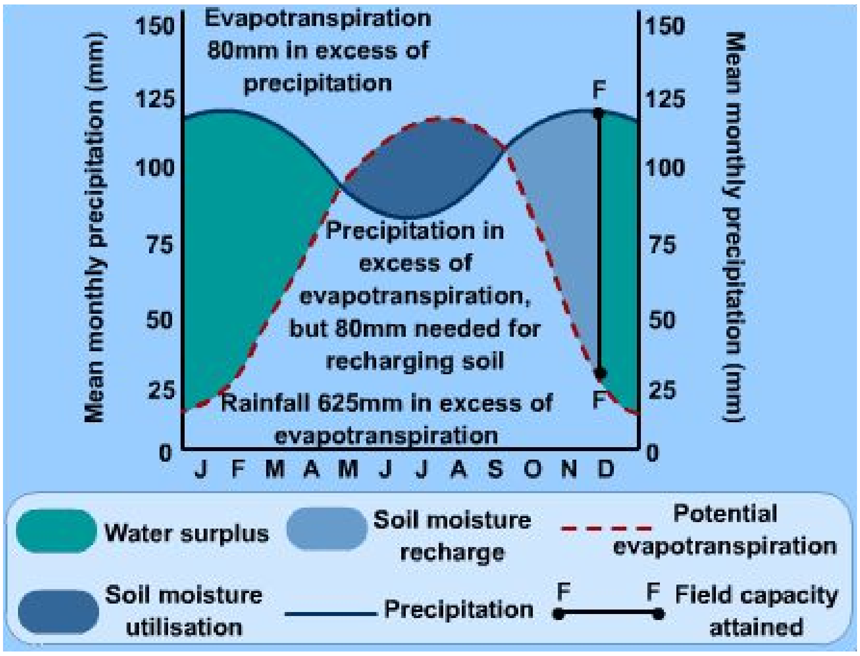
- **Seasonal Changes**:
  - **Spring:** More vegetation growth so **more interception by vegetation.**
  - **Summer:** Likely to be **less rain in summer**. Ground may be harder and therefore more **impermeable** encouraging **surface runoff.**
  - **Autumn:** Less vegetation growth so less interception. Seasonally **more rainfall.**
  - **Winter:** Frozen ground may be **impermeable and encourage runoff**. **Snow discourages runoff** and takes time to melt, slowing down the processes that occur within the water cycle.

- **Agriculture**:
  - **Pastoral farming** relates to livestock. A good way to remember is **P**astoral farmers farm **P**igs. **Livestock** such as **P**igs, cattle, goats, sheep etc, trample the ground **reducing infiltration.**
  - **Arable farming** relates to **crops**. **Ploughing increases infiltration** by creating a looser soil, which decreases surface runoff. However, digging **drainage ditches** (often seen around field edges) increases surface runoff and **streamflow.**
  - **Hillside terracing** (for rice padi fields) increases surface water storage and therefore **decreases runoff.**
  - **Irrigation** (the movement of water by human intervention through tunnels and other conduits) can lead to **groundwater depletion.**

- **Urbanisation**:
  - Creating **roads and buildings** which have **impermeable surfaces** and are likely to have **drains** creates **impermeable surfaces** that **reduce infiltration** but **increase surface runoff**, **reducing lag-time and increasing the flood risk.**
  - **Green roofs and Sustainable Urban Drainage Systems (SUDS)** use grass and soil to reduce the amount of **impermeable surfaces** are helping to tackle the problem of urban flooding in some cities.

The Soil Water Budget

The **soil water budget** shows the annual balance between inputs and outputs in the water cycle and their impact on **soil water** storage/availability. The budget is never the same due to varying conditions year on year and the process is affected by how much rainfall/dry weather there is the previous year. The water budget is also dependent on **type, depth and permeability of the soil and bedrock**. The maximum possible level of storage of water in the soil is is **field capacity.** Once the **field capacity** is reached, any rainfall after this will not infiltrate the soil and is likely to cause flooding. The water budget is dependent on **type, depth and permeability of the soil and bedrock**.



Seasonal Variation of the Soil Water Budget

Autumn: In Autumn, there is a **greater input from precipitation than there is an output from evapotranspiration** as **deciduous trees** lose their leaves and the cooler temperatures mean that the **plants photosynthesise less**. **Soil moisture levels increase** and a **water surplus** occurs.

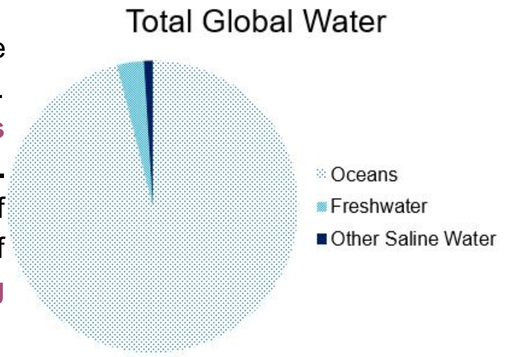
Winter: Potential evapotranspiration from plants reaches a minimum due to the colder temperatures and the precipitation continues to **refill the soil water stores**. Infiltration and percolation will also refill the water table.

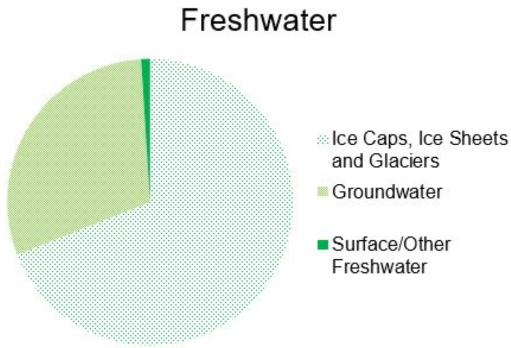
Spring: Around February and March, plants start to grow again and **potential evapotranspiration increases as temperatures get higher and plants start photosynthesising** more. There is still a **water surplus** in this time.

Summer: The hotter weather leads to **utlisation of soil water as evapotranspiration peaks and rainfall is at a minimum**. The **output from evapotranspiration is greater than the input from precipitation** so the **soil water stores are depleting**. A **water deficit may occur** if there is a long hot summer and spring, a lack of winter rainfall, or a drought the year before. The cycle then repeats.

The Water Cycle: Global Scale

The global water cycle is comprised of many stores, the largest being oceans, which contain **97% of global water**. Only **2.5% of stores are freshwater** of which **69% is glaciers, ice caps and ice sheets** and **30% is groundwater**. Surface and other freshwater only accounts for around **1%** of global stores. Other surface and freshwater is made up of **permafrost, lakes, swamps, marshes, rivers and living organisms**.



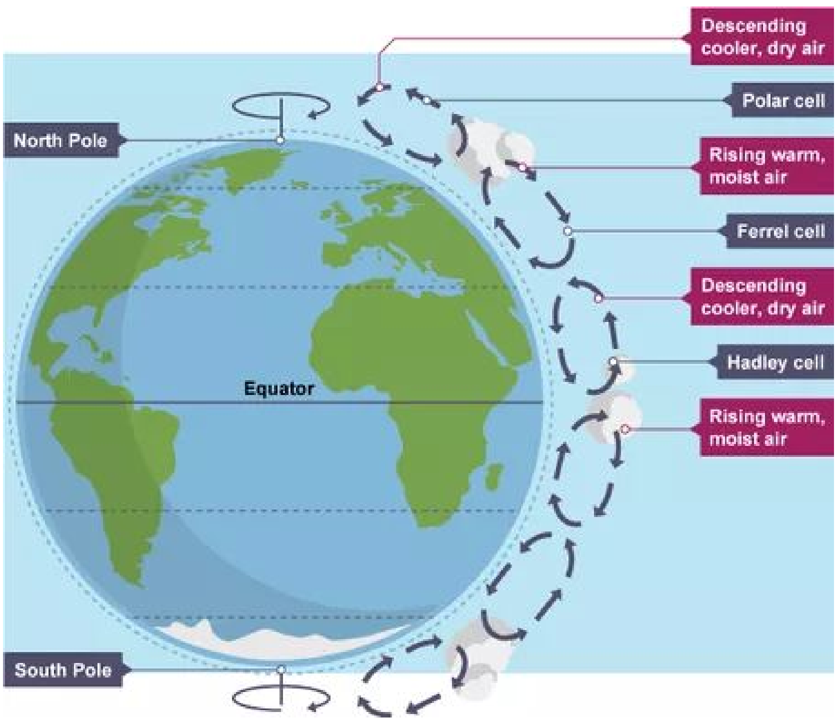


Water can be stored in four areas:

- **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**, whilst **soil water** acts as a more temporary store, holding water for **1-2 months**.

The Inter-Tropical Convergence Zone (ITCZ)



The **global atmospheric circulation model** is the main factor that determines **cloud formation and rainfall**. There are different zones of rising and falling air that leads to precipitation through **convectional rainfall**. This creates a **low pressure zone** on the equator called the **ITCZ**, which has very heavy rainfall and is **partly responsible for monsoons**. This zone moves during the seasons (north and south) as the suns position changes. Where the **Ferrel and Hadley cells** meet, unstable weather occurs and moved by the **jet-stream**, this causes the **changeable weather** experienced in the UK.

The Water Cycle: Changes over Time

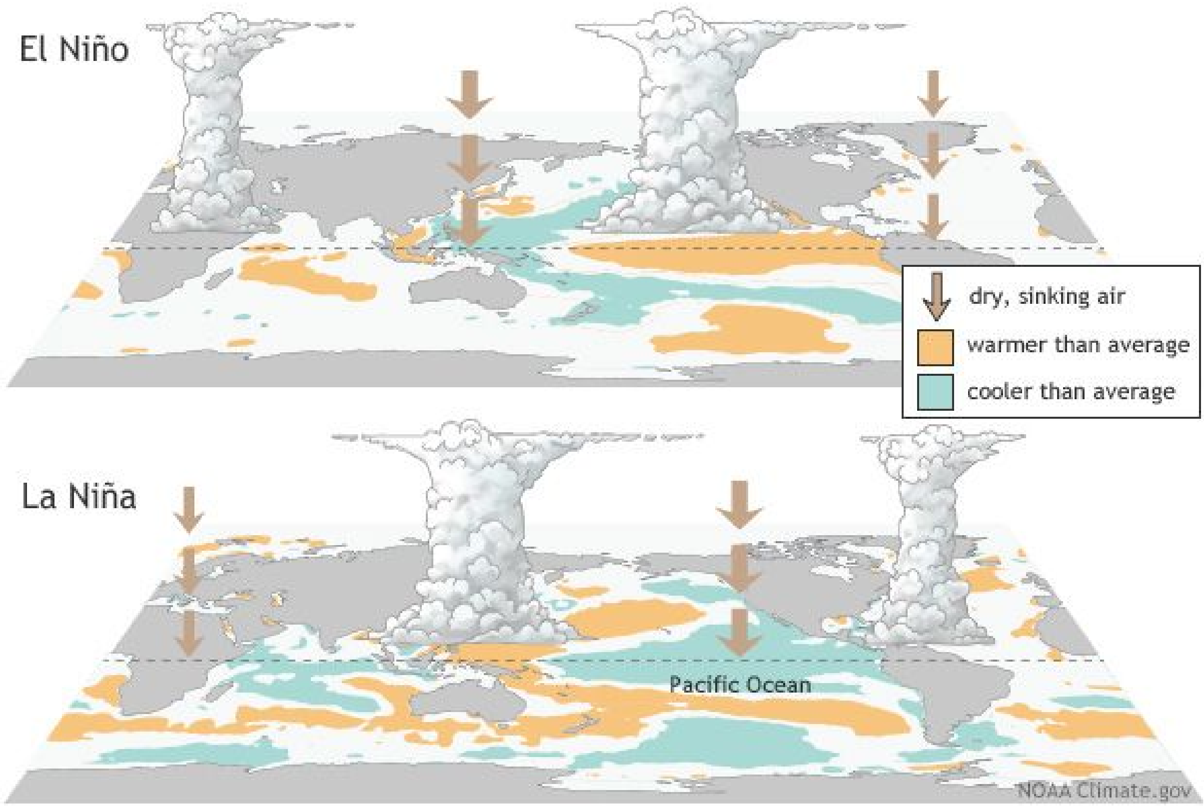
Natural Processes

Seasonal Changes:
- **Less precipitation, more evapotranspiration** in summer because of higher temperatures.
- Reduced flows in the water cycle 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.

Storm Events:
- Cause **sudden increases in rainfall**, leading to flooding and replenishment of some water stores. Unlikely to cause **long-term change.**

Droughts:
- Cause **major stores to be depleted** and the **activity of flows acting within the water cycle to decrease**. May cause **long-term change** as they become more common as a result of **climate change.**

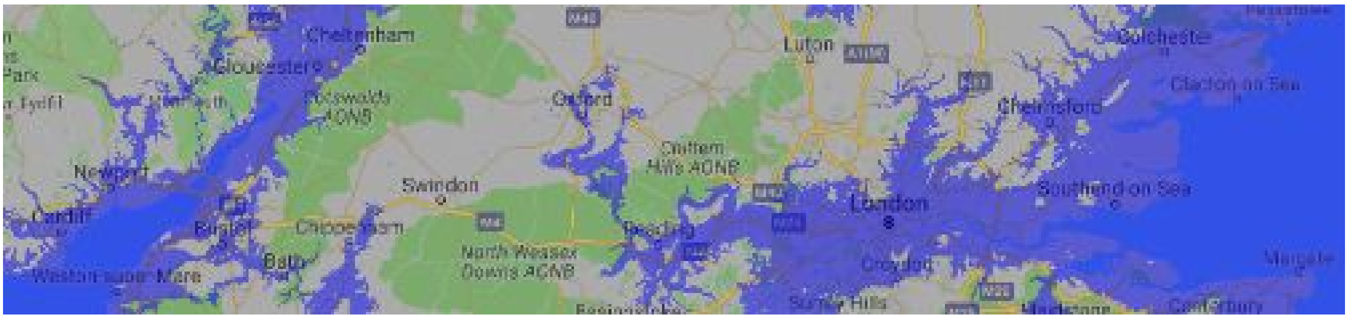
El Niño and La Niña:
- The **El Niño effect** occurs every **2-7 years** and causes warm temperatures in a predictable way.
- The **La Niña effect** occurs every **2-7 years** and causes cooler temperatures in a predictable way.
- It is likely that climate change will **increase the probability of more El Nino's** in future.



Cryospheric Processes:

- In the past **glaciers and icecaps** have stored significant proportions of freshwater through the process of **accumulation.**
- Currently, almost all of the **world's glaciers are shrinking**, **causing sea levels to rise**
- If all the world's glaciers and icecaps were to melt, sea levels would rise by around 60 metres.

The UK with a 60m sea level rise



Source: Firetree

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.**
- **Irrigation** removes water from local rivers, decreasing their flow.

Land Use Change:

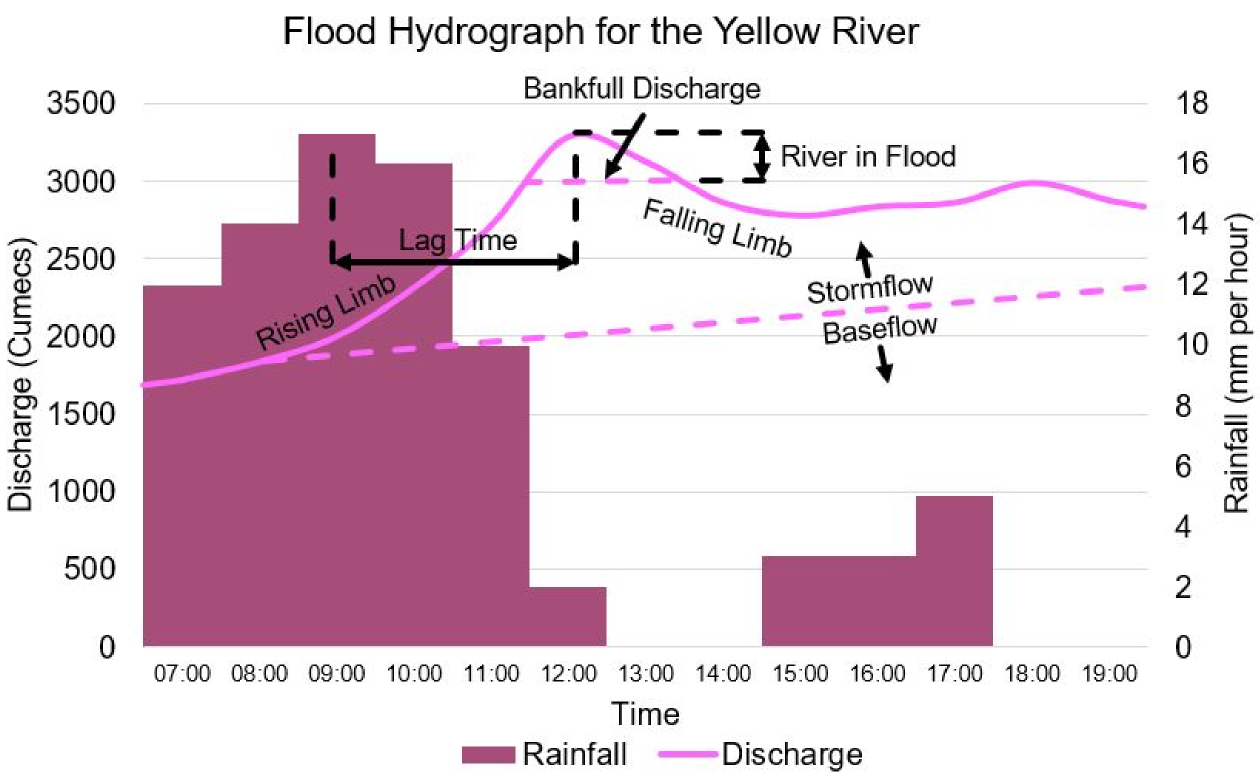
- **Deforestation** (e.g. for farming) **reduces interception, evapotranspiration** and but infiltration increases (dead plant material in forests usually prevents infiltration).
- **Construction reduces infiltration and evapotranspiration**, but increases runoff.

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.**

The combination of **human activity** and **natural variation** will cause the greatest changes to the water cycle.

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 and explained below:

- **Discharge**: The **volume of water** passing through a **cross-sectional point of the river** at any one point in time, measured in **Cubic Metres Per Second (Cumecs)**. Made up of the **baseflow and stormflow.**
- **Rising Limb:** The line on the graph that represents the discharge increasing.
- **Falling Limb:** The line on the graph that represents the discharge decreasing.
- **Lag Time:** The time between **peak rainfall** and **peak discharge.**
- **Baseflow:** The level of **groundwater flow.**
- **Stormflow:** Comprised of **overland flow** and **throughflow.**
- **Bankfull Discharge:** The maximum capacity of the river. If discharge exceeds this then the river will **burst its banks** and be in flood.

Flashy Hydrograph: Short lag time and **high peak discharge**, most likely to occur during a storm event, with favourable drainage basin characteristics

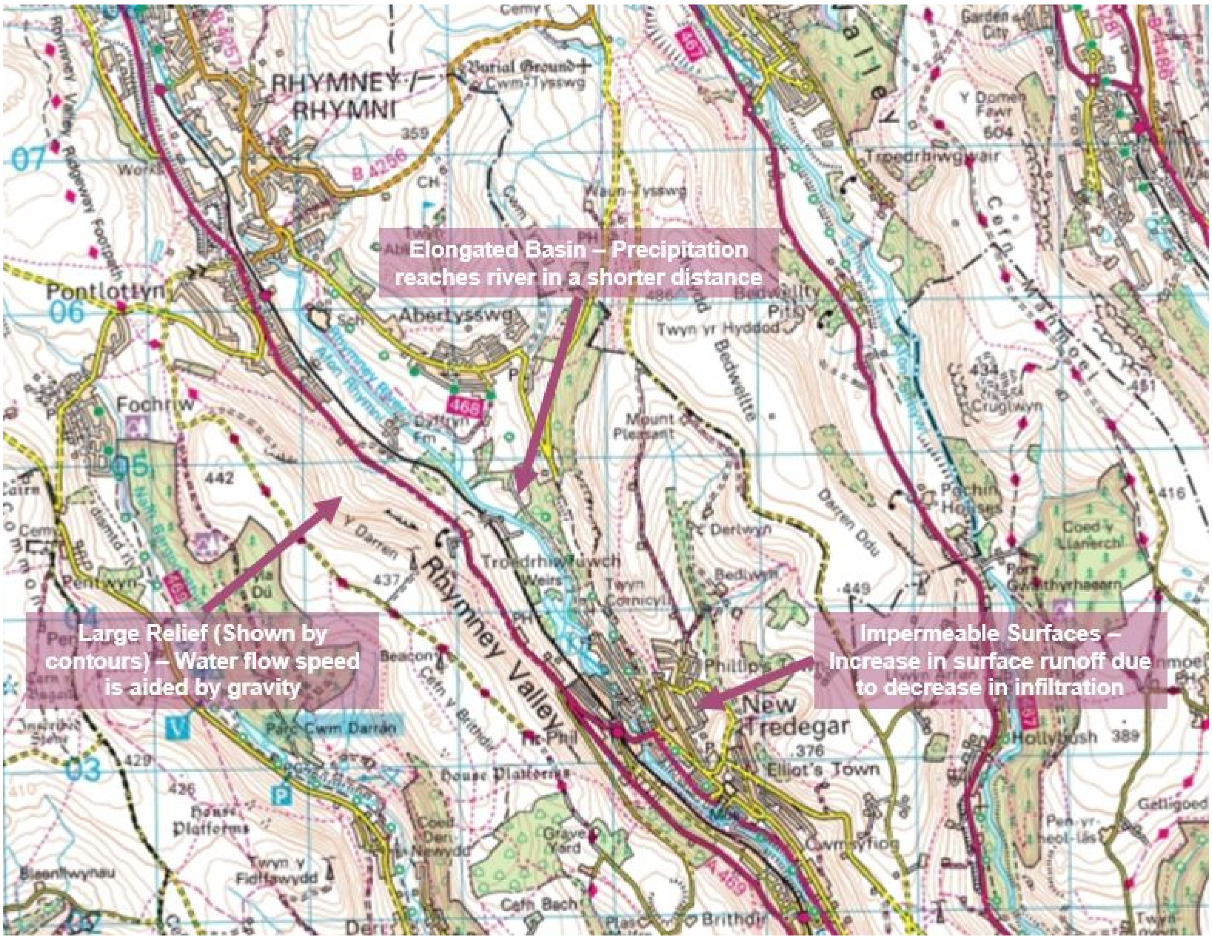
Subdued Hydrograph: Long lag time and **low peak discharge**

Features of Flashy and Subdued Hydrographs:

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, **decrease lag time** and **increase peak discharge** and therefore act to create a **flashy hydrograph** are shown on the **Ordnance Survey (OS) Map**, and others are listed below:



Natural:
- **High Rainfall Intensity** - **Higher discharge potential** from the river and more likely for soil to reach its **field capacity**, thus increasing surface runoff and decreasing the lag time.
- **Antecedent Rainfall** (Rainfall that occurs before the studied rainfall event. e.g. rain the day before) - Increased surface runoff as ground is **saturated** and soil has reached its **field capacity.**
- **Impermeable Underlying Geology** - **Decreased percolation** and therefore **greater levels of throughflow.**
- **High Drainage Density** - Many **tributaries** to main river, increasing **speed of drainage and decreasing the lag time.**
- **Small Basin** - Rainfall reaches the central river more rapidly, decreasing the lag time.

- **Circular Basin** - Rainfall reaches the central river more rapidly, decreasing the lag time.
- **Low Temperatures** - **Less evapotranspiration so greater peak discharge.**
- **Precipitation Type** - Snow or hail takes time to melt before moving towards the river, so rainfall increases the flooding risk.
- **Vegetation Cover** - Forested areas **intercept more rainfall**, decreasing the flood risk, but **exposed areas will transfer water to the river more rapidly**, decreasing lag time.

Human:

- **Urbanisation** - More **impermeable surfaces**, so runoff increased and **surface storage and infiltration are reduced.**
- **Pastoral Farming** - Ground trampled so **less interception and more surface runoff.**
- **Deforestation** - Less interception by trees, so **water reaches the ground and river more quickly**. **More surface runoff and greater flood risk.**

The Carbon Cycle: Local Scale

Transfers in the Carbon Cycle

The **transfers in the carbon cycle** act to **drive and cause changes** in the carbon cycle over time. They all have **impacts of varying magnitude over different lengths of time**.

Photosynthesis - Living organisms convert **Carbon Dioxide** from the atmosphere and **Water** from the soil, into **Oxygen** and **Glucose** using **Light Energy**. By removing CO_2 from the atmosphere, plants are **sequestering carbon (see below)** and reducing the potential impacts of climate change. The process of **photosynthesis** occurs when **chlorophyll** in the leaves of the plant react with CO_2, to create the **carbohydrate glucose**. Photosynthesis helps to maintain the balance between oxygen and CO_2 in the atmosphere. The formula is shown below:

Carbon Dioxide + Water → *Light Energy* → Oxygen + Glucose

Respiration - Respiration occurs when plants and animals **convert oxygen and glucose into energy** which then produces the **waste products of water and CO_2**. It is therefore chemically the opposite of photosynthesis:

Oxygen + Glucose → Carbon Dioxide + Water

During the day, plants photosynthesise, absorbing significantly more CO_2 than they emit from respiration. During the night they **do not photosynthesise** but they do **respire,** releasing more CO_2 than they absorb. Overall, plants absorb more CO_2 than they emit, so are **net carbon dioxide absorbers** (from the atmosphere) and **net oxygen producers** (to the atmosphere).

Combustion - When fossil fuels and organic matter such as trees are burnt, they **emit CO_2 into the atmosphere**, that was previously locked inside of them. This may occur when **fossil fuels are burnt to produce energy**, or if wildfires occur.

Decomposition - When living organisms die, they are **broken down by decomposers** (such as **bacteria and detritivores**) which **respire**, returning CO_2 into the atmosphere. Some **organic matter** is also **returned to the soil** where it is stored adding carbon matter to the soil.

Diffusion - The **oceans can absorb CO_2** from the atmosphere, which has **increased ocean acidity by 30% since pre-industrial times**. The ocean is the biggest carbon store, but with carbon levels increasing seawater becomes more acidic which is harming aquatic life by causing **coral bleaching.** Many of the **world's coral reefs now under threat**.

Weathering and Erosion - Rocks are eroded on land or broken down by **carbonation weathering**. Carbonation weathering occurs when CO_2 in the air mixes with rainwater to create **carbonic acid** which **aids erosion of rocks such as limestone**. The carbon is moved through the water cycle and enters the oceans. **Marine organisms use the carbon in the water to build their shells**. Increasing carbon dioxide levels in the atmosphere, may **increase weathering and erosion as a result, potentially affecting other parts of the carbon cycle**.

Burial and Compaction - When shelled marine organisms die, their shell fragments fall to the ocean floor and become **compacted over time** to form **limestone. Organic matter** from **vegetation and decaying marine organisms** is compacted over time, whether on land or in the sea, to form **fossil fuel deposits**.

Carbon Sequestration - Transfer of carbon from the atmosphere to other stores and can be both **natural and artificial.** A plant sequesters carbon when it photosynthesises and stores the carbon in its mass. Factories are also starting to use carbon sequestration in the form of **Carbon Capture and Storage (CCS)**. CO_2 is captured and transported via **pipeline to depleted gas fields and saline aquifers**.

Advantages:

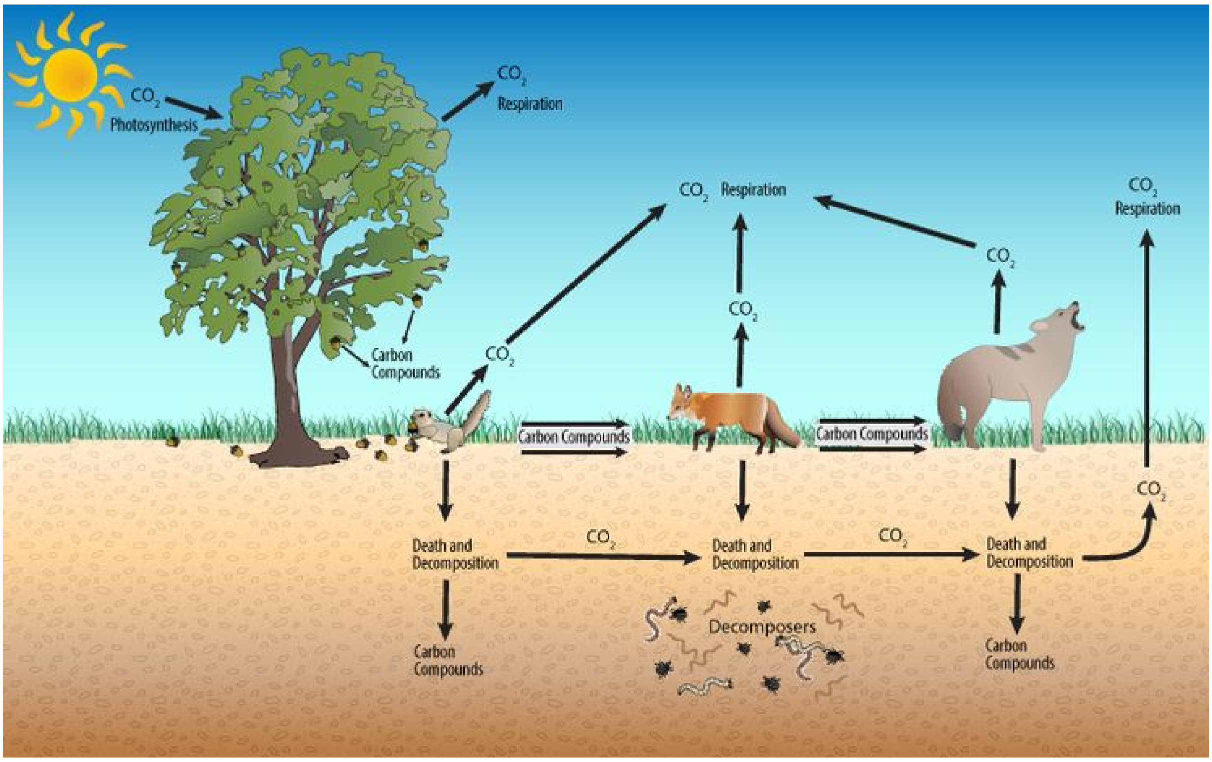
- Can be fitted to existing coal power stations.
- Captures 90% of CO_2 produced.
- There is a demand for CO_2 (Coca-Cola, Plant Growth, Beer etc.), so transport systems via pipeline in liquid form already exist.
- Potential to capture half the world's CO_2 emissions.

Disadvantages:

- High cost is the main restriction to the growth of CCS.
- Increases energy demand of power stations.
- May not be space to fit it to existing power stations.
- Economically viable in some cases as it is used to push oil out the ground, thus further increasing fossil fuel usage.

The carbon cycle occurs on a **local scale** in a plant, or in a **sere**. A **sere** is a stage of a **vegetation succession** and can relate to specific environments. A **vegetation succession** occurs when a **plant community** develops and becomes more complex over time.

You should be aware of how the carbon cycle functions in a **lithosere environment**, as shown below.



Source: https://serc.carleton.edu/eslabs/carbon/1a.html

The **climatic climax** is the final stage of the sere where **environmental equilibrium** is achieved. In most of the UK this would be a **woodland**, but another example would be a **rainforest**. When a sere reaches a climatic climax, the ecosystem is **fully developed** and **stable**, and it will not change dramatically as the equilibrium will counteract any change (unless there is a major climatic or geographical change). **Different seres relate to particular environments** and include:

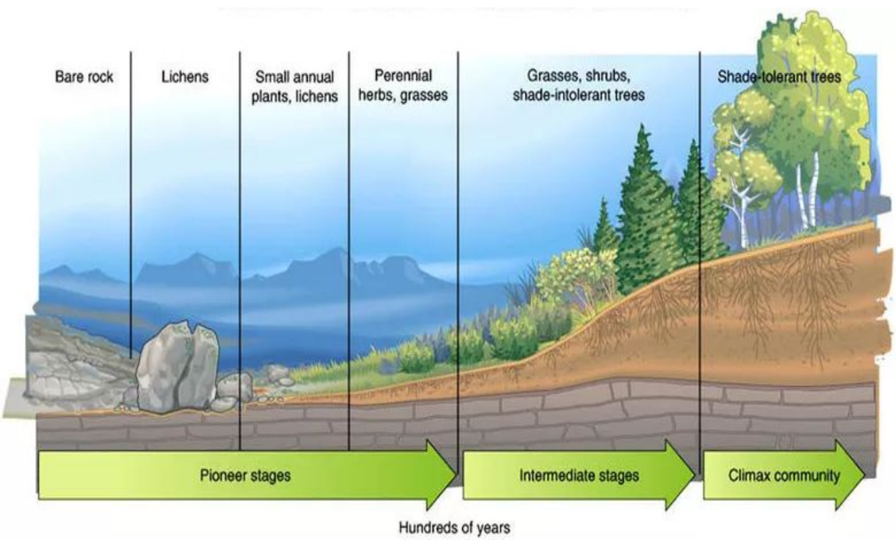
Lithosere - Bare rock

Halosere - Salty environment

Psammosere - Sand coastal environment

Hydrosere - Freshwater environment

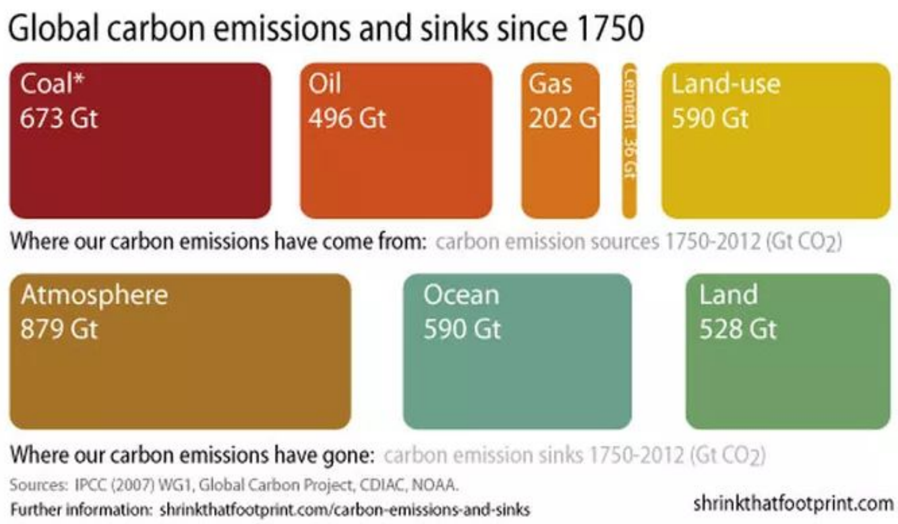
For example, in a **lithosere** over time a soil builds up on the rock from **decaying organic matter.** Plants colonise the soil and the soil continues to build up until it is deep enough for trees to colonise.



Lithosere succession (Source: legacy.owensboro.kctcs.edu)

The Carbon Cycle: Global Scale

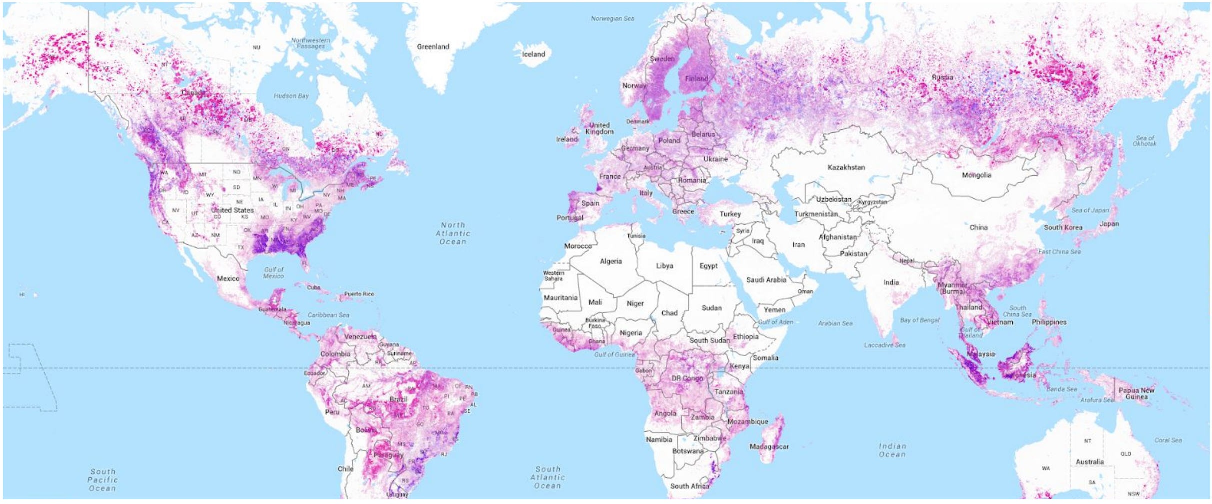
A **carbon sink** is any store which **takes in more carbon than it emits**, so an **intact tropical rainforest** is an example. A **carbon source** is any store that **emits more carbon than it stores** so a **damaged tropical rainforest** is an example.



Main Carbon Stores (In order of magnitude):

- **Marine Sediments and Sedimentary Rocks** - Lithosphere - Long-term
  - Easily the biggest store. **66,000 - 100,000 million billion metric tons of carbon**. The rock cycle and continental drift recycle the rock over time, but this may take thousands, if not millions of years.
- **Oceans** - Hydrosphere - Dynamic
  - The second biggest store contains a tiny fraction of the carbon of the largest store. **38,000 billion metric tons of carbon**. The carbon is constantly being utilised by marine organisms, lost as an output to the lithosphere, or gains as an input from rivers and erosion.
- **Fossil Fuel Deposits** - Lithosphere - Long-term but currently dynamic
  - Fossil fuel deposits used to be rarely changing over short periods of time, but humans have developed technology to exploit them rapidly, though **4000 billion metric tons of carbon** remain as fossil fuels.
- **Soil Organic Matter** - Lithosphere - Mid-term
  - The soil can store carbon for over a hundred years, but deforestation, agriculture and land use change are affecting this store. **1500 billion metric tons of carbon** stored.
- **Atmosphere** - Dynamic
  - Human activity has caused CO_2 levels in the atmosphere to increase by around **40% since the industrial revolution**, causing unprecedented change to the global climate. **750 billion metric tons of carbon** stored.
- **Terrestrial Plants** - Biosphere - Mid-term but very dynamic
  - Vulnerable to climate change and deforestation and as a result carbon storage in forests is declining annually in some areas of the world. **560 billion metric tons of carbon.**

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**. Different amounts of carbon are stored worldwide and one of the stores that is currently changing is trees:



Key: **Pink is forest area lost. Purple is forest area gained.** Source: Global Forest Watch

The map shows how **forests are declining in the tropical areas** in the **southern hemisphere** and **growing in the northern hemisphere**. This is supported by data which shows that tropical areas such as Brazil and Indonesia have seen a **decrease in carbon stocks of around 5 Gigatons of Carbon (GtC) in the last 25 years**, but Russia, USA and China have seen **increases of around 0.3, 2.9 and 2.3 GtC** respectively. Detailed information on forests and climate change shows that:

- **Non-tropical forests** have seen an **increase in carbon sequestration in recent years**, especially in Europe and Eastern Asia, due to **conversion of agricultural land and plantations to new forests.**
- **Forests in industrialised regions** are **expected to increase by 2050** but in the global south, forested areas will decrease.
- **Rate of forest loss has decreased** from 9.5 million hectares per year in the 1990's to 5.5 million hectares per year in 2010-15.
- The eight countries with the largest forested areas are: Russia, Brazil, China, Canada, USA, DRC, Australia and Indonesia.
- **Brazil has the most carbon stored on land and the most extensive deforested area.**
- **China has the largest amount of afforested area.**
- **Net Primary Productivity (NPP)** refers to the amount of carbon absorbed by forests. For tropical forests it is positive all year round, but deciduous forests, have a negative NPP in winter, but across the whole year their NPP is positive.

The Carbon Cycle: Changes Over Time

Natural Processes

Wildfires: Transfer carbon from **biosphere** to **atmosphere** as CO_2 is released through burning. This burning can encourage the growth of plants in the long term. There is much debate about **whether preventing wildfires is beneficial**. They have an important role in the carbon cycle, but may threaten homes. Is it right to extinguish the ones caused by **human activity**, or should we extinguish them because **global warming is providing better conditions for wildfires to occur**?

Volcanic Activity: Carbon stored within the earth is released during **volcanic eruptions**, mainly as CO_2 gas. They contribute a relatively **low proportion of CO_2** to the overall carbon cycle. The **1815 Mt Tambora eruption** in Indonesia produced **sulphur dioxide gas**, which then entered the atmosphere, blocking radiation from the sun and **lowering global temperatures by 0.4 - 0.7°C in 1816**. In this way volcanoes can influence the carbon cycle by **reducing photosynthesis rates**, which will then also affect the water cycle.

Human Impacts

Fossil Fuel Use - **Combustion** transfers CO_2 to the atmosphere from a **long-term carbon sink**. Many of the other human impacts have already been discussed in this document. Nearly everything that we do impacts the carbon cycle in one way or another, from buying a new pair of jeans, to switching the light on or getting a drink of water. You can check your **carbon footprint** here: http://footprint.wwf.org.uk/

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 - **Pastoral farming releases CO_2** as animals respire, affecting the carbon cycle. **Ploughing** can release CO_2 stored in the soil. Farm machinery such as tractors may release CO_2.

Changes to the magnitude of carbon stores over time are called **fluxes** and may happen very rapidly or over thousands of years. Human activity is causing an **unprecedented flux** in the levels of CO_2 in the atmosphere as a direct result of **fossil fuel combustion**.

The **Carbon Budget** is the balance between carbon **inputs and outputs** to a store at any scale or the **balance of exchanges** between the four major stores of carbon:

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.* **Radiative forcing** refers to the difference between incoming solar radiation absorbed by the Earth and the energy radiated back out into space. This has increased in the recent years, leading to more heat being trapped. **CO_2 is the single most important anthropogenic greenhouse gas** in the atmosphere, **contributing around 65% to radiative forcing by greenhouse gases**.

Increases in global temperature due to alteration of the carbon cycle will have significant impacts on the water cycle, leading to **greater levels of evapotranspiration**. The increase in global temperatures may make **summer storms more likely** but **decrease the amount of rainfall in summer** on average, yet **increase the average winter rainfall**.

Causes

- **Land Use Change:** Accounts for a **tenth of carbon release annually** and impacts on **short-term stores** in the carbon cycle, such as the soil and atmosphere. For example:
  - **Farming Practices:** In the Amazon, around **70% of deforestation is for cattle ranching**. Cattle produce significant amounts of **methane**, further contributing to global warming. Scientists are considering whether feeding cows different foods would help to reduce their methane emissions.
- **Fertilisers** are a significant source of greenhouse gases as well as **rice padi fields**, from which methane emissions have increased as a result of **increased productivity** due to higher CO_2 levels. More sustainable grains and seeds like **quinoa** are being considered as substitutes, which require **less water to grow**.

- **Deforestation:** In total, **deforestation accounts for about 20% of all global greenhouse emissions**. The main impact is when the cycle is interrupted and the land is used for other purposes, which then reduces carbon sequestration and land becomes a **carbon source** rather than a **carbon sink**.

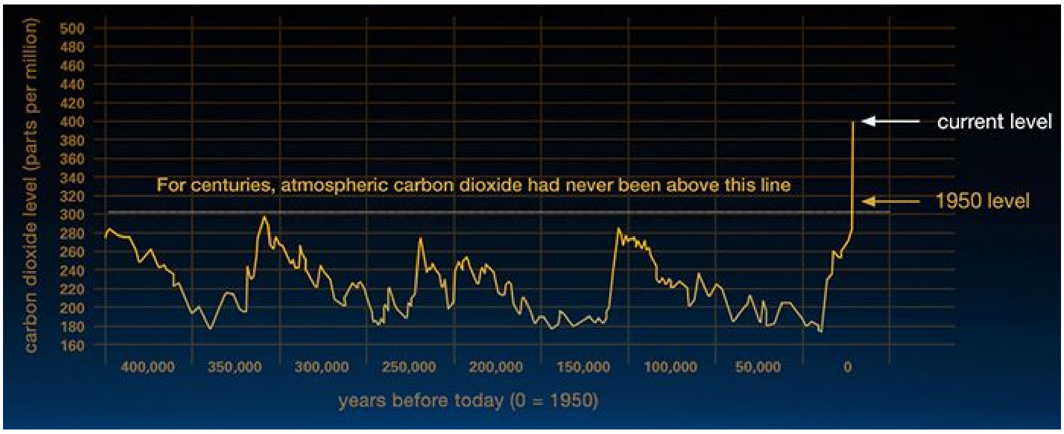
- **Urbanisation:** This is the process of **replacing countryside with buildings and other similar infrastructure**. It affects the **local and global carbon cycles**, by replacing vegetation and covering soils. **Urban areas occupy 2% of the world's land mass**, but these areas **account for 97% of all human caused global CO_2 emissions**. Cement is an important building material, but releases carbon dioxide during production, contributing **7% to global carbon dioxide emissions each year**, so sustainable options for recycling concrete are being developed.

There is also the emergence of **rewilding**, where populated or managed human areas are being reduced or replaced by wildlife. This will hopefully **restore environments** in years to come and the trees that are planted will help mitigate global warming.

Milankovitch Cycles

Vostok ice core data from Antarctica suggests that in the past **temperature change has occurred before carbon dioxide levels have risen**, offering a slightly different explanation for historical global warming. It is possible that **variations in the Earth's orbit** cause periods of time where we experience a greater heating effect from the sun, increasing the global temperatures. This increase in temperatures causes **glaciers** to melt and therefore **increases flows in the carbon cycle**; allowing more CO_2 to enter the atmosphere and for **global temperatures to rise further**. This is an example of **positive feedback**. **The quantity of freshwater flowing into the oceans increases**, causing **temperature fluctuations between Earth's two hemispheres**. As the oceans became warmer, they **release more CO_2** into the atmosphere (colder water can store more CO_2), causing further global temperature rises. So whilst **orbital variations** initiated the warming effect, over 90% of warming was likely as a result of the rise in atmospheric CO_2.

The results of this study are **not widely agreed on**, as any slight **systematic errors** (technical or equipment errors that vary by a consistent amount) in the data collection would **affect the overall conclusions** of the study. It is thought that it is **natural that CO_2 levels and temperature increase** during **interglacial periods.** Many forests colonised areas which became ice free as a result of temperature increases. The causes of present day global warming are more widely agreed upon with **97% of active climate scientists believing that global warming over the last 100 years is very likely to be due to human activity**. The **International Panel on Climate Change (IPCC) say it is 'virtually certain' that humans are to blame for 'unequivocal' global warming**.

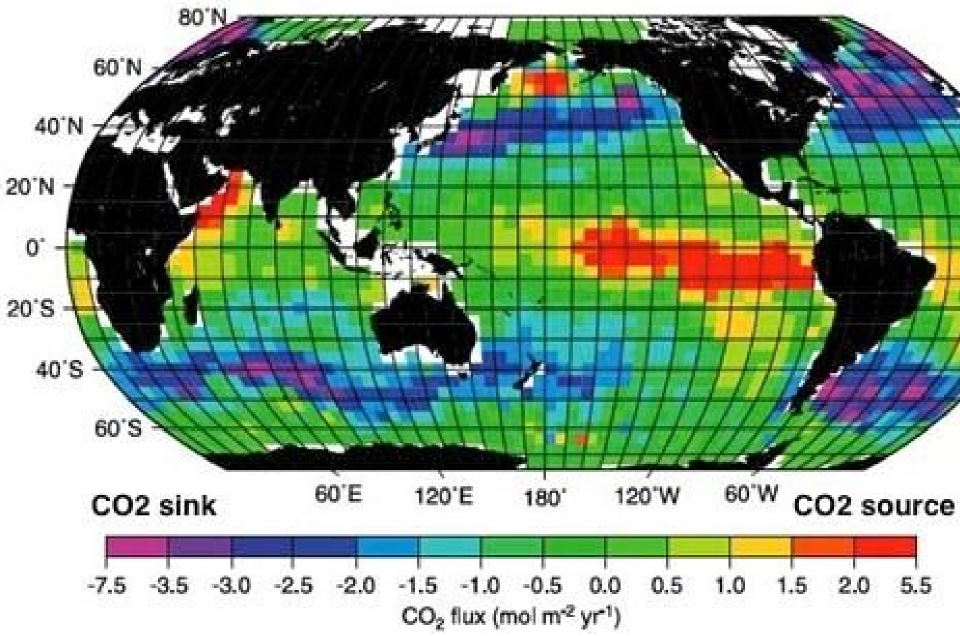


Source: NASA

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.
- Warm oceans also **store less CO_2**, as carbon sequestration is dependent on a cooler ocean. This means higher temperatures could lessen the effects of oceans as **carbon sinks**. Note how warmer, equatorial oceans are classed as CO_2 sources. This sets up a **positive feedback loop** where the greenhouse effect is heightened further.



Source: https://serc.carleton.edu/eslabs/carbon/6a.html

Feedback Loops

A feedback loop is a type of **chain reaction**, where one process leads to another process, leading to another process, and so on. There are two types of feedback loops: positive and negative.

In **negative feedback**, the process that occurs is **counteracted** by an opposing process, causing the effects to cancel each other out and **nothing to change**.

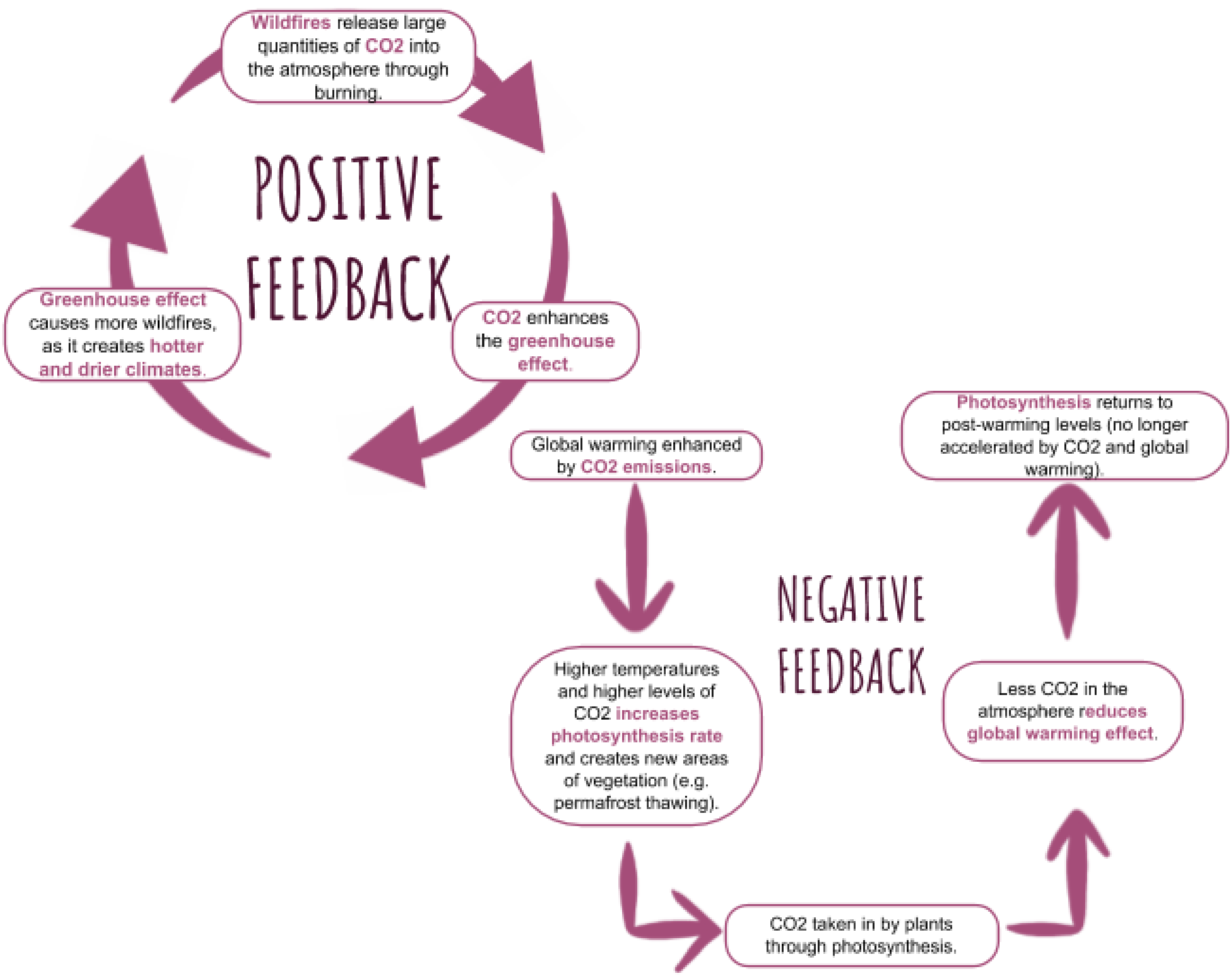
In **positive feedback**, a process occurs, which causes another process to occur, which starts a chain reaction that **heightens** the first process.

Positive Feedback:

- **Wildfires** are more likely in **hotter and drier climates** created by global warming, which release large quantities of CO_2 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 CO_2 and methane** (which has 20 times the warming effect of CO_2), causing warming on a local and global scale. **Permafrost is frozen ground** that remains at a temperature of 0°C or lower for at least 2 consecutive years. 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 CO_2 from the atmosphere, decreasing the warming effect
- Higher temperatures and more CO_2 cause a **greater carbon fertilisation in plants**, so they absorb more CO_2. This reduces the levels of CO_2 in the atmosphere and the rates of warming and **carbon fertilisation** will decrease. The process repeats. Scientists are now investigating whether **carbon fertilisation** is affected by other factors and peaks at a certain atmospheric CO_2 level. If this is the case, then there will be a **limit to how much CO_2 plants can continue to sequester**. It is suggested that **carbon fertilisation is limited by water and nitrogen levels**. If rainfall decreases as a result of climate change, then **carbon fertilisation may decrease** as a result, as water is required for photosynthesis.
- Higher **CO_2 levels** causes phytoplankton to grow (as they feed off CO_2). CO_2 is taken in through photosynthesis and levels decrease as a result, causing phytoplankton to decrease.
- Higher temperatures causes phytoplankton to grow and photosynthesise quicker. **Phytoplankton** release substances that lead to the **formation of clouds**, meaning cloud cover increases. Radiation from the sun is therefore less able to reach the oceans, reducing temperatures. This therefore causes phytoplankton to grow less quickly and photosynthesise slower, reducing cloud cover.



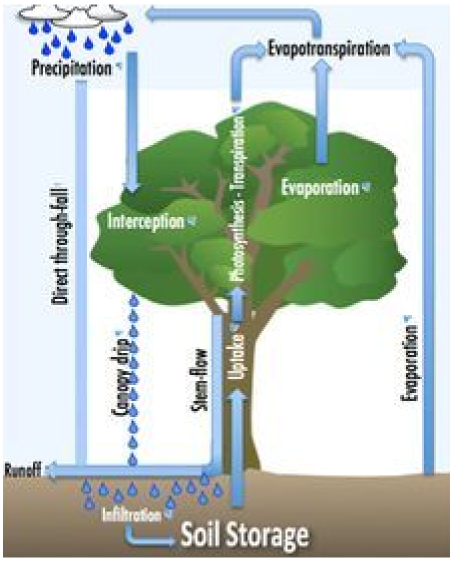
Land Drainage in Moorland Areas

A moorland (also known as peatland) is an expanse of **waterlogged, acidic soil** and **peat** (partially decayed organic matter). Waterlogged grounds stops **oxygen** from permeating, which reduces plant growth. Moorlands are major stores of **carbon dioxide**; in fact they are the largest terrestrial carbon store.

Many areas of **moor/peatland** have been drained by large channels, which means they are **no longer submerged.** They have often been **converted into highly productive farmland** or **plantations in tropical areas** due to their fertile soils. This has caused an **increased flood risk** in local areas as **surface storage is reduced** by draining the moorland and streamflow is increased by digging the drainage ditches. This has impacts on the carbon cycle:

- Moor/peatland is drained.
- **Water table is lowered** affecting flows in the water cycle.
- The dry **peat** (decayed organic matter and vegetation that is **preserved** in wetland environments and has high carbon content) degrades easily.
- As the water table lowers, air is able to aid decomposition of the peat, releasing carbon dioxide.

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** increasing flooding risk.
- **Less evapotranspiration**, so the atmosphere is **less humid and rainfall decreases.**

Natural Rainforest Carbon Cycle:

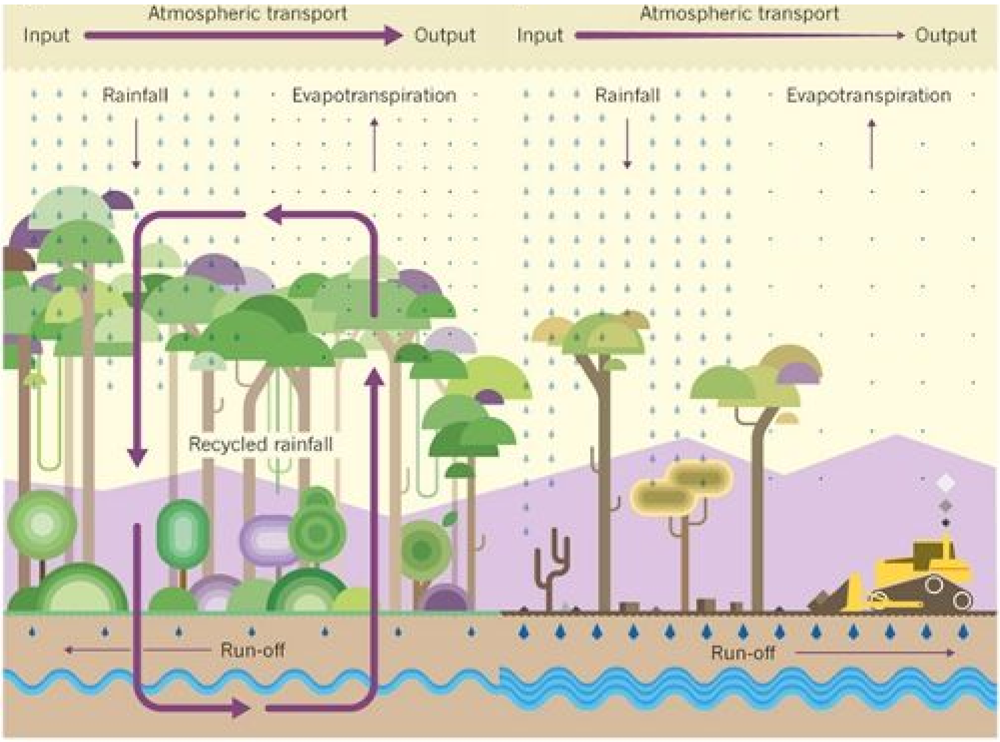
- Trees suited to humid and warm conditions, which promotes photosynthesis.
- They absorb large amounts of oxygen from the atmosphere acting as an important **carbon sink.**
- Decomposition and respiration releases CO_2 back to the atmosphere and soil, where carbon is stored.

Deforested Rainforest Carbon Cycle:

- Lack of trees so **photosynthesis is reduced.**
- **Fires** to clear land leads to CO_2 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, causing soil erosion. If **soil and ash flows into rivers** it increases the carbon content of rivers. The **water** leaves the rainforest cycle as an **output through streamflow** due to **reduced interception and increased surface runoff.** This could cause desertification, potentially reducing overall evapotranspiration and precipitation in these areas. High temperatures could lead to forest migration as some habitats become unsuitable for trees as the climate changes, causing desertification in these areas. This desertification further reduces evapotranspiration and the likelihood of rainfall.
- Alternatively there is **reduced rainfall in the intact forest** as there is **less evapotranspiration** in the deforested area. This causes **drought periods** and the **intact rainforest to deteriorate.**
- The image below shows an intact rainforest water cycle on the left and a degraded tropical rainforest water cycle on the right.



Source: Dr Luiz Aragao

- 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 CO_2 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. More water is stored year round, ensuring a steady and even water supply, which is of better quality as it filtered by the wetlands. The area is more attractive to wildlife and becomes an important habitat. **Carbon storage is also increased** as **peat** is made up of carbon and water. Wildlife benefit from fewer drier conditions and better availability of food sources

Mitigating Climate Change

Mitigation:

- Setting targets to reduce greenhouse gas emissions.
- Switching to renewable sources of energy.
- 'Capturing' carbon emissions and/or storing or burying them (sequestration).

Global Intervention - Paris Climate Deal (COP21):

- Aim to limit the increase of 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.**