

2.1

Year 12
Module 2P

Water and Carbon Cycles



Geography Knowledge Organiser

2.1.1 - Global Systems

Global water cycle

At a global scale there is a fixed amount of water = Closed System (The system's mass balance does not change). At any given moment water is either held in store or is being transferred over varying timescales.

Global water stores include:

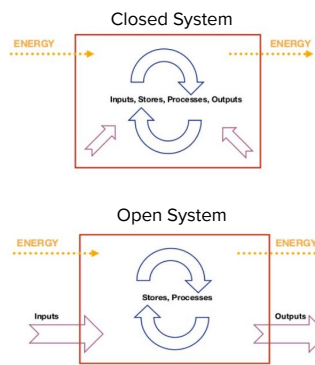
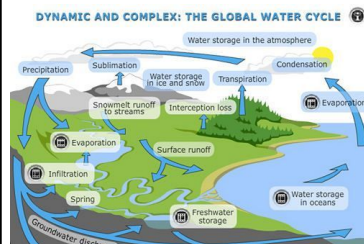
-Atmosphere and ocean

Global water inputs include:

-Precipitation

Global water outputs include:

-Evaporation, condensation



Main global water stores

Store	Volume (Cubic km)	% of total water	% of fresh water
Oceans	1,335,040	96.9	0
Cryosphere	26,350	1.9	68.7
Groundwater	15,300	1.1	30.1
Rivers & Lakes	178	0.01	1.2
Soil Moisture	122	0.01	0.05
Atmosphere	13	<0.01	0.04
Biosphere	0.6	<0.01	<0.01

Temporal and spatial changes

Seasonal changes in cryosphere storage

Accumulation=Input

Ablation=Output

Steady-state equilibrium means system maintains balance over the longer-term. Recent evidence does suggest that the changes in stores may become permanent because of human-induced climate change.

Seasonal changes in rainfall

A monsoon=wet season. Triggered by a periodic alternation of wind direction and velocity. Located in India, Pakistan China as well as East Africa and Australia. This means water transfers from atmosphere to land, and land to sea are seasonally uneven.

Long-term changes in cryosphere storage

This can occur naturally seen through the departure of glacial and interglacial periods. These changes are due to:

-Three cycles affecting the Earth's orbit around the sun- **Milankovitch Cycles**

Year-to-year climatic and rainfall variability

El Nino occurs every 3-7 years and lasts for 18 months. Very dry conditions; precipitation transfers from atmosphere to land are greatly reduced. Longer-term changes with warmer temperatures mean warmer air can hold more moisture so more rain can be expected in some areas. Water transfers from land to ocean would follow with ice sheets melting.

2.1.2 - Catchment hydrology

Drainage basin systems

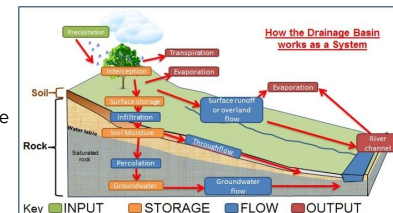
Drainage Basin = Open System

Drainage basin inputs

Precipitation, this can vary alongside type, amount, duration and intensity. All of these will affect have a drainage basin system responds.

High intensity, short duration =Flash Floods

Low intensity, long duration.



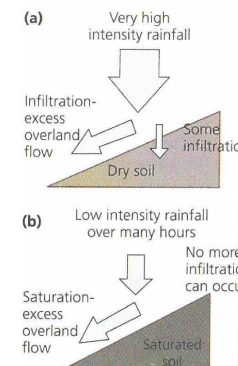
Drainage basin flows

Infiltration-determined by the capacity of the soil (**infiltration capacity**). Rainwater will be held on the ground surface if it falls at a rate that is greater than infiltration capacity (temporary).

Throughflow-relatively slow movement, most effective in the surface horizons of soils. Farming can impact this movement can reduce the soils permeability.

Percolation-transfer from soil to rock

Groundwater flow-depends on rock porosity. The bedrock may be permanently saturated this is called the water table and can vary according to season.



Drainage basin processes

Drainage basin stores

Interception-varies depending on local context and can prevent almost all precipitation reaching the surface. Varies with duration and character of vegetation.

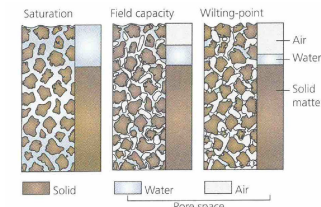
Vegetation store-varies depending on biome.

Surface store-varies depending on relief factors.

Soil moisture store-hygroscopic water (not available for plants) highlight insignificant store. Capillary water held by surface tension and available for plants to use. Water remains in the soil when excess water has drained away. Gravitational water (translational water) is excess water that occupies all large and free-draining spaces.

Channel store-varies depending on climatic and geological factors.

Groundwater store-amount varies due to porosity of rock



Drainage basin outputs

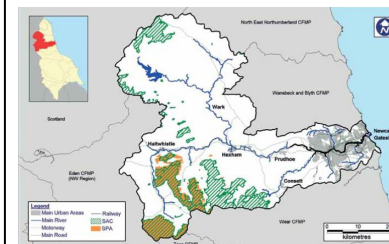
Evaporation-influenced by meteorological factors such as temperature, humidity and wind speed.

Transpiration-influenced by size and type of vegetation; the larger the leaf the greater rate of transpiration.

Channel discharge-water leaving via its main stream/river during a period of time.

Temporal and spatial variations

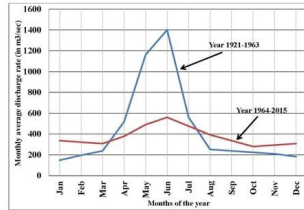
All three outputs are influenced by seasonal changes in local and regional contexts; whilst different types of vegetation adapt to maximise or minimise their rates of transpiration.



2.1.3 - Discharge variations

River regimes

A river regime is the annual variations in the pattern of flow, or discharge of a river measured at a particular point. Storm flow i.e. overland flow and throughflow accounts for some of the annual river flow. Groundwater flow accounts for a steady supply of water between periods of precipitation. Base flow is the normal minimum flow of the river.



Simple regime-characterised by periods of high and low channel flow corresponding with seasonal temperature and rainfall changes.

Complex regime-associated with some of the largest continental rivers e.g. the Colorado River before the construction of the Hoover Dam in 1935. Characterised by several peaks and troughs spread throughout the year relating to snowmelt in the summer months causing significant rise in water levels along the entire river.

Character of River regimes

Physical Factors: annual patterns of precipitation, snowmelt, temperatures and evaporation. Along with factors of relief, vegetation and underlying soil geology.

Human factors: constructions of dams and reservoirs, levels of irrigation and the extent to which water is removed from the river through transfer schemes.

Climatic influences

Climatic influences on hydrographs

Rainfall intensity and duration determines rate of 'flashy response'.

Antecedent conditions-if the soil was already saturated because of previous rainfall then overland flow would have occurred early resulting in 'flashy response'. Seasonal effects of evaporation and transpiration. If these outputs are minimal e.g. during winter then more 'flashy response'.

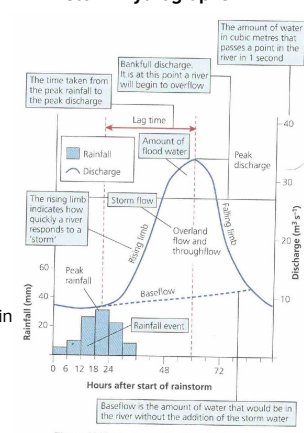
Non-Climatic influences on hydrographs

Relief-steep relief and impermeable geology favour 'flashy' hydrographs.

Poorly drained areas e.g. peat moorlands result in limited interception storage and more precipitation hitting the surface.

Soil and land use-Clay=low infiltration capacity. Agriculture impacts on a local level e.g. well-established pastures can give a relatively high infiltration rate. Urban gardens/lawns offer the same effective infiltration.

Storm Hydrographs



Drainage Basin Shape

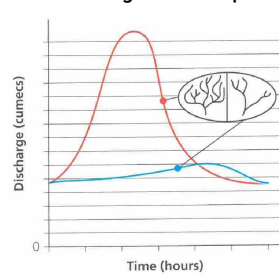


Figure 14 The influence of drainage density on flood hydrographs (basins with high drainage density have flashier flows)

2.1.4 - Precipitation & runoff

For the water cycle to function, water vapour in the atmosphere needs to change state into precipitation. Therefore, condensation must take place first.

Formation of condensation

Cooling of the air below its dew point or, Continued evaporation resulting in saturation of the air. Condensation leads to cloud formation and possibly precipitation. Water droplets in the atmosphere form when condensation takes place around a small dust or sea salt particles known as **condensation nuclei**.

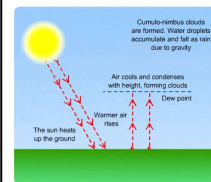
Air uplift and condensation

Air uplift and condensation

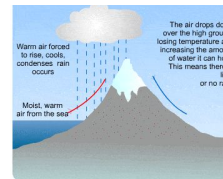
Air must rise in the atmosphere and cool to its saturation point.

Reasons for air uplift

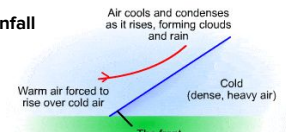
Convective Rainfall



Orographic Rainfall



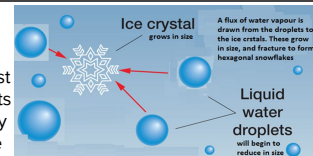
Frontal Rainfall



Theories of precipitation formation

The Bergeron-Findeisen process "Ice crystal of growth"

Clouds at high altitude, with temperatures just below 0°C contain a mixture of water droplets and ice crystals. The ice crystals grow quickly at the expense of the water droplets. The ice crystals fracture and hexagonal ice shapes develop with larger surface areas. Now more water vapour can condense around these larger snowflakes. Eventually, the snowflakes become too large and dense and begin to fall to the ground passing warmer air to melt and produce rain.



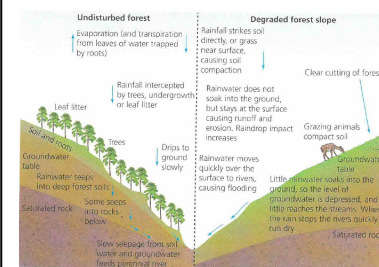
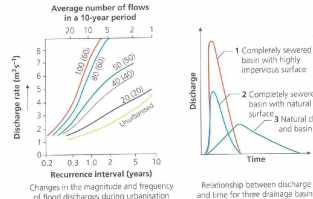
Collision process

Supersized condensation nuclei provide seeds around which water droplets form. Far larger and heavier than normal-sized droplets. The larger droplets fall and collide with smaller and absorb them.

Causes of excess run-off

Excess run-off can occur naturally through physical factors e.g. seasonal variations and storm activity.

Excess run-off can be generated through human causes e.g. changes in land use e.g. urbanisation, deforestation,



2.1.5 - Water cycle deficit

$$\text{Water Balance} = P - Q + ET + \Delta S$$

P= Precipitation Q=Discharge ET=Evapotranspiration
ΔS=Positive/negative changes in water storage

Water deficit exists when precipitation is lower than the combined loss of water due to evapotranspiration and run off.

Meteorological causes of drought

Drought conditions

Meteorological drought= an extended period of low or absent rainfall relative to the average for a region.

Agricultural drought= when there is insufficient moisture for average crop production.

Hydrological drought= when available water reserves fall below acceptable levels.

1976 UK Drought

1975-1976 where hot, dry years; SE England was about 50% rainfall average. 45 days with no rain.

Causes: Northwards shift of the jet stream (lasting 18 months). Weather systems that generate frontal rain flow the jet stream so much of the UK's expected rainfall was diverted northwards.

Human causes of drought

Human causes of deficit

Aquifer depletion=over extraction of surface water resources due to total population growth, agricultural demands and use of water in industry.

Shrinking of the Aral Sea

Once the fourth-largest inland sea covering an area of 68,000 square km. Now it only covers 10% of its original area. Steadily shrunk since the 1960's Causes-Soviet government schemes to divert the river water feeding into the Aral Sea. Irrigation for fruit and cotton farming.

Recharge of aquifers

Natural and artificial recharge of aquifers

Aquifers are permeable, porous water-bearing rocks such as chalk and New Red Sandstone.

They are naturally recharged over time by percolating rain water. However, if too much water is taken from them too quickly then they will dry out before they have a chance to recharge.

Artesian aquifers

Develop where sedimentary rocks have formed a syncline structure with the aquifer confined between impermeable rock layers.

London Basin:

Confined artesian aquifer consists of a saturated layer of chalk which is sandwiched between two layers of impermeable materials.

Rainwater enters the chalk aquifer, groundwater then flows by gravity through the chalk.

The level to which the water rises naturally is determined by the height of the water table in areas of recharge at the edges of the basin. If the groundwater is tapped by a well or a borehole, water will flow to the surface under its own pressure. By the 1990s, the water table began to recover after years of exploitation.

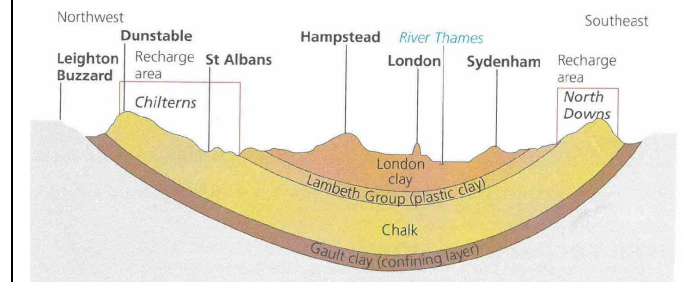
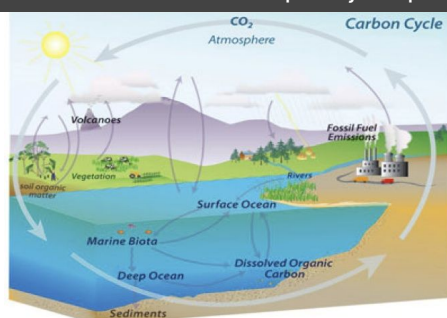


Figure 22 Geological section through the London Basin

2.1.6 - Global carbon cycle

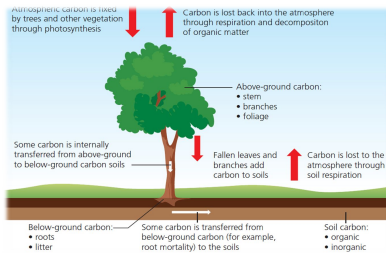
Carbon pathways and processes



Fast carbon cycle flows (short-term, local scale)

Land-atmosphere

Carbon sequestration- Natural capture and storage through photosynthesis, respiration, decomposition and fossil fuel combustion.



Stores-Amount of carbon held.
Flow-movement/transfer between stores.
Processes- physical mechanisms that drive the inputs, outputs and flows e.g. photosynthesis.
Mass balance- at a global scale, the total amount of carbon is conserved over time.

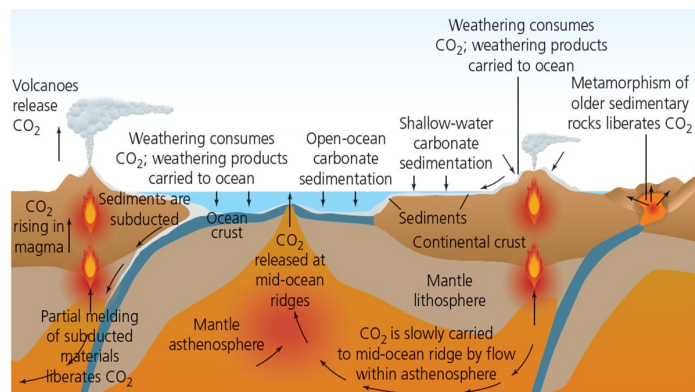
Fast carbon cycle flows

Atmosphere-ocean
 Oceans take up carbon by 'carbon cycle pump' mechanisms through the process of diffusion. CO₂ can be transferred to deep ocean areas where cold dense surface waters sink. Phytoplankton absorb carbon through photosynthesis and take the carbon through food chains.

Slow carbon cycle flows

Land-ocean

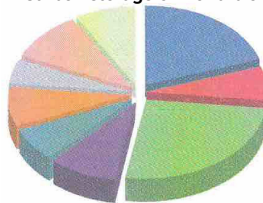
Cycling of carbon between bedrock stores on the land and the oceans occurs through processes of weathering, erosion and deposition over very long time-scales and at continental scale.



2.1.7 - Stores in biomes

Ecosystem carbon storage

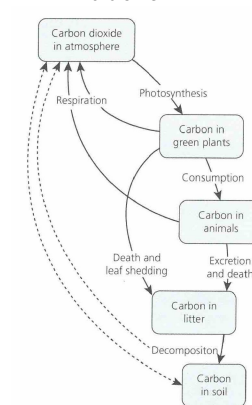
Carbon storage of world biomes



Key

- Tropical forest 20%
- Temperate forest 7%
- Boreal forest 26%
- Agriculture 9%
- Wetlands 7%
- Tundra 8%
- Desert 5%
- Temperate grassland 10%
- Tropical savanna 8%

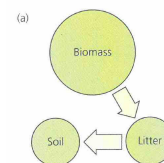
Carbon flows and stores in a biome



Tropical Rainforest carbon storage

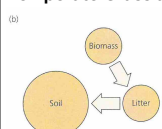
Plants are evergreen and the trees have large leaves that maximise their rate of transpiration and growth. Carbon storage in animals is relatively high because of the large number of habitats provided.

Rainforest carbon storage and flows
 550 GtC is stored in tropical rainforest biomass and soil. Exchanges of carbon between atmosphere, biosphere and soil are rapid. Warm, humid conditions cause rapid decomposition of dead organic matter and quick release of CO₂. Heavy rainfall means soils are leached and only retain limited amounts of organic carbon in the form of humus.



Temperate Grassland carbon storage

The lack of rainfall is a major limiting factor preventing the growth of thick forest cover. Instead short perennial (long-lived) grasses dominate. Physical factors affecting plant growth and carbon storage are, light causing seasonal variations in plant growth and biomass carbon storage. Temperature and precipitation.



Grassland carbon storage and flows

In total, 185 GtC is stored in temperate grasslands biomass and soil. Double the amount of carbon is stored below the ground. Warm, humid conditions in autumn ensure rapid decomposition and quick release of CO₂. As a result the litter store is small in this biome. Exchanges vary greatly according to season.

Changes in biome carbon stores due to human activity

Deforestation
 Afforestation & Carbon offsetting
 Agricultural activity

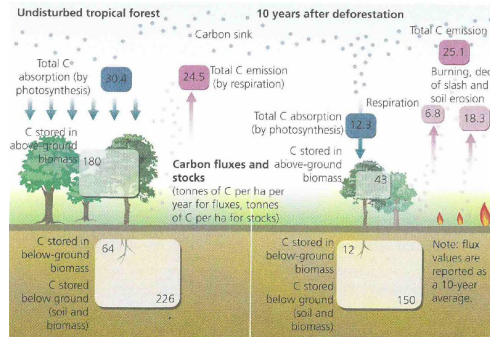


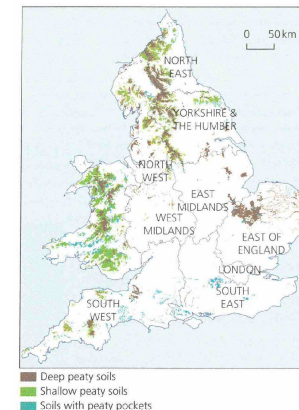
Figure 31 The impact of deforestation on the carbon cycle over a ten-year period

2.1.8 - Peatlands stores

Peat formation and carbon storage

Peat formation

Peat is a thick layer of black or dark brown thick and wet soil material. Partially decomposed vegetable matter and plant remains are slowly compressed as more material is added each year. Over time, layer upon layer of dead matter accumulates until depths of 2-4m in the UK decomposition is prevented by waterlogged environment which creates oxygen-deficient anaerobic conditions.



Anaerobic conditions are the product of specific hydro-topography. Fen peatlands, Blanket peatlands and Raised bogs.

Carbon storage in peat (A carbon sink)

Over half of all UK soil carbon is stored in peatlands due to its deep organic layer. With 90% of this in Scotland. Carbon stored in peatland is equivalent to 3 years of total UK carbon emissions. Only 5% of Wales has deep peatland soils however, it represents 30% of the country's total soil carbon storage. Globally, peatlands store double the amount of carbon that is stored in all of the world's forests, an estimated 550 billion tonnes.

Peat management and carbon store restoration

England's peatlands are currently sources of greenhouse gases. Some upland areas are still capturing carbon but must have become sources for carbon emissions. Due to land use changes and mismanagement.

Peat management rationale

Peatland restoration could help the UK reach their reduction targets for long-term greenhouse gas emissions. Local and national governments may be able to offset greenhouse gas emissions provided by economic activity.

Peatland management

Restoration in practice

Re-establishment of a plant cover dominated by peatland species including sphagnum mosses
 Re-wetting of drained peatland by raising and stabilising the local water table

Example: Southern Pennines in Yorkshire

Blocked erosional gullies with stone dams to help raise the water table and retain moisture in the peatlands, thereby restoring anaerobic conditions. Re-introduced wetland species e.g. cottongrass and sphagnum moss



2.1.9 - Water and carbon links

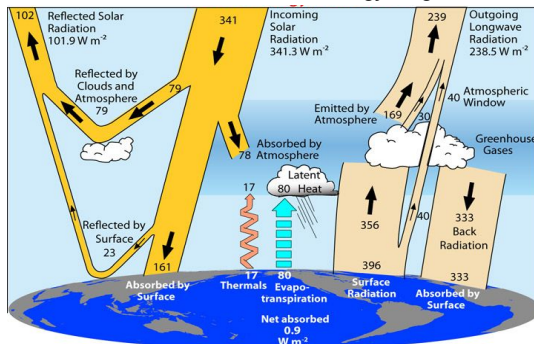
Increasing atmospheric carbon storage

In 2015, global mean surface temperature reached a new record of +0.87°C relative to 1951-1980 average. The ten warmest years since 1880 have all been since 1998.

Carbon dioxide rises-WHY?

Industrial revolution
Population growth
Economic development
Widespread deforestation
Ice melt-permanent ice in high mountains and polar ice caps causing 'trapped carbon' to be released.

Carbon emission and the energy budget



31% of incoming solar radiation is reflected by clouds, aerosols and gases in the atmosphere and by the land surface
69% is absorbed; almost 50% is absorbed at the Earth's surface, especially by oceans.
69% of this surface absorption is re-radiated as longwave radiation.

Increasing carbon emissions mean that more heat is being radiated back towards the ground surface. The energy budget is changing; more heat is being retained, resulting in warming, more energetic climate systems.

Impacts of rising greenhouse gas emissions on the water cycle

Impacts of rising greenhouse gas emissions on the water cycle

There are signs the world's water cycle and oceans have already been affected by recent increases in atmospheric carbon storage.

- Amount, type and patterns of precipitation (including extreme weather events)
- River discharge (flood-rich period or lower river discharge in others)
- Sea level rise
- Acidification of the oceans

Water and carbon cycle at a local scale

Daily interaction through carbon transported in solution by river water
Ecosystems function as stores of both water and carbon and influence the way a range of carbon transfers and water flows operate

Deforestation can lead to increased overland flow, which in turn causes soil erosion and the permanent loss of carbon storage capacity.
Increasing atmospheric carbon concentrations are changing global climate and water cycle stores and flows.

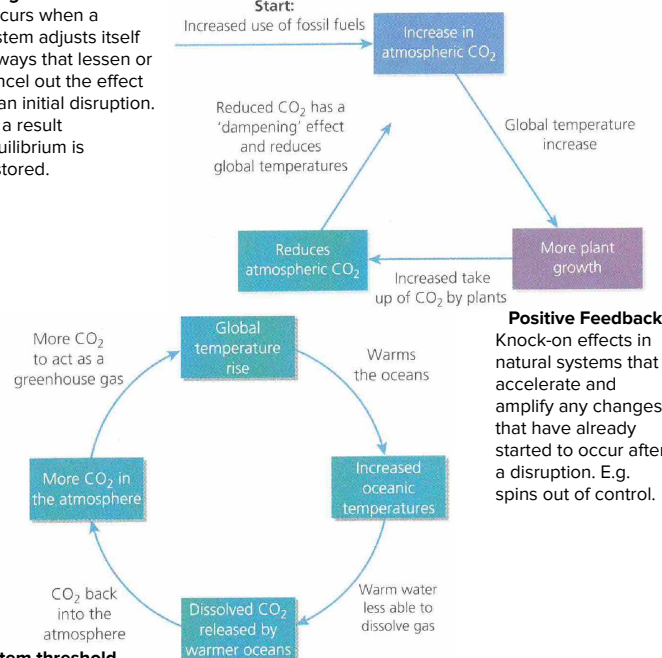
Desertification shows how reduced vegetation cover may lead to reduced carbon sequestration in biomes and also reduced soil carbon. Less vegetation cover may reduce the remain soil's infiltration capacity. This means infiltration-excess runoff will take place when rain does occur resulting in soil erosion and gullyng. Accelerated soil erosion will reduce carbon storage even more.

2.1.10 - Feedback cycles

Equilibrium, feedback and thresholds

Negative Feedback

Occurs when a system adjusts itself in ways that lessen or cancel out the effect of an initial disruption. As a result equilibrium is restored.



Positive Feedback

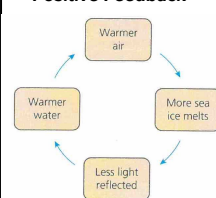
Knock-on effects in natural systems that accelerate and amplify any changes that have already started to occur after a disruption. E.g. spins out of control.

System threshold

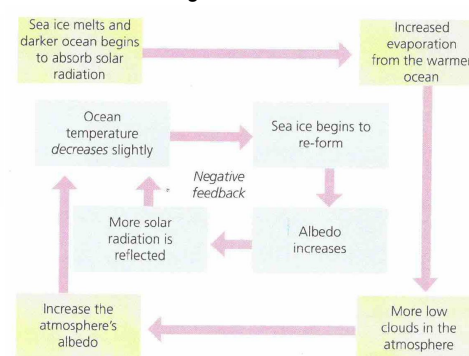
This is a crucial limit that must not be crossed if accelerated and potentially irreversible changes are to be avoided

Cryosphere feedback

Positive Feedback



Negative Feedback



Methane feedback

Atmosphere warms-permafrost melts-large volumes of methane released-atmosphere warm up quicker-even more methane released by more melting permafrost.

Terrestrial and marine carbon feedback

Increasing water vapour in the atmosphere-further temperature rises-more condensation-more reflection of solar radiation
A reduction in seawater's ability to absorb surplus CO₂ from atmosphere as warmer waters-waters begin to release rather than absorb.

Home study questions



DEVELOPING

Suggest how human activities may result in falls in water levels in aquifers. [4 Marks]

Using examples, **explain** the difference between positive and negative feedback in systems. [5 marks]

SECURING

Explain how natural processes give rise to short-term fluctuations in the size of atmospheric CO₂ store. [5 marks]

Explain how carbon is transferred from the land to the oceans b weathering and river transport. [5 marks]

MASTERING

To what extent do geological factors influence water and carbon cycle flows in different contexts. [20 marks]

Analyse the effects of forest removal on operation of physical systems. *Refer to both water and carbon cycle in your answer.* [20 marks]

CHALLENGE

Create a flow diagram to show how water and carbon cycles are related.

Summarise the human mitigation strategies and the effectiveness of each one at trying to minimise the impact of climate change.