Topic: Water, carbon, climate & life on earth
3.1.1.4 Water and carbon cycles

What you need to know
How carbon stores and cycles support life on earth.
How water stores and cycles support life on earth.
How feedbacks within and between the cycles has links to climate change.
How changes in the cycles can have implications for life on earth.
How human intervention in the carbon cycle can mitigate the impacts of climate change.

Introduction:

The cycling of water and carbon are integral to current and future life on earth. The consequences of alterations between the cycles can result in significant climate change.

Both cycles are understood through a systems approach. Both cycles have a series of inputs, processes, stores and outputs.

Carbon stores and cycles

Carbon is integral to life on earth. It is found as carbon based molecules in various forms – as carbon dioxide and methane in the atmosphere, as organic matter in soils formed by the decomposition of organic material, sedimentary ocean bed layers, in carbon-rich rocks and in vegetation. The key carbon cycles operate at the terrestrial, atmospheric and oceanic level.

- The cycling of carbon between the land and atmosphere is known as the fast carbon cycle. This is the movement of carbon from living things up into the atmosphere. With carbon dioxide, this takes place through the process of respiration from plants and animals and both CO2 and methane (CH4) are released through the decomposition of plants and animals. Ultimately this transfer of carbon into the atmosphere is directly affected by humans by land use change and industrial processes (see below).

- As well as terrestrial processes, the ocean carbon cycle is important to consider. Carbon is stored here as dissolved CO2 in the water and also in carbon compounds in marine organisms. The input to the ocean store is through absorption via a gas exchange with the atmosphere. Carbon is also transferred into the oceans through precipitation of naturally (and anthropogenic) acid rain. Much carbon is stored in a carbon sink on the floor of shallow oceans as accumulating sediments from a persistent ‘rain’ of dead and decaying marine organism remains and the excrement of plankton and other creatures in the upper sea layers.

- The cycling of carbon between surface bedrock and atmospheric or ocean stores is known as the slow carbon cycle. The weathering of surface carbon-bearing rocks by acid rain (carbonic acid formed as a result of atmospheric moisture reacting with carbon dioxide) over millions of years leads to a terrestrial-ocean carbon transfer as rivers transport weathered rock into the oceans. Vast quantities of carbon are stored in sedimentary deposits on the ocean floor. Over millions of year, with tectonic plate movement, they are eventually subducted into the mantle at a destructive plate margin. The carbon content is then returned to the atmosphere through volcanic activity (usually as CO2), where it contributes to the formation of acid rain to start the cycle again.

Water stores and cycles:

Water is stored in three states: as liquid water in the oceans, river and lakes; as ice; and as atmospheric moisture in the form of gaseous water vapour. Water is cycled between key stores by a variety of processes at different rates of flux.

- Liquid water storage (**Hydrosphere**): This storage accounts for 96.5% of all water on earth. Processes impacting upon this important store include runoff and precipitation inputting water to the store and evaporation moving water from the ocean into the atmospheric store. These changes have minimal impact upon the storage capacity, however long tem climatic change events such as ice ages do have the potential to lower the storage capacity significantly.

- Ice storage (**Cryosphere**): This storage accounts for 1.7% of all water on earth. Processes impacting upon the store include precipitation (as snow) and outputs include ice melt. Major stores include the Antarctic and Greenland ice sheets, polar sea ice and mountain glaciers. Annual changes to ice coverage have minimal impact upon storage capacity. However, as with the hydrospheric storage, during ice ages cryospheric storage increases and during warmer inter-glacials it reduces.

- Bedrock storage (**Lithosphere**): This storage also accounts for 1.7% of all water on earth. Whilst the level of storage capacity is low, this store captures water for the longest periods of time. Water can flow through the lithosphere into underground aquifers but this transfer may be relatively slow, often taking many years. Some water is stored within bedding planes, joints and pores in rocks and can remain there for hundreds of years.

- Atmospheric moisture storage (**Atmosphere**): This storage accounts for 0.001% of water on earth. Water is removed from water surfaces through evaporation and is then stored temporarily as water vapour and condensation before being released back to earth as precipitation. Additionally, transpiration from plants releases water vapour into the atmosphere.

These four dominant 'spheres' are supplemented by two others that have a role: the **Biosphere** (all living things, including plants and animals) and the **Pedosphere** (the soil layer that contains both organic carbon as soil bacteria and remains of plants, and non-organic carbon from infiltration by acidic rain).

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How feedbacks within and between the cycles has links to climate change:

Where the fluxes (transfers) within the stores and processes of both cycles change this can increase the likelihood of global climate change. Distinct changes occur mainly as a result of human processes. Anthropogenic release of carbon dioxide and methane can result in a rapid warming effect on the earth as solar radiation is trapped in the lower atmosphere and can't escape to space so easily. This increase of atmospheric carbon gas occurs due to the activities of an ever increasing human population. Rising demand for food has led to a greater methane output as a result of cattle (digestion) and rice farming (marsh gas). The burning of hydrocarbons for heating, electricity generation and transport has been a major factor releasing carbon from long-term fossil-fuel stores. Human destruction of natural vegetation has reduced a natural climate sink that would otherwise absorb atmospheric carbon. Changes to climate can then affect the processes and stores of both the carbon and water cycles.

Water cycle:

- A warming world is leading to a change in water cycle processes. Cryosphere stores are shrinking leading to an increase in hydrosphere stores.

- Regionally, rainfall patterns will alter, with some regions receiving more rain and others receiving much less than has been normal.

- A colder world increases cryosphere and reduces hydrosphere stores. Lithosphere and atmosphere storage decline but to a much lesser degree.

Carbon cycle:

- Climate change also impacts upon carbon cycle processes. The natural storage of carbon, in particular in the oceans, the soil and vegetation can be affected by climate change. Warmer oceans are less able to absorb atmospheric carbon dioxide and melting cryosphere soils are beginning to release significant quantities of stored methane from accumulated tundra peats. Both can amplify global warming through a positive feedback cycle. Equally, changes in global temperature will result in widespread extinction of many vegetation species through the inability to survive in a warmer or drier world. Also, in a warmer climate where rainfall is less, many species can't adapt - so ultimately die or will be affected by large scale forest fires, which are becoming more frequent in certain areas of the world. The release of extra CO2 from forest fires will only exacerbate the climatic change occurring.

How changes in the cycles can have implications for life on earth:

Increases in atmospheric carbon dioxide are resulting in many issues around the world. Increased global temperatures can lead to the following events:

- Sea level rise through thermal expansion of existing ocean volumes plus cryospheric water storage melts are forecast to lead to low lying coastal land being flooded, human crises, mass migration and environmental damage in the coming decades.

- Changing rainfall patterns as climate bands move away from tropical zones. Many areas will experience longer periods of drought, leading to environmental issues such as soil erosion, fires, tropical disease extension and issues for food production. Social and economic deterioration and mass migration will also occur as a result. Other areas will experience increased rainfall, causing flash floods.

- Increasing evaporation from oceans in tropical areas is likely to result in an increase in the intensity, extent and frequency of tropical storms causing severe damage to the natural and built environment where they are experienced.

Human intervention in the carbon cycle and mitigating the impacts of climate change:

Increasing anthropogenic emissions of carbon dioxide from the burning of fossil fuels, alongside the increase in agricultural processes and transport have increased the warming effect of the atmosphere. Levels of carbon dioxide are increased further by deforestation to provide land for agriculture and for housing. This reduces the carbon store potential and releases stored biosphere carbon to the atmosphere.

There are three main mitigation strategies in response to the impacts of climate change:

1. Reducing carbon emissions through low carbon technology – prioritising renewable energy resources, recycling, minimising energy use and implementing energy conservation measures. Agreed international caps, protocols and laws to stabilise, then reduce atmospheric carbon emissions. Carbon trading schemes reward emitters that reduce carbon emissions and penalise those that continue to release $CO2$. These can include both enforced and voluntary measures.

2. Carbon capture through reforestation (planting on cleared forest land) and afforestation (planting on land that hasn't previously had forest) schemes. Some carbon trading schemes pay land-owners to plant forests to absorb the equivalent of $CO2$ that is released by emitters elsewhere on the planet.

3. Carbon capture when fossil fuels are burnt and the emission gas is artificially sequestered (buried) in underground rocks, such as depleted oil and gas fields.

