WATER AND CARBON CYCLES: PROCESSES IN THE WATER CYCLE

GLOBAL STORES OF WATER

Hydrosphere (96.5%): Liquid water on the Earth's surface, e.g. oceans, lakes.
Cryosphere (1.7%): Frozen areas of the planet, e.g. glaciers and ice sheets.
Lithosphere (1.7%): Water stored in rocks, e.g. aquifers.
Atmosphere (0.001%): Water stored in the air, e.g. water vapour and clouds

INPUTS AND OUTPUTS

Precipitation: Any form of water falling from the atmosphere to the Earth's surface – includes rain, snow, sleet, and hail.
Evaporation: Sun heats the surface of water (e.g. rivers and lakes) changing it from a liquid to a gas (water vapour).
Transpiration: Water released from plants into the air. When combined with evaporation, it forms evapotranspiration.
Condensation: Water vapour in the air cools (dew point) and changes into liquid water – this leads to cloud formation.

OPEN OR CLOSED?

Water cycle = closed system.
Drainage basin = open system.

STORES AND FLOWS

Surface stores: Water stored in lakes and river channels.
Groundwater: Water stored within porous rock underground.
Water table: The upper level of saturated rock.
Interception: Leaves, stems and trunks can stop water from reaching the ground - temporarily hold water.
Absorption: Vegetation takes up water through the root system.

TRANSFERS

Surface run-off: Water flowing over the Earth's surface (overland flow) – when ground is waterlogged or impermeable.
Infiltration: Downward movement of water into soil – affected by soil type, vegetation, land use, etc.
Percolation: Downward movement of water through rocks underground – important for replenishing groundwater stores.
Throughflow: Horizontal movement of water through soil to return to a river, can be accelerated by plant roots or animal activity.
Groundwater flow (base flow): Slow, horizontal flow of water through sub-surface rock – helps maintain river flow during dry periods.
Stem flow: Water dripping from leaves or flowing down stems and trunks to reach the ground.
Channel flow: Movement of water within the river channel – driven by gravity and influenced by channel gradient, shape, and roughness.

FRONTAL RAINFALL

Occurs when two air masses of different temperatures meet. The warmer, less dense air is forced to rise over the cooler, denser air. As the warm air rises, it cools and condenses to form clouds, leading to rainfall. Common in mid-latitude regions – associated with weather fronts and prolonged periods of rain.

CONVECTIONAL RAINFALL

Occurs when the ground is heated by the sun, causing warm air to rise rapidly. As the air rises, it cools and condenses to form clouds, leading to heavy rain. Common in tropical regions and during summer months in temperate areas – associated with thunderstorms and heavy downpours.

OROGRAPHIC (RELIEF) RAINFALL

Occurs when moist air is forced to rise over a mountain range. As the air ascends, it cools and condenses to form clouds, resulting in precipitation on the windward side of the mountains. The windward side receives heavy rainfall, while the leeward side (rain shadow) remains dry. Common in mountainous regions.

WATER AND CARBON CYCLES: WATER BALANCE AND SOIL MOISTURE BUDGETS

WATER BALANCE

This equation is the balance between the inputs and outputs within a drainage basin and is used by hydrologists to plan for future water supply and flood control…

$P = Q + E +/- S$

P = precipitation
Q = run-off
E = evapotranspiration
S = changes in storage

RIVER REGIME

Rivers will always have a regime which they follow – some months the discharge of the river will be higher than others. The water balance looks at how the amount of precipitation compares with the water leaving the system as runoff or as evapotranspiration.

This balance will change throughout the year and will be affected by the overall climate of the area near to the river.

'Usual' conditions: Precipitation will be matched by run-off and evapotranspiration giving a 'normal' river level.

WATER BALANCE CONDITIONS

Water surplus: Excess water available - soil is fully saturated, and any additional precipitation leads to excess water. This surplus water can result in surface runoff, increasing river discharge and potentially leading to flooding.

Water deficit: Less water within the system – evapotranspiration exceeds precipitation and soil moisture is depleted. Can lead to falling river levels and water stress, and irrigation may be needed.

Recharge: When soil moisture is replenished by precipitation after a dry period – important to ensure that soil moisture levels are maintained.

Field capacity: The maximum amount of water that soil can hold before it becomes saturated.

Utilisation: The process by which plants use the available soil moisture. During this period, plants draw water from the soil to meet their needs. Monitoring utilisation helps in understanding plant water requirements and managing irrigation schedules.

SOIL MOISTURE BUDGET DIAGRAMS

Show how much water is in the soil at different times – they help us understand when the soil is full of water and when it's dry.

This information is useful for predicting floods in several ways:

Knowing when the soil is full: When the soil is already full of water, any extra rain can't soak in and will run off the surface. This runoff can cause rivers to rise and potentially flood. By knowing when the soil is full, we can be ready for possible floods.

Checking soil saturation: These diagrams help us see how much water the soil can still absorb. If the soil is already wet, it can't take in much more water, leading to more runoff and a higher chance of flooding.

Estimating run-off: By looking at the soil moisture levels, we can guess how much water will run off during rain. If the soil is wet, more water will run off, increasing flood risk.

Seasonal changes: Soil moisture diagrams show how soil water levels change with the seasons (helping plan for different times of the year)…

- During rainy seasons – the soil gets saturated faster, raising flood risk
- During dry seasons – the soil can absorb more water, lowering flood risk

WATER AND CARBON CYCLES: FACTORS AFFECTING THE RISK OF FLOODING

BANKFULL CAPACITY

The maximum amount of water that a river channel can hold before it overflows its banks. This capacity is influenced by the channel's shape, size, and the surrounding landscape.

PHYSICAL FACTORS THAT INCREASE FLOOD RISK

Precipitation:

- Intense or prolonged rainfall – can saturate the ground,
- leading to increased surface runoff
- Heavy, short-duration rainfall – creates a flashy hydrograph
- due to rapid runoff
- Prolonged, steady rainfall – can lead to a subdued hydrograph as water infiltrates the soil before reaching the river

Geology: Rock type affects infiltration…

- Impermeable rocks (e.g., clay, granite) – prevent infiltration, leading to more surface run-off
- Impermeable surfaces (e.g. concrete, tarmac) – create a flashy hydrograph due to quick run-off
- Permeable rocks (e.g. sandstone, chalk) – allow infiltration, leading to a subdued hydrograph

Soil type: Soil permeability affects water absorption, e.g. sandy soils absorb more water than clay soils.

Relief: The slope of the land influences the speed at which water flows into rivers…

- Steep slopes – cause rapid run-off as it's easier for water to run over the land than infiltrate the soil (flashy hydrograph
- Gentle slops – water moves more slowly (subdued hydrograph)

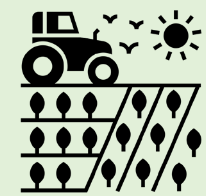
Drainage basin shape: Affects how quickly water reaches the river..

- Circular basins – concentrate water flow quickly (flashy hydrograph)
- Elongated basins – spread water flow over a longer period (subdued hydrograph)

HUMAN FACTORS THAT INCREASE FLOOD RISK

Urbanisation: Development of cities and towns with impermeable surfaces (e.g. concrete and tarmac) increases surface runoff. Building often takes place on the flood plain. Urban areas create a flashy hydrograph due to rapid runoff from impermeable surfaces.

Deforestation: Removal of trees reduces interception and increases surface runoff. Trees normally absorb water and slow its movement. Deforested areas create a flashy hydrograph due to increased runoff, whereas forested areas lead to a subdued hydrograph as trees intercept and absorb water.



Agriculture: Farming methods, such as ploughing and crop rotation, affect soil structure and water movement. Fields without crops can channel water quickly. Poor agricultural practices create a flashy hydrograph due to increased runoff. Additionally, drainage channels are used to remove excess water from fields, which can quickly channel water away, creating a flashy hydrograph.

Drainage systems: Efficient drainage systems can quickly channel water away from urban areas but may increase flood risk downstream

- Well-maintained drainage systems – can create a flashy hydrograph due to rapid water movement
- Poorly maintained systems – may lead to a subdued hydrograph as water is retained longer

WATER AND CARBON CYCLES: FLOOD HYDROGRAPHS

WHAT ARE HYDROGRAPHS?

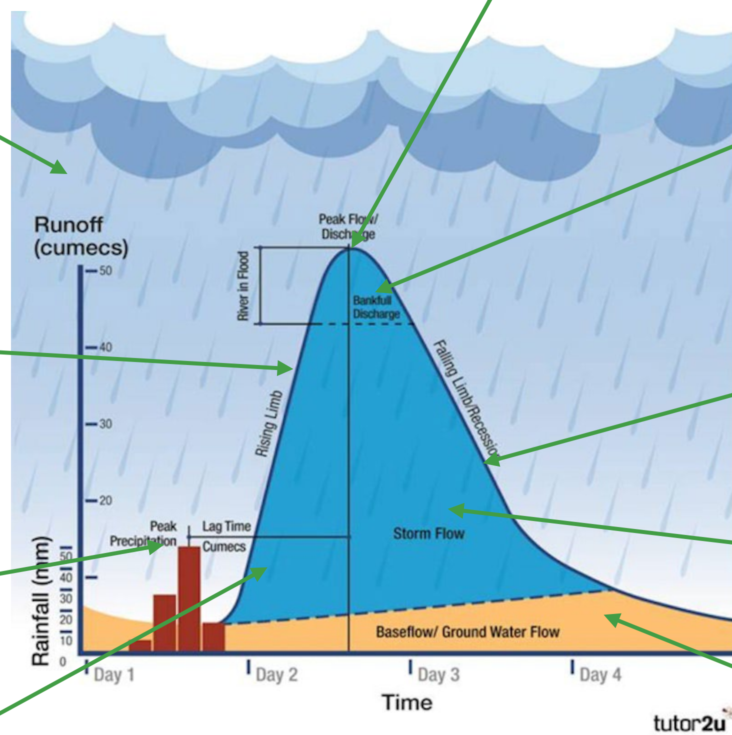
Flood (storm) hydrographs are graphs that show how a drainage basin responds to a period of rainfall. Hydrologists use them to plan for flood situations and times of drought.

PEAK DISCHARGE

The maximum flow rate of water passing through a river or stream at a given point and time, usually following a period of heavy rainfall or snowmelt.

CUMECS

Short for cubic metres per second (m^3/s), cumecs is a unit of measurement for the flow rate of water, typically used to describe the discharge of a river or stream.



BANKFULL DISCHARGE

The flow rate at which a river fills its channel to the point of overflowing. It is the maximum discharge that the river channel can hold without flooding. This can vary from river to river depending on multiple different factors.

RISING LIMB

The part of a hydrograph that shows the increase in river discharge following a rainfall event. It represents the period when water is rapidly entering the river system.

FALLING LIMB

The part of a hydrograph that shows the decrease in river discharge after the peak has been reached. It represents the period when the flow is receding.

PEAK PRECIPITATION

The highest amount of rainfall recorded during a specific period, usually within a storm event. It indicates the maximum intensity of rainfall.

STORM FLOW

The additional flow in a river or stream resulting from a storm event. It includes both surface runoff and any increased flow from tributaries.

LAG TIME

The time interval between peak precipitation and peak discharge in a river. It represents the delay between the heaviest rainfall and the highest river flow.

HOW CAN HYDROGRAPHS HELP PREDICT FLOODING?

They show how river discharge changes over time in response to rainfall. By analysing the shape of hydrographs, we can understand how quickly and significantly a river responds to precipitation, which helps in flood prediction and management.

BASE FLOW

The normal, sustained flow of a river or stream, primarily fed by groundwater. It represents the typical flow level in the absence of recent rainfall.

WATER AND CARBON CYCLES: PICKERING – A CASE STUDY OF A RIVER CATCHMENT

LOCATION

Pickering is a small market town in North Yorkshire, bordering the North York Moors National Park.
Pickering Beck: Source is in the national park – flows for 18 miles through Pickering.

SLOW THE FLOW SCHEME

This scheme attempts to increase natural water storage retention using sustainable methods where possible to increase lag time and hence reduce flood risk.
Has it worked? No significant flood event has occurred since its completion in 2015.

FLOOD HISTORY

Pickering has flooded four times in the last twenty years, pushing them to create the 'slow the flow' initiative with Oxford University in 2009.

CAUSES OF FLOODING

Deforestation for land use change: Trees were removed over a long period of time in the east of the catchment to make way for sheep farming – this has reduced the rate of interception and infiltration, increasing surface run-off.
Draining the moors: To increase the amount of usable land for agriculture – this significantly decreases the lag time as the drainage channels lead directly into the river.
Impermeable surfaces: Pickering is a small town with many new housing estates – much of the land in the town has been covered in concrete and tarmac which are impermeable, increasing surface run-off and decreasing the lag time.

SLOW THE FLOW STRATEGIES – BENEFITS AND DRAWBACKS...

CHECK DAMS AND BLOCKED DRAINAGE CHANNELS

Farmers were taught to instal check dams (which slow down the water on the moors) and block drainage channels with hay bales – increasing storage capacity on the moors significantly.
Benefits: Simple method to put in place and relatively cheap.
Drawbacks: Decreased the area of usable land in farmers fields, so depended on incentives from the local community for effective 'buy-in'.

AFFORESTATION

Around 40,000 trees were planted in the east of the catchment drainage basin to increase interception, infiltration and throughflow. This helped to increase lag time as much of the area was also on steep slopes.
Benefits: Led to a significant increase in biodiversity and increase ecosystem services such as habitats for pollinators.
Drawbacks: Reduced the amount of land area available for arable agriculture.

WOODY DEBRIS DAMS

167 dams made from wood were installed in the upper course of the river to hold water there, rather than allowing discharge to increase downstream.
Benefits: A relatively cheap and sustainable method of decreasing flood risk.
Drawbacks: Increased flood risk in the upper course, meaning drained farmland is less usable for farmers.

EARTH BUND:

A large earthen dam and culvert were installed in the upper course at a cost of £500,000. It can store as much as 120,000m3 of flood water and limit its release downstream.
Benefits: Very effective and will eventually support biodiversity as the earth is 're-wilded'.
Drawbacks: Very expensive for such a small town meaning its replicability is compared to the other strategies.

WATER AND CARBON CYCLES: PROCESSES IN THE CARBON CYCLE

GLOBAL STORES OF CARBON

Atmosphere: Mainly stored as carbon dioxide (CO_2), but also shorter-lived methane (CH_4).
Biosphere: All living organisms are composed of carbon.
Cryosphere: The frozen ground of tundra and Arctic regions containing plant material.
Pedosphere: Soil contains much organic carbon and the remains of dead plants and animals.
Lithosphere: Many rocks contain carbon, e.g. chalk/ limestone.
Hydrosphere: The oceans contain dissolved CO_2, and marine organisms and their remains.

SLOW CARBON CYCLE

Operates over millions of years and cycles carbon between land and atmospheric or ocean stores due to weathering and tectonic processes.

5 stages:

1. The transfer of carbon into the oceans from the atmosphere and land surface e.g. weathering
2. The deposition of carbon compounds on the ocean floor
3. The conversion of ocean sediments into carbon-rich rock
4. The transfer of carbon rocks to tectonic margins
5. The return of carbon compounds to the atmosphere in volcanic eruptions

FAST CARBON CYCLE

Operating on a daily basis – cycling carbon between land and the atmosphere as living things breathe and digest food. Several natural processes are central to this…

Photosynthesis: Plants and algae use sunlight to convert CO_2 and water into glucose and oxygen – removes CO_2 from the atmosphere and stores carbon in plant biomass.
Respiration: Animals release CO_2 into the atmosphere, soil and oceans by animals as they exhale.
Decomposition: Decomposers, such as bacteria and fungi, break down dead organic matter, releasing CO_2 and CH_4 into the atmosphere.
Combustion: Natural fires release carbon compounds from vegetation to the atmosphere
Ocean-atmosphere exchange: Mutual transfer of CO_2 between the lower atmosphere and ocean surfaces. The flow can go in either direction depending on the balance of CO_2 between the two stores, temperature and conditions of air and water.

HUMAN PROCESSES IN THE CARBON CYCLE

Fossil fuel combustion: Burning coal, oil, and natural gas for energy releases large amounts of CO_2 into the atmosphere – contributing to the greenhouse effect.
Deforestation: The removal of trees for agriculture, urban development, logging, energy development, etc, reduces the CO_2. Trees act as a carbon sink – when they are burned the stored carbon is released into the atmosphere.
Agriculture: Farming activities, such as rice paddies and livestock farming, release CH_4, a potent greenhouse gas. The use of chemical fertilisers can also increase soil respiration and CO2 emissions.
Cement production: The production of cement involves heating limestone (calcium carbonate), which releases CO_2 as a byproduct – a significant source of industrial CO_2 emissions.

LINKS BETWEEN NATURAL AND HUMAN PROCESSES

Human activities often disrupt natural carbon processes, leading to an imbalance in the carbon cycle…

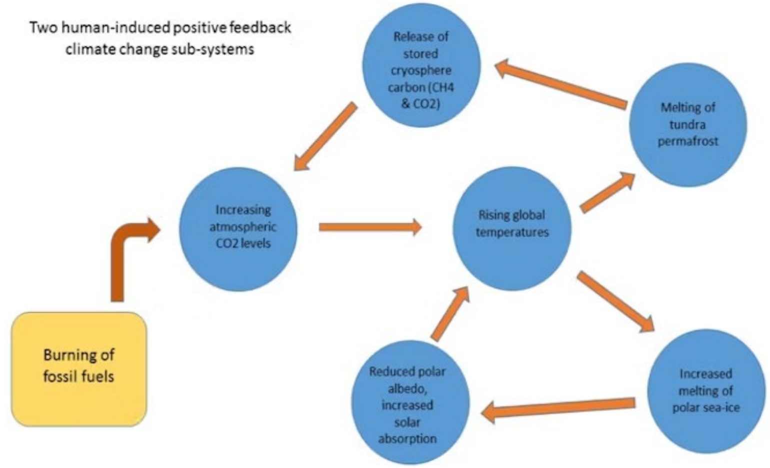
- Deforestation reduces the capacity of forests to absorb CO2
- Fossil fuel combustion adds more CO2 to the atmosphere than natural processes can remove

Understanding these interactions is crucial for managing carbon emissions and mitigating climate change.

WATER AND CARBON CYCLES: FEEDBACK IN THE WATER AND CARBON CYCLES

KEY TERMS

Dynamic equilibrium: A state of balance between inputs and outputs in a system that is constantly changing (e.g. the carbon cycle).
Negative feedback loop: The movement back towards dynamic equilibrium – dampening down of change.
Positive feedback loop: The movement further away from dynamic equilibrium – an amplification or intensification of change, e.g. human impact on the carbon cycle.
Tipping point: If atmospheric carbon dioxide passes a certain level, a positive feedback cycle will be triggered and further increases of atmospheric carbon are virtually inevitable.



POSITIVE FEEDBACK CYCLES

Permafrost melting: Rising temperatures cause permafrost to thaw, releasing stored carbon in the form of CO_2 and methane into the atmosphere. These greenhouse gases contribute to further warming and more permafrost thawing.
Ocean warming: Warmer oceans are less able to dissolve CO_2 in seawater, leading to more CO_2 being released into the atmosphere, enhancing the greenhouse effect, causing further warming.

NEGATIVE FEEDBACK CYCLES

Increased photosynthesis: Higher CO_2 levels can stimulate plant growth, leading to more CO2 being absorbed from the atmosphere through photosynthesis. This process helps to reduce atmospheric CO_2 levels and mitigate warming.
Ocean carbon uptake: As atmospheric CO2 levels rise; the oceans can absorb more CO_2. This process helps to remove CO2 from the atmosphere, although it can also lead to ocean acidification.

LINKS BETWEEN THE WATER AND CARBON CYCLES

Photosynthesis and respiration: Plants use water and CO_2 during photosynthesis to produce oxygen and glucose. During respiration, plants and animals release CO_2 and water back into the atmosphere. This process is a key component of both the water and carbon cycles.
Ocean-atmosphere exchange: The oceans play a crucial role in both cycles by absorbing CO_2 from the atmosphere and releasing it back through processes like diffusion and upwelling. Water movement in the oceans helps transport carbon, affecting global carbon distribution.
Weathering and erosion: Water contributes to the weathering of rocks, which releases carbon stored in minerals into rivers and eventually the oceans. This process is part of the slow carbon cycle and helps regulate atmospheric CO_2 levels.
Soil carbon storage: Water availability affects soil moisture, which influences the decomposition of organic matter and the release or storage of carbon in soils. Wet conditions can slow decomposition, leading to carbon storage, while dry conditions can accelerate it.

WATER AND CARBON CYCLES: MITIGATING CLIMATE CHANGE

THE CARBON BUDGET

A concept used in climate policy to help set emissions reduction targets in a fair and effective way. It refers to the maximum amount of cumulative net global anthropogenic (human-caused) CO_2 emissions that can be emitted to limit global warming to a specific temperature threshold.

CLIMATE CHANGE CONFERENCES

International meetings where countries discuss and negotiate actions to address climate change, e.g. UN Conference of the Parties (COP).

Example: Paris Agreement to limit global warming to below 2°C above pre-industrial levels, ideally 1.5°C – signed by 195 countries.

Advantages: International cooperation and commitment to reducing greenhouse gas emissions, and sharing of knowledge, technology, and best practices.

Disadvantages: Can be influenced by political and economic interests, leading to compromises; and implementation of commitments can be slow and inconsistent as some agreements lack binding enforcement mechanisms.

AFFORESTATION

Planting trees to increase forest coverage.

Example: China's Grain for Green Program - converted over 28 million hectares of cropland to forest since 1999.

Advantages: Increases carbon sequestration by absorbing CO2 through photosynthesis; Enhances biodiversity by providing habitats for wildlife.; Prevents soil erosion and improves water retention.

Disadvantages: Can lead to loss of agricultural land and affect food production; Poorly managed projects may reduce biodiversity and introduce invasive species; Requires long-term maintenance and monitoring.

RENEWABLE ENERGY

Energy derived from natural sources that are replenished on a human timescale, e.g. solar, wind, hydro, geothermal. In 2023, 29% of global electricity generation was from renewable sources, with wind and solar being the fastest-growing.

Advantages: Reduces reliance on fossil fuels, decreasing greenhouse gas emissions; Provides a sustainable and inexhaustible energy source; Creates jobs and stimulates economic growth in the renewable sector.

Disadvantages: High initial investment and infrastructure costs.; Intermittent energy supply (e.g., solar and wind) requires storage solutions; Geographic limitations may affect the feasibility of certain renewable sources.

DIRECT AIR CARBON CAPTURE

Technology that removes CO2 directly from the atmosphere using chemical processes. Captured CO_2 can be stored underground or used in various products.

Example: Clime works' Orca plant in Iceland, which captures 4,000 tonnes of CO2 per year and stores it underground

Advantages: Removes CO_2 directly from the atmosphere, reducing greenhouse gas concentrations; Can be deployed in various locations, not limited to emission sources; Potential to produce valuable by-products, such as synthetic fuels.

INDUSTRIAL AND ENERGY CARBON CAPTURE

Technologies that capture CO2 emissions from industrial processes and power plants before they are released into the atmosphere. The captured CO2 can be stored underground or used in various products

Example: The Petra Nova project in Texas, USA, which captures 1.4 million tonnes of CO2 annually from a coal-fired power plant.

Advantages: Captures CO2 emissions at the source, preventing them from entering the atmosphere; Can be integrated into existing industrial processes and power plants; Helps industries transition to lower-carbon operations.

Disadvantages for both: High energy and financial costs for operation and maintenance; Requires significant infrastructure and technological development; Potential environmental impacts from storage and disposal of captured CO2.

WATER AND CARBON CYCLES: FARMING AND CLIMATE CHANGE

PROBLEM: AGRIBUSINESS

Large-scale, industrial farming operations that often involve monoculture (growing a single crop over a large area) and intensive livestock farming. Responsible for 11% of global greenhouse gas emissions in 2023.

Impact on climate change:

- Large-scale monoculture farming often relies on heavy machinery, which burns fossil fuels and emits CO_2
- Intensive livestock farming produces significant amounts of methane (NH_4)
- Synthetic fertilisers and pesticides lead to nitrous oxide (N_2O) emissions

Example: USA - large-scale corn and soybean farms.

PROBLEM: LAND USE CHANGE

Involves altering the natural landscape for agricultural purposes, e.g. converting forests into crop plantations.

Impact on climate change: Deforestation reduces the number of trees that can absorb CO_2, leading to higher atmospheric CO_2 levels. Additionally, the process of clearing land often involves burning vegetation, which releases stored carbon into the atmosphere. Land use change can also disrupt soil carbon storage, releasing CO_2 and other greenhouse gases.

Example: Between 2001 and 2019 24 million hectares of the Amazon rainforest were cleared for farming, e.g. cattle ranching and soybean.

PROBLEM: FERTILISER USE

Chemical or organic substances used to enhance plant growth. Nitrogen-based fertilisers are used in modern farming.

Impact on climate change: Manufacturing fertilisers requires energy, often from fossil fuels, leading to CO_2 emissions; When used fertilisers can release N_2O through soil microbial processes. N_2O is a greenhouse gas with a global warming potential approximately 300 times that of CO_2.

SOLUTION: REGENERATIVE AGRICULTURE

Involves farming practices that restore soil health, increase biodiversity, and enhance ecosystem services. E.g. crop rotation and integrating livestock.

Mitigation: These practices improve soil carbon sequestration, reduce greenhouse gas emissions, and enhance resilience to climate change.

Example: Gabe Brown's farm in North Dakota, USA, uses regenerative practices to improve soil health and increase carbon sequestration.

Additional benefits: Improves soil fertility, increases water retention.

Issues: Requires changes in traditional farming practices and may have higher initial costs. Adoption can be slow due to lack of knowledge and resources.

SOLUTION: AGROFORESTRY

Integrates trees and shrubs into crop land, combining agriculture and forestry.

Mitigation: Trees sequester carbon, reduce soil erosion, and improve microclimates, enhancing crop yields and resilience to climate change.

Example: The Inga Foundation's work in Central America promotes the use of Inga trees in agroforestry systems to restore degraded land and improve food security.

Additional benefits: Provides additional income from timber, fruits, and other tree products. Enhances biodiversity and soil health.

Issues: Requires long-term planning and investment. Trees take time to mature.

SOLUTION: ORGANIC FARMING

Doesn't use chemicals - use natural inputs like compost and manure instead.

Mitigation: Reduces greenhouse gas emissions from fertiliser production and application. Enhances soil carbon sequestration.

Example: The Rodale Institute in Pennsylvania, USA, conducts research and promotes organic farming practices.

Additional benefits: Improves soil health and biodiversity. Produces healthier food with fewer chemical residues.

Issues: Lower yields compared to conventional farming – labour intensive/expensive

WATER AND CARBON CYCLES: AMAZON RAINFOREST CASE STUDY - PROCESSES

WATER CYCLE IN THE AMAZON RAINFOREST

- The Amazon rainforest receives over 2,000 mm of rainfall annually
- Trees release vast amounts of water vapour into the atmosphere through evapotranspiration, contributing to cloud formation and further rainfall
- Trees also release condensation nuclei, around which raindrops can form
- Example: Tanguro Ranch – land that had previously been rainforest was converted to cattle grazing land and now only 850mm of rainfall in comparison to 2000mm

The Amazon's complex water cycle involves the movement of water from the Andes mountains, through the rainforest, and into the Atlantic Ocean. This cycle supports regional rainfall patterns and nutrient transport, essential for the ecosystem's health.

CARBON CYCLE IN THE AMAZON RAINFOREST

- The Amazon rainforest acts as a significant carbon sink, storing approximately 100 billion tonnes of carbon in its vegetation
- Trees absorb carbon dioxide (CO_2) during photosynthesis, converting it into biomass (trunks, branches, leaves)
- Decomposition and respiration release stored carbon back into the atmosphere
- Deforestation and land-use changes can turn the Amazon from a carbon sink into a carbon source, contributing to climate change
- The Amazon maintains high net primary productivity (NPP), capturing large amounts of carbon despite nutrient-poor soils
- Indigenous forest management practices help maintain the forest's role as a carbon sink in comparison to large scale cattle ranching practices

INFLUENCE OF THE INTERTROPICAL CONVERGENCE ZONE (ITCZ)

The ITCZ is a critical component of the tropical rain belt, significantly influencing the Amazon's water and carbon cycles.

What? The ITCZ is a narrow band of intense precipitation and rising air near the equator, where the northerly and southerly trade winds converge.

Result?

- This convergence leads to high levels of rainfall in the Amazon, supporting the dense vegetation and the processes of evapotranspiration and photosynthesis
- The ITCZ's position and intensity can affect the distribution and amount of rainfall in the Amazon, impacting the water cycle and, consequently, the carbon cycle
- Changes in the ITCZ due to climate change can alter rainfall patterns, potentially affecting the Amazon's ability to sequester carbon and maintain its role as a carbon sink

HOW ARE THEY LINKED?

Trees play a dual role by releasing water vapour into the atmosphere and absorbing CO_2 for photosynthesis..

- The moisture released by trees supports rainfall, which sustains the forest's growth and carbon sequestration capacity
- The movement of water through the Amazon basin transports nutrients essential for plant growth, indirectly supporting carbon storage

Amazon River plume: Extends into the Atlantic Ocean and influences ocean nutrient cycles and carbon sequestration

Climate regulation: The Amazon's water and carbon cycles are crucial for regional and global climate regulation – changes in these cycles, such as increased deforestation, can disrupt rainfall patterns and carbon storage, exacerbating climate change.

WATER AND CARBON CYCLES: AMAZON RAINFOREST CASE STUDY - DEFORESTATION

AGRICULTURE

Grazing land: In Brazil, cattle ranching accounts for approximately 80% of deforested land in the Amazon. Vast areas of forest are cleared to create to graze cattle.

Plantations: Soybean production also leads to extensive clearing with large-scale farming of soybeans, used in animal feed and various products.

HUMAN SETTLEMENT AND POPULATION GROWTH

Put additional pressure on the forest as land is cleared for housing, agriculture, and other needs. In the Brazilian Amazon, the expansion of settlements like Altamira has led to significant deforestation. These settlements often serve as hubs for further agricultural and logging activities.

LOGGING

Both commercial and illegal. Trees are cut down for timber, which is sold for construction, furniture, and other uses.

Selective logging: Targets high-value trees like mahogany and teak, but it often leads to further forest degradation.

In the Tapajós National Forest in Brazil, logging operations have caused extensive damage, even in areas designated for sustainable use.

ILLEGAL ACTIVITIES

E.g. unauthorized logging and land grabbing, often occur in protected areas and indigenous territories. Illegal logging operations in the Amazon frequently involve the use of forged permits and cutting more than authorized quotas.

MINERAL EXTRACTION

E.g. gold, iron ore, and bauxite – large areas of forest are cleared for mining, causing significant environmental damage.

Carajás Mine: The world's largest iron ore mine, has led to extensive deforestation. Mining operations often require the construction of roads, staff housing, and other infrastructure, which further contributes to forest loss.

CLIMATE CHANGE

Exacerbates the problem by increasing the frequency and severity of droughts and fires. These fires can be both natural and human-induced, leading to significant forest loss.

The Amazon experienced severe droughts in 2005 and 2010, which resulted in widespread forest fires and significant deforestation. Climate change also affects the Amazon's ability to generate its own rainfall, further stressing the ecosystem.

INFRASTRUCTURE DEVELOPMENT

Building roads: e.g. the Trans-Amazonian Highway opened access to remote areas – leads to further deforestation by opening up the forest to agriculture, logging, and mining.

Building dams and reservoirs for HEP: e.g. the Belo Monte Dam, floods vast areas of forest, leading to habitat loss and ecosystem disruption.

HOW DOES IT AFFECT WATER?

Deforestation reduces the number of trees available for evapotranspiration, a process where trees release water vapor into the atmosphere. This reduction leads to decreased cloud formation and rainfall, disrupting the water cycle.

HOW DOES IT AFFECT CARBON?

Trees in the Amazon act as significant carbon sinks, absorbing carbon dioxide (CO_2) during photosynthesis and storing it in their biomass. When trees are cut down or burned, the stored carbon is released back into the atmosphere as CO_2, contributing to greenhouse gas emissions. This shift can turn the Amazon from a carbon sink Into a carbon source, exacerbating global climate change

WATER AND CARBON CYCLES: AMAZON RAINFOREST CASE STUDY - SUSTAINABLE MANAGEMENT

AGROFORESTRY

Integrates trees and shrubs into agricultural landscapes, promoting biodiversity and sustainable land use.

Example: Tomé-Açu Cooperative in Pará, Brazil – farmers grow crops like cacao and açaí alongside native trees, enhancing soil fertility, reducing erosion, and providing diverse income sources.

Socio-economic benefits:

- Provides stable income for small farmers by diversifying crops and products
- Restores degraded lands, improving long-term agricultural productivity
- Reduces dependency on single-crop farming, enhancing food security

Disadvantage: Requires significant initial investment and technical knowledge, which can be a barrier for small-scale and indigenous farmers

ECOTOURISM

Promotes conservation by providing economic incentives to protect natural areas.

Example: The Yachana Lodge in Ecuador – located in a remote area of the Amazon, it employs local people and supports community development while minimizing environmental impact. Visitors learn about the rainforest and its conservation, fostering a deeper appreciation and commitment to its protection.

Socio-economic benefits:

- Generates employment opportunities for local communities
- Supports cultural preservation by involving indigenous communities in tourism activities
- Provides funding for conservation projects and wildlife protection

Disadvantage: Can lead to environmental degradation if not managed properly, such as over-visitation and habitat disturbance.

SUSTAINABLE LOGGING

Sustainable logging ensures that timber extraction does not harm the forest's long-term health – only certain trees are felled, allowing the forest to regenerate naturally so timber resources remain available for future generations.

Example: Precious Woods Amazon, a company operating in Brazill.

Socio-economic benefits:

- Provides economic opportunities and supports local economies through job creation
- Generates revenue from timber sales while maintaining forest health
- Encourages the use of sustainable practices, reducing illegal logging activities

Disadvantage: Monitoring and enforcement of sustainable practices can be challenging, leading to potential exploitation and illegal logging.

PROTECTED AREAS AND CONSERVATION PROGRAMS

Establishing protected areas helps preserve large tracts of rainforest from deforestation and degradation.

Example: The Central Amazon Conservation Complex (CACC) in Brazil is one of the largest protected areas, covering 60,000 km². It is classified as a World Heritage Site by the United Nations, which means it is protected by international treaties. Limits are placed on hunting, logging, and fishing, and access is restricted to ensure the area's ecological integrity.

Socio-economic benefits:

- Protects biodiversity, ensuring the survival of numerous plant and animal species
- Supports ecosystem services such as water purification and climate regulation
- Provides opportunities for sustainable tourism and research, generating income for local communities

Disadvantage: Can limit access to natural resources for local communities, potentially affecting their livelihoods.