A LEVEL GEOGRAPHY REVISION GUIDE

Paper 1: Physical Geography

2020

THE WATER AND CARBON CYCLES
Water cycles

1.1 The global hydrological cycle is of enormous importance to life on earth.

- The global hydrological cycle's operation as a closed system (inputs, outputs, stores and flows) driven by solar energy and gravitational potential energy.
- The relative importance and size (percentage contribution) of the water stores (oceans, atmosphere, biosphere, cryosphere, groundwater and surface water) and annual fluxes between atmosphere, ocean and land.
- The global water budget limits water available for human use and water stores have different residence times; some stores are non-renewable (fossil water or cryosphere losses).

1.2 The drainage basin is an open system within the global hydrological cycle.

- The hydrological cycle is a system of linked processes: inputs (precipitation patterns and types: orographic, frontal, convectional) flows (interception, infiltration, direct runoff, saturated overland flow, throughflow, percolation, groundwater flow) and outputs (evaporation, transpiration and channel flow).
- Physical factors within drainage basins determine the relative importance of inputs, flows and outputs (climate, soils, vegetation, geology, relief).
- Humans disrupt the drainage basin cycle by accelerating processes (deforestation; changing land use) and creating new water storage reservoirs or by abstracting water. (Amazonia)

1.3 The hydrological cycle influences water budgets and river systems at a local scale.

- Water budgets show the annual balance between inputs (precipitation) and outputs (evapotranspiration) and their impact on soil water availability and are influenced by climate type (tropical, temperate, polar examples).
- River regimes indicate the annual variation of discharge of a river and result from the impact of climate, geology and soils as shown in regimes from contrasting river basins. (Yukon, Amazon, Indus).
- Storm hydrographs shape depends on physical features of drainage basins (size, shape, drainage density, rock type, soil, relief and vegetation) as well as human factors (land use and urbanisation). (P: the role of planners in managing land use).

2.1 Deficits within the hydrological cycle result from physical processes but can have significant impacts.

- The causes of drought, both meteorological (short-term precipitation deficit, longer trends, ENSO cycles and hydrological.
- The contribution human activity makes to the risk of drought: over-abstraction of surface water resources and ground water aquifers. (Sahelian drought; Australia).
- The impacts of drought on ecosystem functioning (wetlands, forest stress) and the resilience of these ecosystems.

2.2 Surpluses within the hydrological cycle can lead to flooding, with significant impacts for people.

- Meteorological causes of flooding, including intense storms leading to flash flooding, unusually heavy or prolonged rainfall, extreme monsoonal rainfall and snowmelt.
- Human actions that can exacerbate flood risk (changing land use within the river catchment, mismanagement of rivers using hard engineering systems.)
- Damage from flooding has both environmental impacts (soils and ecosystems) and socio-economic impacts (economic activity, infrastructure and settlement). (UK flood events 2007 or 2012).

2.3 Climate change may have significant impacts on the hydrological cycle globally and locally.

- Climate change affects inputs and outputs within the hydrological cycle: trends in precipitation and evaporation.
- Climate change affects stores and flows, size of snow and glacier mass, reservoirs, lakes, amount of permafrost, soil moisture levels as well as rates of runoff and stream flow.

- Climate change resulting from short-term oscillations (ENSO cycles) and global warming increase the uncertainty in the system; this causes concerns over the security of water supplies. (F: projections of future drought and flood risk)

3.1 There are physical causes and human causes of water insecurity.

- The growing mismatch between water supply and demand has led to a global pattern of water stress (below 1,700 m^3 per person) and water scarcity (below 1000 m^3 per person).
- The causes of water insecurity are physical (climate variability, salt water encroachment at coast) as well as human (over abstraction from rivers, lakes and groundwater aquifers, water contamination from agriculture, industrial water pollution).
- The finite water resource faces pressure from rising demand (increasing population, improving living standards, industrialisation and agriculture), which is increasingly serious in some locations and is leading to increasing risk of water insecurity. (F: projections of future water scarcity).

3.2 There are consequences and risks associated with water insecurity.

- The causes of and global pattern of physical water scarcity and economic scarcity and why the price of water varies globally.
- The importance of water supply for economic development (industry, energy supply, agriculture) and human wellbeing (sanitation, health and food preparation); the environmental and economic problems resulting from inadequate water.
- The potential for conflicts to occur between users within a country, and internationally over local and trans-boundary water sources (Nile, Mekong). (P: role of different players).

3.3 There are different approaches to managing water supply, some more sustainable than others.

- The pros and cons of the techno-fix of hard engineering schemes to include water transfers, mega dams and desalination plants (Water transfers in China).
- The value of more sustainable schemes of restoration of water supplies and water conservation (smart irrigation, recycling of water) (Singapore). (A: contrasting attitudes to water supply).
- Integrated drainage basin management for large rivers (Nile, Colorado) and water sharing treaties and frameworks (United Nations Economic Commission for Europe (UNECE) Water Convention, Helsinki and the Water Framework Directive and Hydropower, Berlin). (P: role of players in reducing water conflict risk).

Carbon Cycles

1.1 Most global carbon is locked in terrestrial stores as part of the long-term geological cycle.

- The biogeochemical carbon cycle consists of carbon stores of different sizes (terrestrial, oceans and atmosphere), with annual fluxes between stores of varying size (measured in Pg/Gt), rates and on different timescales.
- Most of the earth's carbon is geological, resulting from the formation of sedimentary carbonate rocks (limestone) in the oceans and biologically derived carbon in shale, coal and other rocks.
- Geological processes release carbon into the atmosphere through volcanic out-gassing at ocean ridges/subduction zones and chemical weathering of rocks.

1.2 Biological processes sequester carbon on land and in the oceans on shorter timescales.

- Phytoplankton sequester atmospheric carbon during photosynthesis in surface ocean waters; carbonate shells/tests move into the deep ocean water through the carbonate pump and action of the thermohaline circulation.
- Terrestrial primary producers sequester carbon during photosynthesis; some of this carbon is returned to the atmosphere during respiration by consumer organisms.
- Biological carbon can be stored as dead organic matter in soils, or returned to the atmosphere via biological decomposition over several years.

1.3 A balanced carbon cycle is important in sustaining other earth systems but is increasingly altered by human activities.

- The concentration of atmospheric carbon (carbon dioxide and methane) strongly influences the natural greenhouse effect, which in turn determines the distribution of temperature and precipitation.
- Ocean and terrestrial photosynthesis play an important role in regulating the composition of the atmosphere. Soil health is influenced by stored carbon, which is important for ecosystem productivity.
- The process of fossil fuel combustion has altered the balance of carbon pathways and stores with implications for climate, ecosystems and the hydrological cycle.

2.1 Energy security is a key goal for countries, with most relying on fossil fuels.

- Consumption (per capita and in terms of units of GDP) and energy mix (domestic and foreign, primary and secondary energy, renewable versus non-renewable).
- Access to and consumption of energy resources depends on physical availability, cost, technology, public perception, level of economic development and environmental priorities (national comparisons USA versus France).
- Energy players (P: role of TNCs, The Organisation of the Petroleum Exporting Countries (OPEC), consumers, governments) have different roles in securing pathways and energy supplies.

2.2 Reliance on fossil fuels to drive economic development is still the global norm.

- There is a mismatch between locations of conventional fossil fuel supply (oil, gas, coal) and regions where demand is highest, resulting from physical geography.
- Energy pathways (pipelines, transmission lines, shipping routes, road and rail) are a key aspect of security but can be prone to disruption especially as conventional fossil fuel sources deplete (⌉ Russian gas to Europe).
- The development of unconventional fossil fuel energy resources (tar sands, oil shale, shale gas, deep water oil) has social costs and benefits, implications for the carbon cycle, and consequences for the resilience of fragile environments. (Canadian tar sands, USA fracking, Brazilian deep water oil) (P: role of business in developing reserves, versus environmental groups and affected communities)

2.3 There are alternatives to fossil fuels but each has costs and benefits.

- Renewable and recyclable energy (nuclear power, wind power and solar power) could help decouple fossil fuel from economic growth; these energy sources have costs and benefits economically, socially, and environmentally and in terms of their contribution they can make to energy security. (changing UK energy mix).
- Biofuels are an alternative energy source that are increasing globally; growth in biofuels however has implications for food supply as well as uncertainty over how 'carbon neutral' they are. (Biofuels in Brazil)
- Radical technologies, including carbon capture and storage and alternative energy sources (hydrogen fuel cells, electric vehicles) could reduce carbon emissions but uncertainty exists as to how far this is possible.

3.1 Biological carbon cycles and the water cycle are threatened by human activity.

- Growing demand for food, fuel and other resources globally has led to contrasting regional trends in land-use cover (deforestation, afforestation, conversion of grasslands to farming) affecting terrestrial carbon stores with wider implications for the water cycle and soil health.
- Ocean acidification, as a result of its role as a carbon sink, is increasing due to fossil fuel combustion and risks crossing the critical threshold for the health of coral reefs and other marine ecosystems that provide vital ecosystem services.
- Climate change, resulting from the enhanced greenhouse effect, may increase the frequency of drought due to shifting climate belts, which may impact on the health of forests as carbon stores. (Amazonian drought events)

3.2 There are implications for human wellbeing from the degradation of the water and carbon cycles.

- Forest loss has implications for human wellbeing but there is evidence that forest stores are being protected and even expanded, especially in countries at higher levels of development (environmental Kuznets' curve model). (A: attitudes of global consumers to environmental issues)
- Increased temperatures affect evaporation rates and the quantity of water vapour in the atmosphere with implications for precipitation patterns, river regimes and water stores (cryosphere and drainage basin stores) (Arctic) (F: uncertainty of global projections).
- Threats to ocean health pose threats to human wellbeing, especially in developing regions that depend on marine resources as a food source and for tourism and coastal protection.

3.3 Further planetary warming risks large-scale release of stored carbon, requiring responses from different players at different scales.

- Future emissions, atmospheric concentration levels and climate warming are uncertain owing to natural factors (the role of carbon sinks), human factors (economic growth, population, energy sources) and feedback mechanisms (carbon release from peatlands and permafrost, and tipping points, including forest die back and alterations to the thermohaline circulation). (F: uncertainty of global projections)
- Adaptation strategies for a changed climate (water conservation and management, resilient agricultural systems, land-use planning, flood-risk management, solar radiation management) have different costs and risks.
- Re-balancing the carbon cycle could be achieved through mitigation (carbon taxation, renewable switching, energy efficiency, afforestation, carbon capture and storage) but this requires global scale agreement and national actions both of which have proved to be problematic. (A: attitudes of different countries, TNCs and people)

Glossary of Definitions

Acidification - The gradual reduction of pH of the oceans, due to dissolving carbon dioxide from the atmosphere.
Afforestation - Planting trees and vegetation in the aim of increasing forest cover.
Anticyclone- A system of high pressure, causing high temperatures and unseasonably high evaporation rates.
Aquifer- A permeable or porous rock which stores water.
Biofuel - Burning crops and vegetation for electricity and heat.
Carbon Capture & Storage (CCS) - The capture of carbon dioxide emissions directly from the factory, pumped into disused mines rather than being released into the atmosphere.
Carbon Fluxes- The movement of carbon between stores.
Carbon Neutral- A process that has no net addition of carbon dioxide to the environment.
Carbon Stores- Places where carbon accumulates for a period of time such as rocks and plant matter.
Channel Flow- Water flowing in a rivulet, stream or river.
Choke Points- Points in the logistics of energy and fuel that are prone to restriction.
Combustion- The process of burning a substance, in the presence of oxygen, to release energy.
Convectional Precipitation- Solar radiation heats the air above the ground, causing it to rise, cool & condense forming precipitation (often as thunderstorms).
Cryosphere- The global water volume locked up within a frozen state (i.e. snow and ice).
Decomposition- The break down of matter, often by a decomposer which releases carbon dioxide through their own respiration.
Depression- A system of low pressure, with fronts of precipitation where low and high pressure air masses meet.

Desalination Plant- The conversion of seawater to freshwater, suitable for human consumption.
Desublimation- The change of state of water from gas to solid, without being a liquid (the opposite process to sublimation).
Drainage Basin- The area of land drained by a river and its tributaries.
Drainage Density- The total length of all rivers & streams divided by the area of the drainage basin.
Drought- An extended period of deficient rainfall relative to the statistical average for the region (UN).
Economic Water Scarcity- When water resources are available but insufficient economic wealth limits access to it.
Energy Mix- The composition of a country's energy sources.
Energy Security- The ownership and full control of a country's energy source, production and transportation.
Energy Pathway- The movement of energy from its extraction or source, through pipes, freight logistics or cabling.
Energy Players- Key companies and individuals who own, distribute and sell energy and energy sources.
Enhanced Greenhouse Effect- The build-up of greenhouse gases in the atmosphere, reducing the amount of solar radiation reflected into space.
ENSO Cycles- El Niño Southern Oscillations - naturally occurring phenomena that involves the movement of warm water in the Equatorial Pacific.
Evapotranspiration- The combined total moisture transferred from the Earth to the atmosphere, through evaporation and transpiration.
Frontal Precipitation- Where air masses of different temperatures meet at a front, one mass will be forced over another, causing precipitation beneath the front.
Global Hydrological Cycle- The continuous transfer of water between land, atmosphere and oceans. The Earth is a closed system.
Groundwater Flow- Water moving horizontally through permeable or porous rock due to gravity.
Hydrological Drought- Insufficient soil moisture to meet the needs of vegetation (crops, trees, plants) at a particular time
Infiltration- The movement of water vertically through the pores in soil.
Integrated Drainage Basin Management- Establishing a frame of coordinated efforts between administrations (e.g. local government) and stakeholders (e.g businesses) to achieve balanced management of a basin (World Bank).
Inorganic Carbon- Carbon stored in carbonated rocks.
Interception- Raindrops are prevented from falling directly onto the ground, instead hitting the leaves of a tree.
Meteorological Drought- When long-term precipitation trends are below average.
Monsoon- The drastic variation between wet and dry seasons for sub-tropical areas, caused by a changed prevailing wind. Can lead to annual flooding.
Non-Renewable- A source of energy that can only be used once to generate electricity or takes thousands of years to replace e.g. Fossil Fuels.
Nuclear Fusion- The process of joining atomic nuclei together, to produce energy.
PEC- Oil and Petroleum exporting countries. An organisation that supports and coordinates fossil fuel exporting countries.
Open System- A system affected by external flows and inputs (such as a drainage basin, or a sediment cell).
Organic Carbon- Carbon stored in plant material and living organisms.

Outgassing- The release of dissolved carbon dioxide (e.g. at plate boundaries, warming the oceans).
Percolation- Water moving vertically from soil into permeable rock.
Photosynthesis- The process of converting carbon dioxide and water into glucose and oxygen. All plants and some organisms rely on this process to survive.
Physical Water Scarcity- A physical lack of available freshwater which cannot meet demand.
Phytoplankton- Small organisms that rely on photosynthesis to survive, so intake carbon dioxide from the atmosphere.
Primary Energy- The initial source of energy, as it is naturally found. This could be natural ores, water, crops or radioactive material.
Relief Precipitation- Precipitation caused when air masses are forced to rise over high land, determined by the relief/ morphology of the land.
Renewable- Primary energy that can be re-used to produce electricity or has a short lifetime, therefore any used can be replaced quickly e.g. Hydroelectric, biomass, solar.
Respiration- The process of converting glucose and oxygen into carbon dioxide and energy. Some organisms rely on respiration to survive.
River Regime- The pattern of river discharge over a year.
Runoff- Water flowing over the surface of the ground eg. after precipitation or snowmelt.
Salinisation- Where salt water contaminates freshwater stores or soils, creating saline conditions and reducing human use/ consumption.
Saltwater Encroachment- The movement of saltwater into freshwater aquifers or soils. This may be caused by sea level rise, storm surges or over-extraction.
Secondary Energy- The product of primary energy, mostly electricity.
Sequestration- The transfer of carbon from the atmosphere to stores elsewhere - living biosphere, inorganic rocks, etc.
Smart Irrigation- Providing crops with a water supply less than optimal, to make crops resistant to water shortages.
Storm Hydrograph- Variation of river discharge over a short period of time (days).
Sublimation -The change of state of water from solid to a gas, without being a liquid.
Thermohaline Circulation- The movement of volumes of seawater from cold deep water to warm water surface water.
Throughflow-Water moving horizontally through the soil, due to gravity.
Tipping Point- A critical threshold where any changes to a system after the tipping point are irreversible.
Transpiration- The process through which water evaporates through the stomata in plants' leaves.
Urbanisation- The growth of populations in towns and cities.
Water Budget- The annual balance between inputs and outputs within a system.
Water Conservation- Strategies to reduce water usage and demand.
Water Recycling- The treatment and purification of waste water, to increase supply.
Water Scarcity- There are limited renewable water sources (between 500 and 1000 cubic metres per capita per year).
Water Security- The ability to protect and access a sustainable source to adequately meet demand.
Water Sharing Treaty- International agreements for transboundary sources.
Water Transfer- Hard engineering projects, such as pipelines or aqueducts, that divert water between basins to meet demand.
Watershed- The boundary between neighbouring drainage basins.

Water and Carbon Cycles: Systems

Systems are composed of:

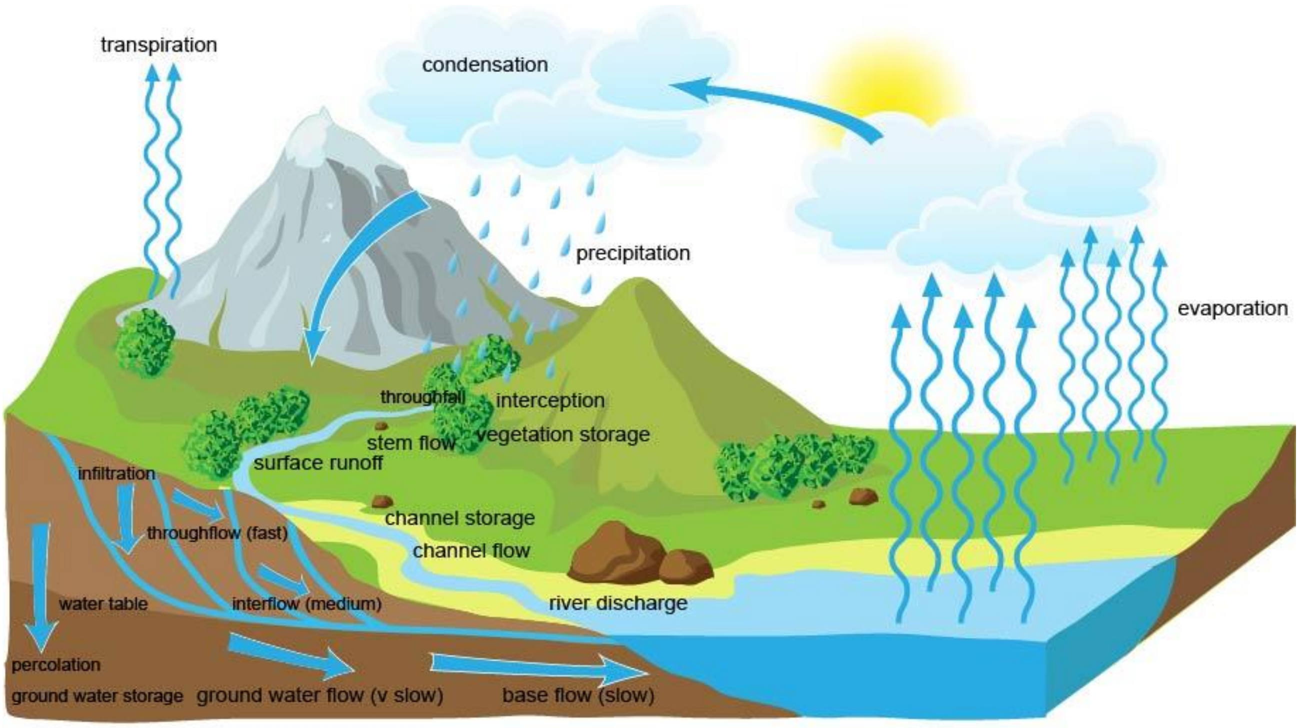
- **Inputs** - Where matter or energy is added to the system
- **Outputs** - Where matter or energy leaves the system
- **Stores** - Where matter or energy builds up in the system
- **Flows** - Where matter or energy moves in the system
- **Boundaries** - Limits to the system (e.g. watershed)

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.



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 **infiltration 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 soilsdrain 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 **sheet flow**(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.

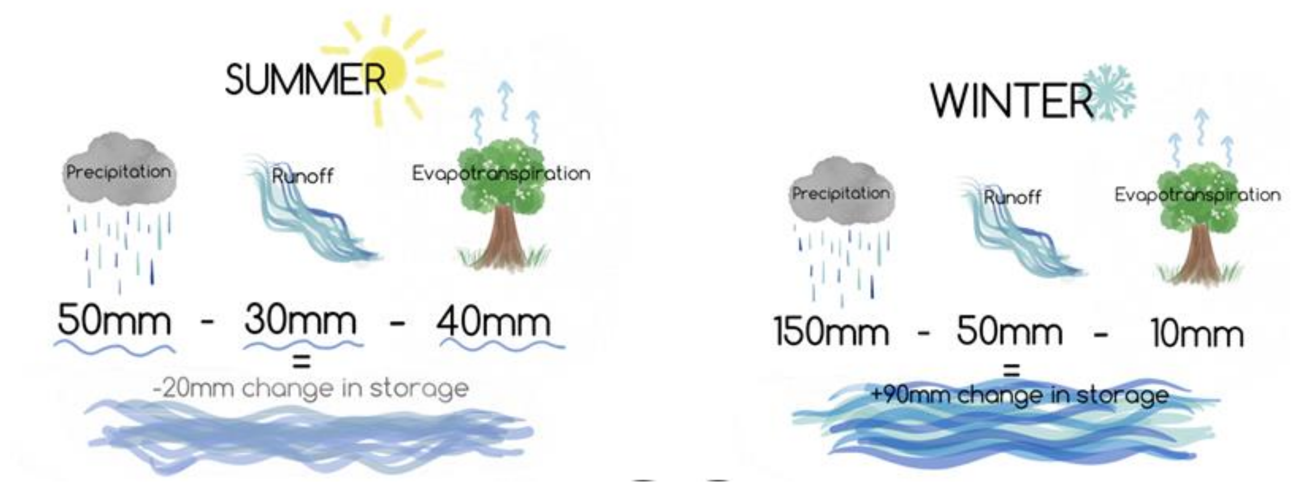
The Water Balance

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.**

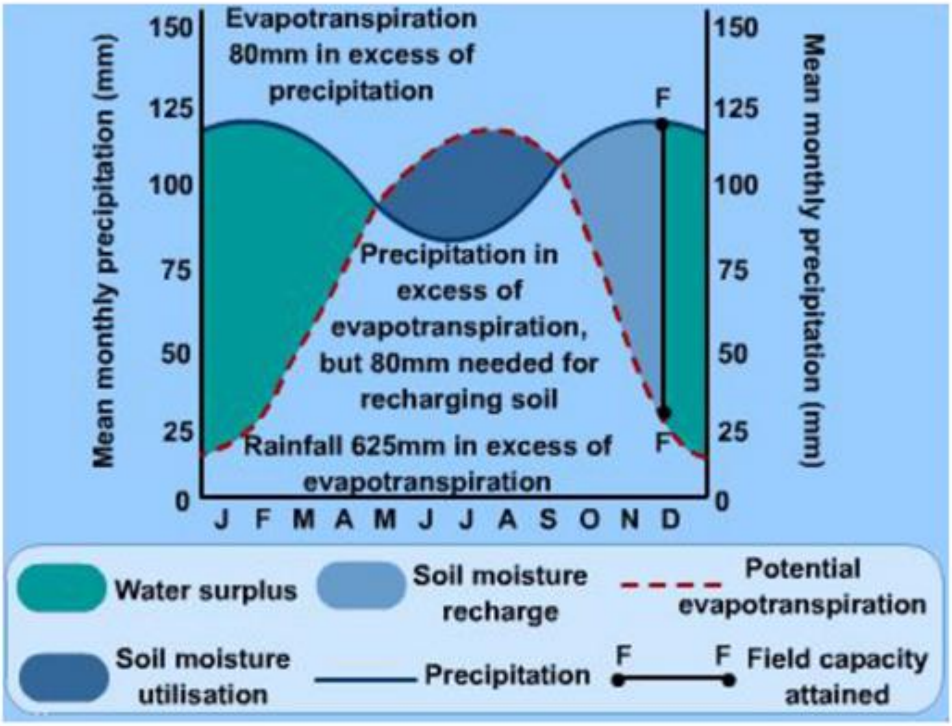
    - **Hillside terracing** (for rice padi fields) increases surface water storage and therefore **decreases runoff.**

    - **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 **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.

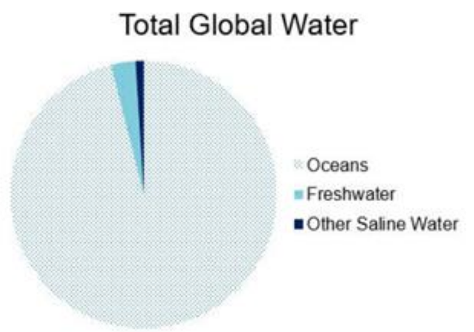
Spring: Around February and March, plants start to grow again and **potential evapotranspiration increases as temperatures get higher and plants start photosynthesising** more. There is still a **water surplus** in this time.

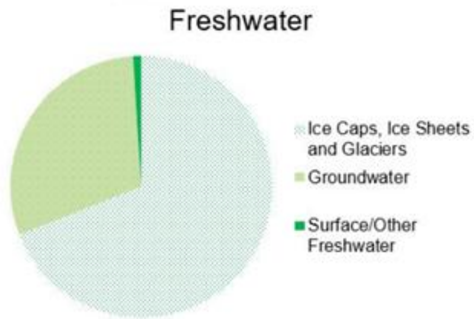
Summer: The hotter weather leads to **utlisation of soil water as evapotranspiration peaks and rainfall is at a minimum**. The **output from evapotranspiration is greater than the input from precipitation** so the **soil water stores are depleting**. A **water deficit may occur**if there is a long hot 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**.



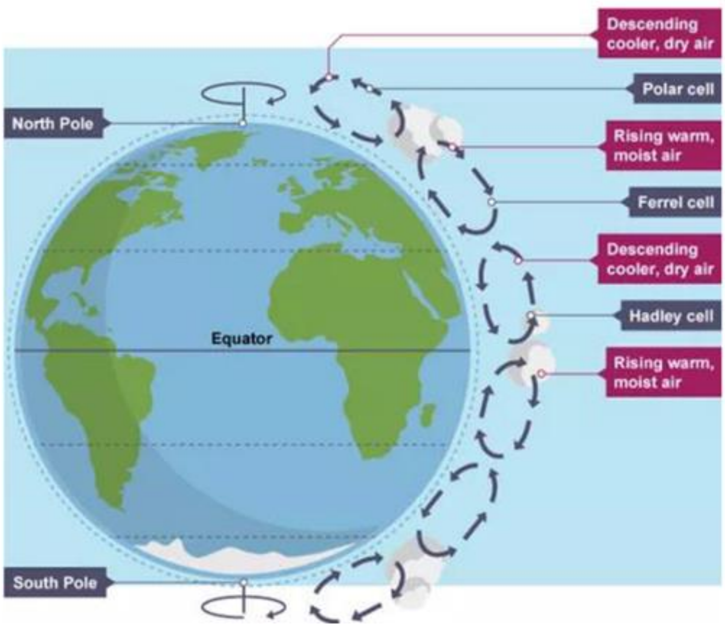


Water can be stored in four areas:

- **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 **deeperfossil 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.**

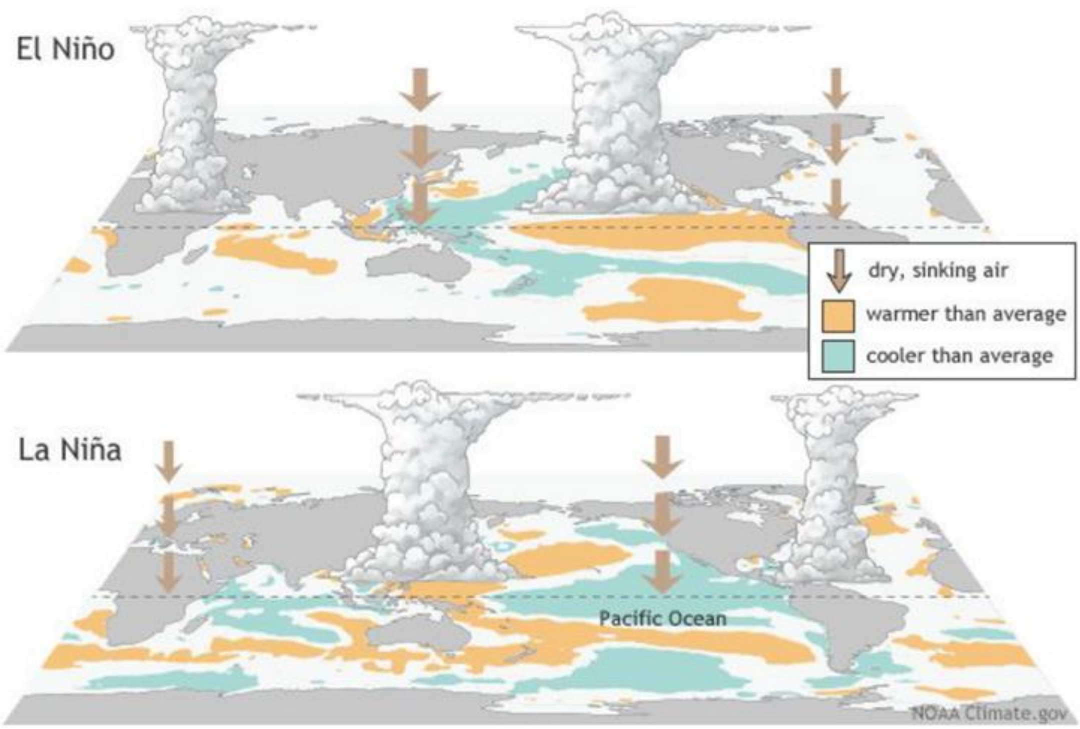
Droughts:

- 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

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.

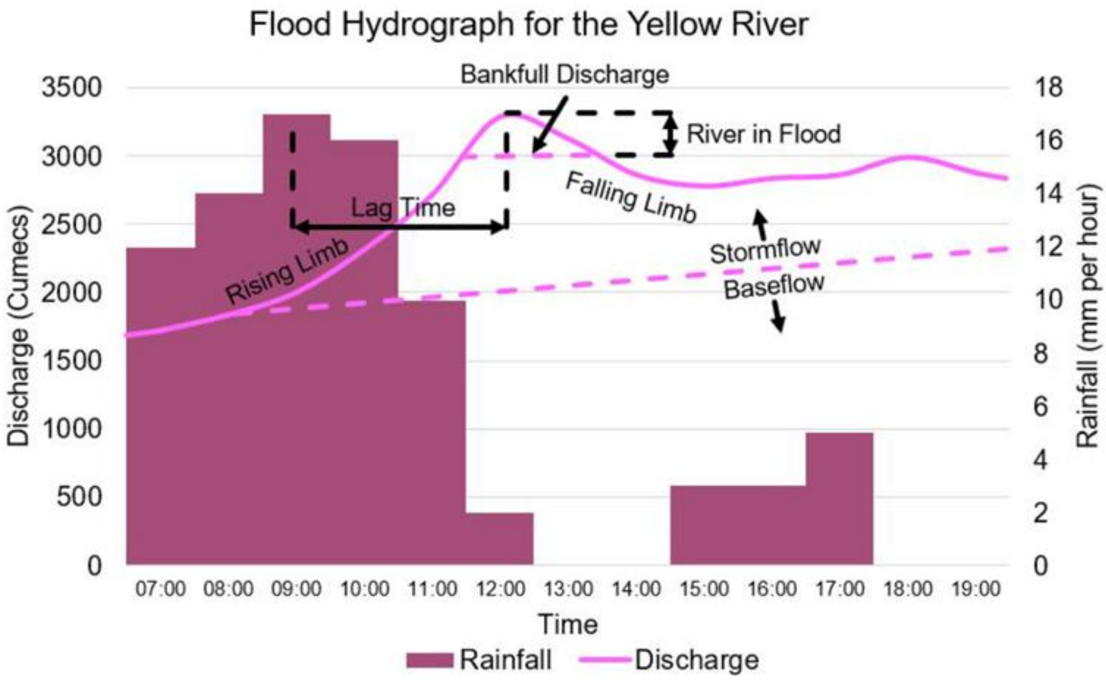
Water Abstraction (water removed from stores for human use):
- This reduces the volume of water in **surface stores** (e.g. lakes).

- **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

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 **base flow 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

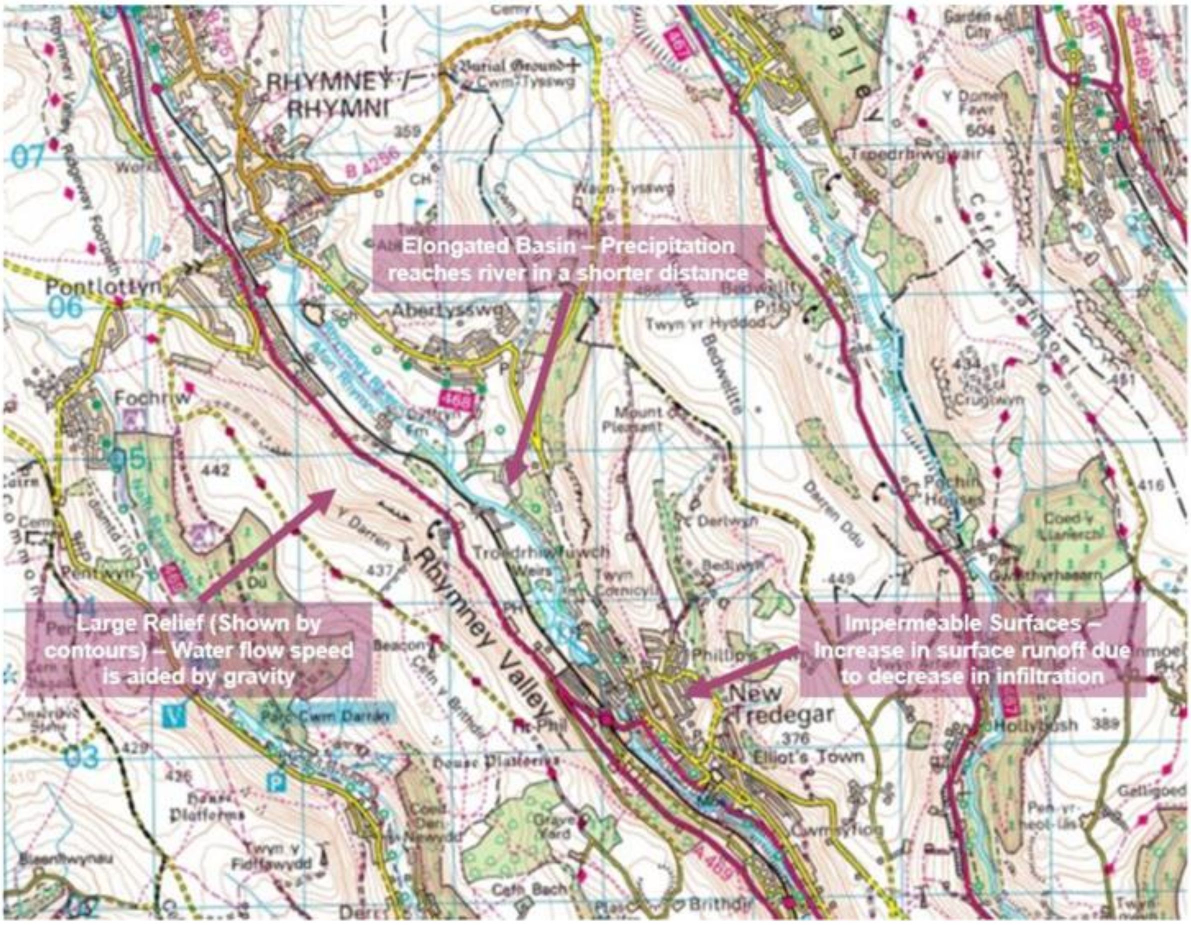
Subdued Hydrograph: Long lag timeand **low peak discharge**

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**[redacted]. 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**[redacted] **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:

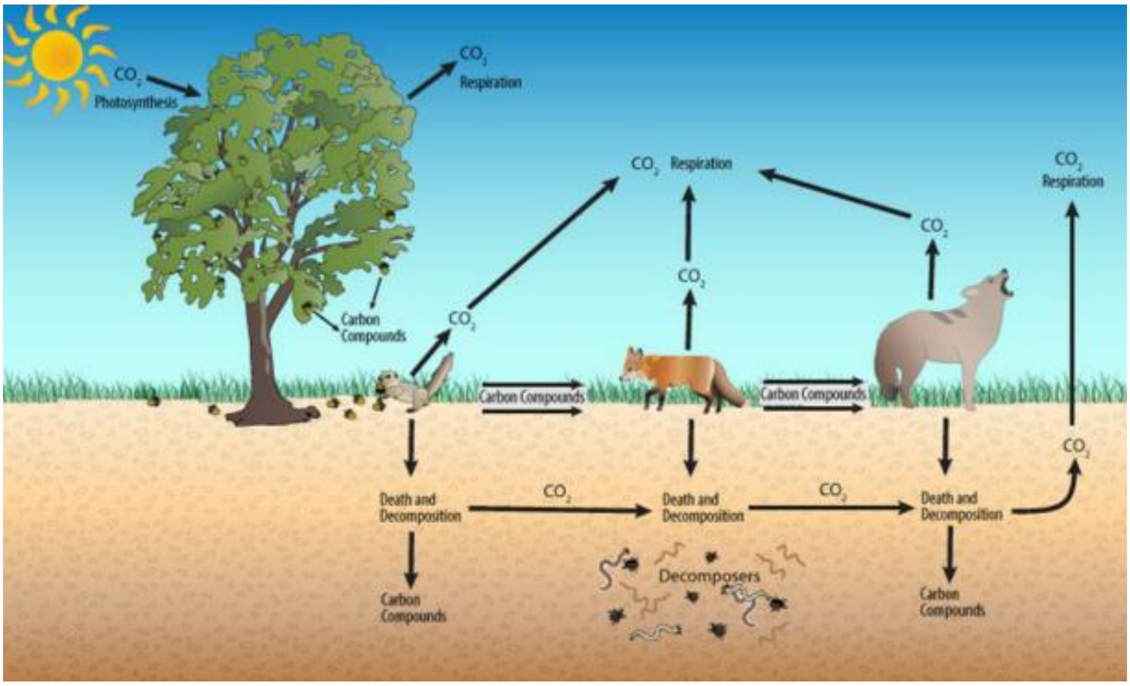
- Can be fitted to existing coal power stations.
- Captures 90% of CO_2 produced.
- There is a demand for CO_2 (Coca-Cola, Plant Growth, Beer etc.), so transport systems via pipeline in liquid form already exist.
- Potential to capture half the world's CO_2 emissions.

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.



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:

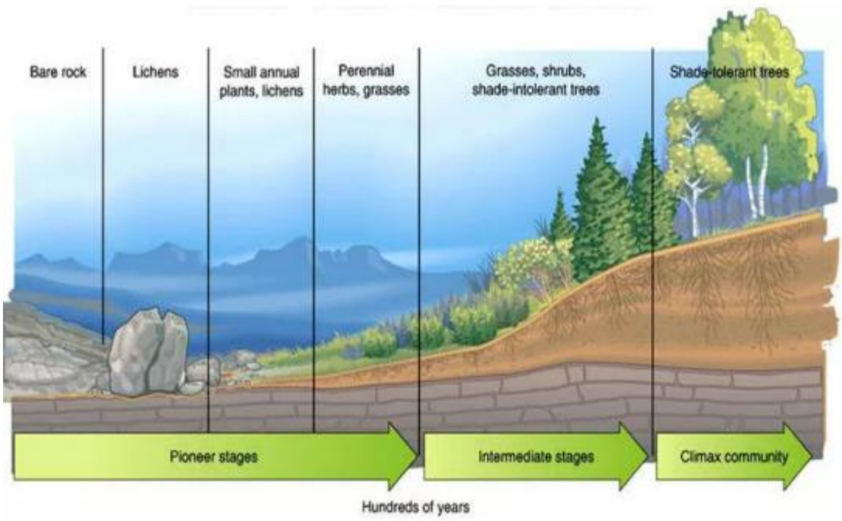
Lithosere - Bare rock

Halosere - Salty environment

Psammosere - Sand coastal environment

Hydrosere - Freshwater environment

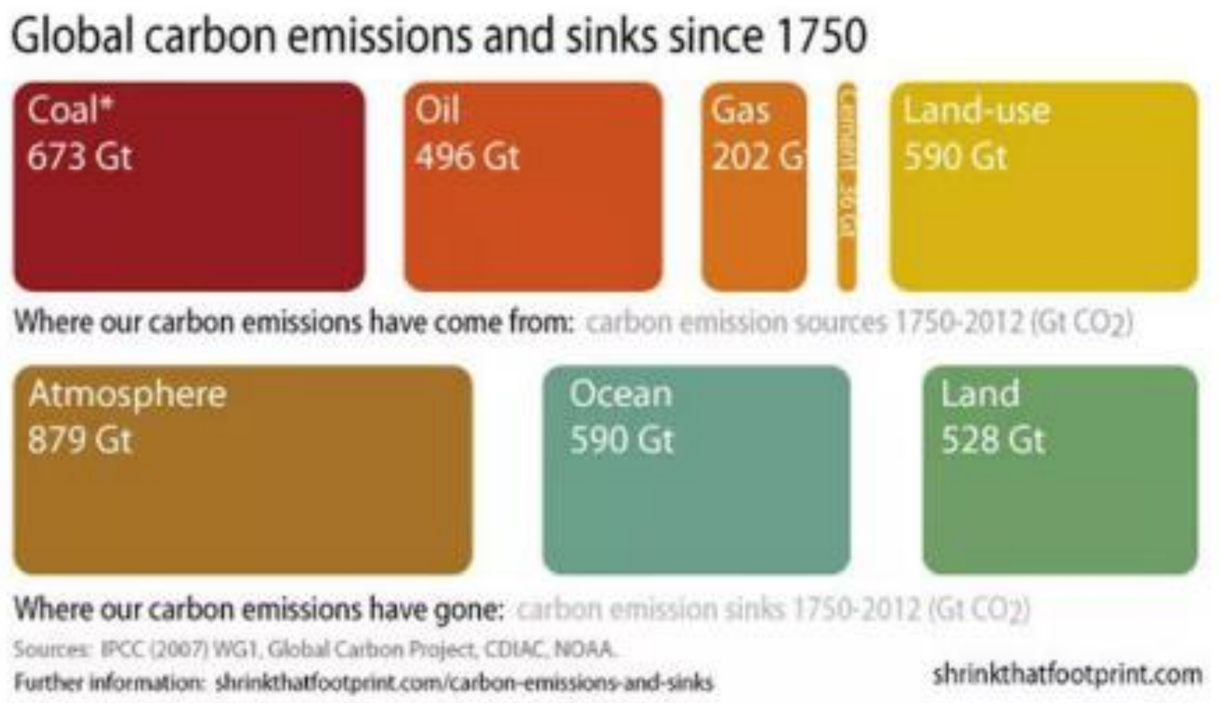
For example, in a **lithosere** over time a soil builds up on the rock from **decaying organic matter.** Plants colonise the soil and the soil continues to build up until it is deep enough for trees to colonise.



Lithosere succession

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 - **Arable farmingreleases 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 storesover 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:

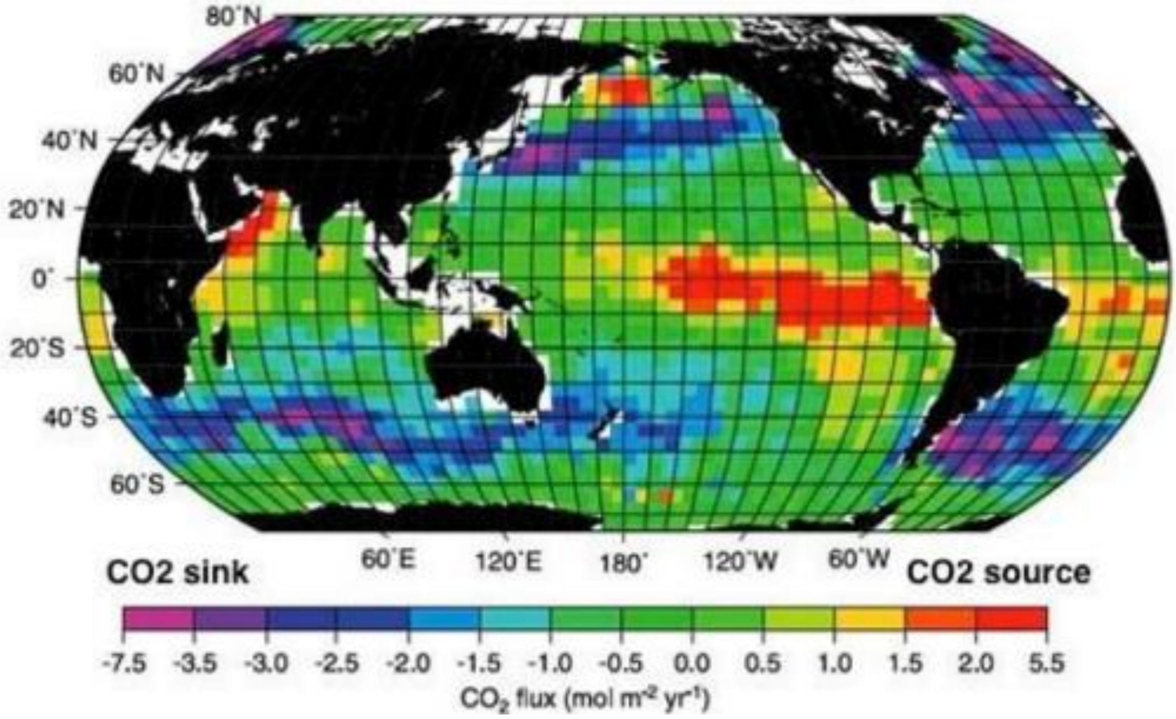
- **High rates of photosynthesis and respiration** in forests lead to **greater humidity, cloud cover and precipitation**

- **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 l**imit 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:

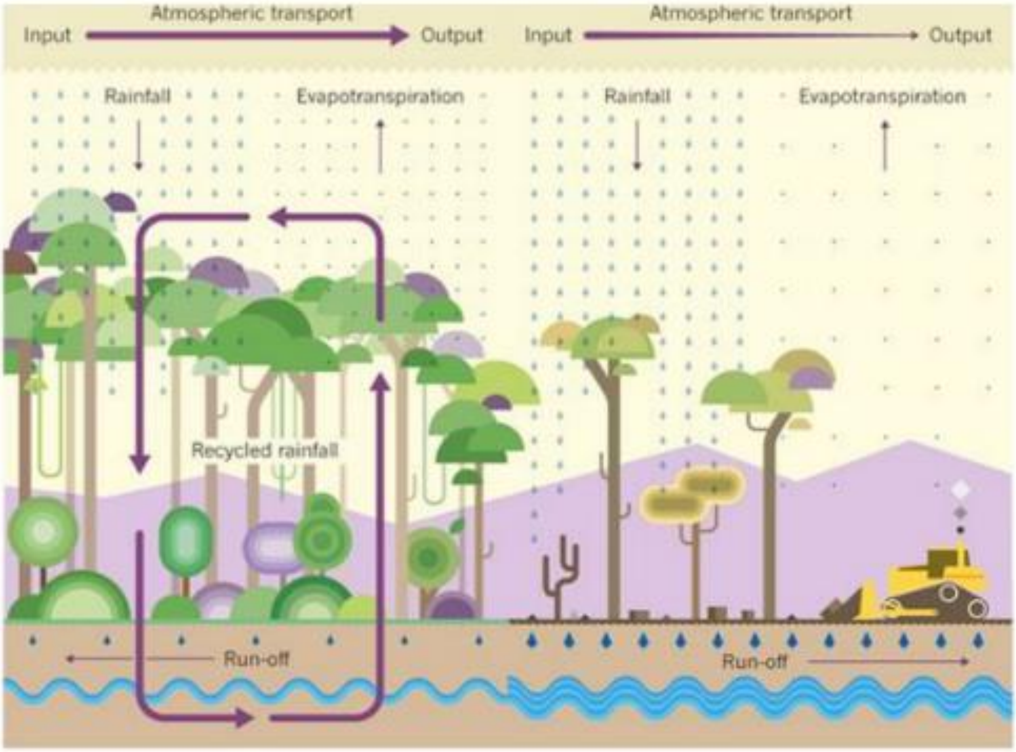
- Lack of trees so **photosynthesis is reduced.**
- **Fires** to clear land leads to CO_2 being released into the atmosphere. **Forests become a carbon source** instead of a carbon sink.
- **Lack of life** until new plants grow.
- **Low rates of decomposition** occurs in this environment.

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.



- 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.
- **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.

- Improving home insulation.

- Recycling.

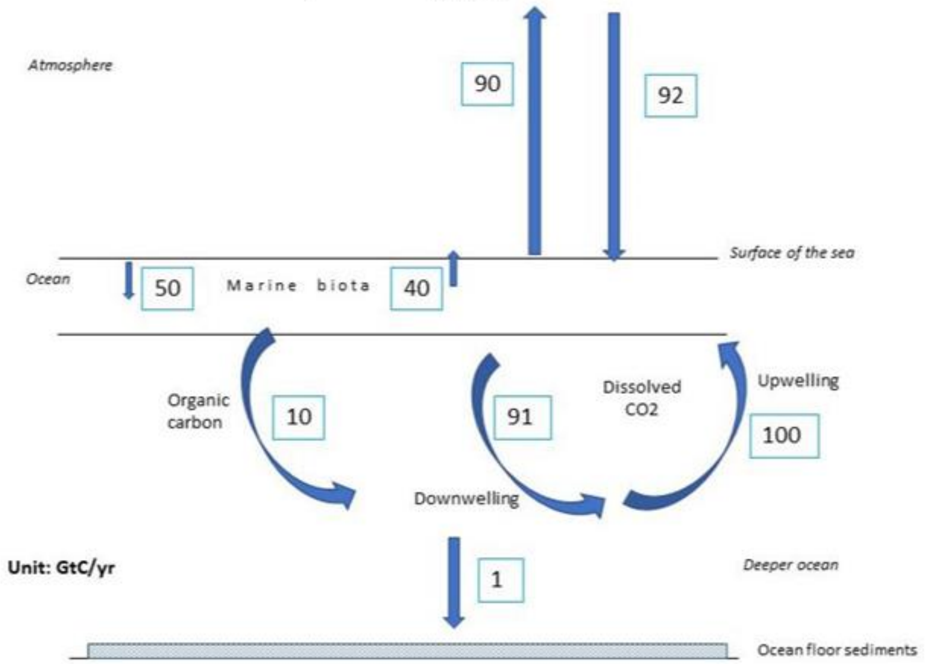
- Using energy more wisely and use of **smart meters** and using **public transporter car sharing schemes** and **calculating personal carbon footprints.**

Sample Assessment Questions

1. Explain what is meant by stores in relation to carbon cycles. (4 marks)

2. Using Figure 1 analyse the ways in which carbon is stored in oceans. (6 marks)

Figure 1



3. **Assess the relative importance of the water cycle in influencing marine carbon processes (20 marks)**

Mark schemes

1. Explain what is meant by stores in relation to carbon cycles. (4 marks)

AO1: Knowledge and understanding of stores as a concept and its connection to carbon cycles.
AO2: Application of knowledge and understanding to explain how stores operate at different scales and differ within individual carbon cycles.

Notes for answer:

- 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.
- 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.

2. Using Figure 1 analyse the ways in which carbon is stored in oceans. (6 marks)

AO3: Reponses should be focused on effective analysis of the data in figure 1. Expect to see comment on quantitative evidence of a range of stores and the significance of transfers between stores.

Level 2 (4-6 marks)
AO3: Clear analysis of the quantitative evidence provided which makes appropriate use of evidence in support. Clear connection(s) between different aspects of the data.

Level 1 (1-3 marks)
AO3: Basic analysis of the quantitative evidence provided which makes limited use of evidence in support. Basic connection(s) between different aspects of the data.

Notes for answer:

- By far the largest store of carbon in oceans is dissolved carbon. This will be predominantly in the form of carbon dioxide, which is absorbed from the atmosphere.

- There is a mutual carbon exchange between the atmosphere and ocean, with a small net gain by the ocean in general (92:90)

- The ocean store circulates dissolved carbon dioxide from upper layers to deeper waters. Upwelling currents bring more carbon to the surface than down-welling carbon accounts for. This is because it also brings descending organic carbon to the surface.

- A biological store of marine carbon (biota) involves ocean organisms that absorb carbon dioxide from the upper sea as part of photosynthesis (phytoplankton). Others feed on the phytoplankton (zooplankton) giving a biotic release of carbon dioxide to the ocean store from respiration and digestion, but which is a fifth less than has been absorbed.

- Waste from these surface organisms, as well as decaying residue sinks to lower levels of the ocean. 90% is carried back to the surface by upwelling currents, while a very small proportion (10%) sinks to the ocean floor as sediments.

- Over long periods of time sea bed sediments may become a carbon store in the lithosphere. Despite only a very small proportion of carbon sinking to the sea floor annually, very significant deposits accumulate. Many of these stores change volume rapidly and possibly locally according to ocean and atmospheric conditions (ocean biomass and algal blooms), while others operate on long time-scales and over large spatial scales (ocean floor sediments).

3. Assess the relative importance of the water cycle in influencing marine carbon processes (20 marks)

AO1: Knowledge and understanding of processes in the water cycle impacting upon marine carbon processes.
AO2: Application of knowledge and understanding to assess the relative importance of factors and processes in the water cycle influencing marine carbon processes. Response should come to a view in relation to the extent of the influence.

Notes for answers:
AO1

- Processes in the water cycle which directly relate to the marine carbon cycle. (river discharge of carbon-rich water into marine environments).

- Processes in the marine carbon cycle which do not directly relate to the water cycle. (accumulation of carbon-rich sediments on the sea floor).

- Factors which may be changing the influence of the water cycle on marine carbon processes. (changes in rainfall regime).

- Global distribution of places where there may be a greater or lesser influence of the water cycle on marine carbon processes.

- The role of water in eroding carbon-rich terrestrial rocks and transferring soluble carbon into marine waters. Marine calcification processes and their contribution to marine carbon transfers and stores.

- The role of water in increasing the acidity of oceans and the impact on marine calcification processes.

- The role of water in coastal eutrophication and influence on algal blooms. The impact of these on ocean carbon processes.

- The role of water in causing pollution of marine environments and the impacts on marine organisms and their role in marine carbon processes.

- The role of water (through melting ice) in changing the nature of ocean currents and their impact on marine carbon processes. Melting icebergs also release iron and trace elements eroded from the Antarctic/Greenland surfaces causing phytoplankton in their wake to be stimulated, and producing a negative feedback effect on climate change as they absorb CO2.

- Case study of a specific marine environment that has been influenced by water-cycle impacts. This may illustrate the scale and spatial distribution of influences as well as temporal duration, degree of permanence and effect on system equilibrium.

AO2

- Evaluation: Response may argue that the fact that marine environments form much of the hydrosphere and represent the major store of water on earth, then all marine carbon processes are taking place within a key component of the water cycle and could not occur without this store. However, the transfers of water into the store can influence rates, scale and intensity of some marine processes.

- Analysis: the water cycle transfers soluble carbonates into the marine system as a result of precipitation falling on to carbon-rich rocks, chemical weathering, and transfer into oceans. But this is dependent upon the distribution of carbon-rich rocks; where surface rocks are composed of non-carbon rich minerals, or are resistant to erosion, there will be limited transfer.

- Analysis: atmospheric water vapour combines with CO2 to form carbonic acid, which transfers carbon into marine environments through direct rainfall upon oceans. However, while this may increase the carbon content of oceans it may inhibit calcification as oceans become more acidic and carbonate ions become less accessible to marine organisms. Shell-building by marine organisms is reduced, affecting the transfer of carbon from sea water to organisms to sea bed sediments.

- Analysis: river systems can introduce agricultural nutrients into coastal waters stimulating organic growth in the form of algal blooms (eutrophication). The digestion of these phytoplankton by zooplankton can increase the 'marine snow' of digested detritus falling to the sea floor. This may feed lower-layer marine life, be carried by currents away from the coasts, or accumulate as carbon-rich sediments on the sea floor. This process is more likely to be limited to coastal areas in regions where there is heavy application of commercial agricultural chemical fertiliser.

- Analysis: more intense evaporation of warmer ocean waters in tropical storms can impact marine systems through physical interactions. More intense and frequent hurricanes can disturb sediments and interrupt the metastable equilibrium more frequently. This can be lethal to sensitive marine environments such as coral reefs and disrupt permanently their part in converting soluble carbon to solid forms, disrupting the marine biological carbon sequence.

- Evaluation: the duration, degree of permanence/reversibility, and spatial scale of these influences on marine carbon systems should be discussed. The more significant and less significant influences on marine carbon cycles should be considered.

- Overall evaluation: More sophisticated responses will recognise that marine carbon processes occur as a carbon sub-system within the larger water cycle that involves oceans as the major store. Changes to the atmospheric carbon cycle are affecting the water cycle, which in turn has specific feedback on marine carbon processes that are becoming more intense as long-term equilibrium in the systems is being disrupted by anthropogenic activity.

COASTAL LANDSCAPES AND SYSTEMS

1.1 The coast, and wider littoral zone, has distinctive features and landscapes.

- The littoral zone consists of backshore, nearshore and offshore zones, includes a wide variety of coastal types and is a dynamic zone of rapid change.
- Coasts can be classified by using longer term criteria such as geology and changes of sea level or shorter term processes such as inputs from rivers, waves and tides.
- Rocky coasts (high and low relief) result from resistant geology (to the erosive forces of sea, rain and wind), often in a high energy environment, whereas coastal plain landscapes (sandy and estuarine coasts) are found near areas of low relief and result from supply of sediment from different terrestrial and offshore sources, often in a low-energy environment.

1.2 Geological structure influences the development of coastal landscapes at a variety of scales.

- Geological structure is responsible for the formation of concordant and discordant coasts.
- Geological structure influences coastal morphology: Dalmatian and Haff type concordant coasts and headlands and bays on discordant coasts.
- Geological structure (jointing, dip, faulting, folding) is an important influence on coastal morphology and erosion rates, and also on the formation of cliff profiles and the occurrence of micro-features, e.g. caves.

1.3 Rates of coastal recession and stability depend on lithology and other factors.

- Bedrock lithology (igneous, sedimentary, metamorphic) and unconsolidated material geology are important in understanding rates of coastal recession.
- Differential erosion of alternating strata in cliffs (permeable/impermeable, resistant/less resistant) produces complex cliff profiles and influences recession rates.
- Vegetation is important in stabilising sandy coastlines through dune successional development on sandy coastlines and salt marsh successional development in estuarine areas.

1.4 Marine erosion creates distinctive coastal landforms and contributes to coastal landscapes.

- Different wave types (constructive/destructive) influence beach morphology and beach sediment profiles, which vary at a variety of temporal scales from short term (daily) through to longer periods
- The importance of erosion processes (hydraulic action, corrosion, abrasion, attrition) and how they are influenced by wave type, size and lithology.
- Erosion creates distinctive coastal landforms (wave cut notches, wave cut platforms, cliffs, the cave-arch-stack stump sequence).

1.5 Sediment transport and deposition create distinctive landforms and contribute to coastal landscapes.

- Sediment transportation is influenced by the angle of wave attack, tides and currents and the process of longshore drift.
- Transportation and deposition processes produce distinctive coastal landforms (beaches, recurved and double spits, offshore bars, barrier beaches and bars, tombolos and cuspate forelands), which can be stabilised by plant succession.
- The Sediment Cell concept (sources, transfers and sinks) is important in understanding the coast as a system with both negative and positive feedback, it is an example of dynamic equilibrium.

1.6 Subaerial processes of mass movement and weathering influence coastal landforms and contribute to coastal landscapes.

- Weathering (mechanical, chemical, biological) is important in sediment production and influences rates of recession.
- Mass movement (blockfall, rotational slumping, landslides) is important on some coasts with weak and/or complex geology.
- Mass movement creates distinctive landforms (rotational scars, talus scree slopes, terraced cliff profiles).

1.7 Sea level change influences coasts on different timescales

- Longer-term sea level changes result from a complex interplay of factors both eustatic (ice formation/melting, thermal changes) and isostatic (post glacial adjustment, subsidence, accretion) and tectonics.
- Sea level change has produced emergent coastlines (raised beaches with fossil cliffs) and submergent coastlines (rias, fjords and Dalmatian).
- Contemporary sea level change from global warming or tectonic activity is a risk to some coastlines.

1.8 Rapid coastal retreat causes threats to people at the coast.

- Rapid coastal recession is caused by physical factors (geological and marine) but can be influenced by human actions (dredging or coastal management the Nile Delta, Guinea and Californian coastlines).
- Subaerial processes (weather and mass movement) work together to influence rates of coastal recession.
- Rates of recession are not constant and are influenced by different factors both short- and longer term (wind direction/fetch, tides, seasons, weather systems and occurrence of storms).

1.9 Coastal flooding is a significant and increasing risk for some coastlines.

- Local factors increase flood risk on some low-lying and estuarine coasts (height, degree of subsidence, vegetation removal); global sea level rise further increases risk (Bangladesh, the Maldives).
- Storm surge events can cause severe coastal flooding with dramatic short-term impacts (depressions, tropical cyclones) can cause severe coastal flooding (the Philippines, Bangladesh).
- Climate change may increase coastal flood risk (frequency and magnitude of storms, sea level rise) but the pace and magnitude of this threat is uncertain.

1.10 Increasing risks of coastal recession and coastal flooding have serious consequences for affected communities.

- Economic losses (housing, businesses, agricultural land, infrastructure) and social losses (relocation, loss of livelihood, amenity value) from coastal recession can be significant, especially in areas of dense coastal developments (Holderness, north Norfolk).
- Coastal flooding and storm surge events can have serious economic and social consequences for coastal communities in both developing and developed countries (the Philippines, Bangladesh and Netherlands).
- Climate change may create environmental refugees in coastal areas (Tuvalu Islands).

1.11 There are different approaches to managing the risks associated with coastal recession and flooding.

- Hard engineering approaches (groynes, sea walls, rip rap, revetments, offshore breakwaters) are economically costly and directly alter physical processes and systems.
- Soft engineering approaches (beach nourishment, cliff regrading and drainage, dune stabilisation) attempt to work with physical systems and processes to protect coasts and manage changes in sea level.
- Sustainable management is designed to cope with future threats (increased storm events, rising sea levels) but its implementation can lead to local conflicts in many countries (Maldives, India).

1.12 Coastlines are now increasingly managed by holistic integrated coastal zone management (ICZM).

- Coastal management increasingly uses the concept of littoral cells to manage extended areas of coastline. Throughout the world, countries are developing schemes that are sustainable and use holistic ICZM strategies.
- Policy decisions (No Active Intervention, Strategic Realignment and Hold The Line Advance The Line) are based on complex judgements (engineering feasibility, environmental sensitivity, land value, political and social reasons); Cost Benefit Analysis (CBA) and Environmental Impact Assessment (EIA) are used as part of the decision making process.

- Policy decisions can lead to conflicts between different players (homeowners, local authorities, environmental pressure groups) with perceived winners and losers in countries at different levels of development (developed and developing or emerging countries) (Happisburgh and Sundarbans).

Coasts Glossary - AQA Geography A-Level

Abrasion- A form of erosion where loose material 'sandpapers' the walls and floors of the river, cliff or glacier. Also known as attrition.

Backshore-The upper beach closest to the land, including any cliffs or sand dunes.

Beach Morphology- The surface shape of the beach.

Coastal Recession- The retreat of a coastline due to erosion, sea-level rise or submergence.

Concordant Coast- A coastline where bands of alternate geology run parallel to the coast.

Corrasion- A form of erosion when breaking waves fling material (rocks, sediment, shells. etc) at a cliff face, physically knocking off material.

Corrosion- The acid in seawater and some types of seaweed attacks particular rock minerals, causing erosion and weakening.

Dalmatian Coast- A concordant coastline with several river valleys running perpendicular to the coast. They become flooded to produce parallel long islands and long inlets.

DEFRA's 1:1 Cost-Benefit Analysis- The evaluation of a coastal town's economic value compared to the cost of the management required. Costs are tangible and intangible and can be economic or other costs such as a visual impact.

Discordant Coast- A coastline where bands of alternate geology run perpendicular to the shore.

Dynamic Equilibrium- Where a natural system tries to achieve a balance by making constant changes in response to a constantly changing system.

Emergent Coast- A coastline that is advancing relative to the sea level at the time.

Eustatic - Global changes to sea levels.

Fetch- The distance the wave travels before it reaches the coastline. Distance to the nearest land mass in the direction in which the wave travels.

Fjord - Long narrow inlet deeper in the middle section than at the mouth, created when sea levels rise relative to the land, flooding coastal glacial valleys.

Foreshore- The lower part of the beach covered twice a day at high tide (the part of the beach that receives the most regular wave action).

Freeze Thaw - A form of physical sub-aerial weathering where water freezes in the cracks of a rock, expands and enlarges the crack, therefore weakens the rock.

Geology- The structure and arrangement of a rock.

Glacial Erosion- The removal of loose material by glacier ice, involving plucking, abrasion, crushing and basal meltwater. (necessary in the formation of Fjords).

Grading- The layering of sediments based on their size.

High-energy Environment- A coast where wave action is predominantly large destructive waves, causing much erosion.

Hydraulic Action- The pressure of compressed air forced into cracks in a rock face will cause the rock to weaken and break apart.

Integrated Coastal Zone Management (ICZM) - Large sections of coastline (often sediment cells) are managed with one integrated strategy and management occurs between different political boundaries.

Impermeable- A rock that does not allow rainwater to pass through.

Isostatic- A change in local coastline or land height relative to sea level.

Littoral Cell- A section of the coast, within which involves much sediment movement. A littoral cell is not a closed system.

Longshore Drift- The transportation of sediment along a beach. Longshore Drift is determined by the direction of the prevailing wind.

Low-energy Environment- A coast where wave action is predominantly small constructive waves, causing deposition and leading to beach accretion.

Mass Movement - The falling or movement of rock, often due to Gravity.

Nearshore- The area before the shore where the wave steepness and breaks before they reach the shore and then reform before breaking on the beach. It extends from the low-tide zone and then out to sea.

Permeable- A rock that allows rainwater to pass through it.

Plant Succession- Change to a plant community due to growing conditions adapting (eg. sand dunes and salt marshes).

Ria- Narrow winding inlet which is deepest at the mouth, formed when sea levels rise causing coastal valleys to flood.

Saltation- Smaller sediment bounces along the sea bed, being pushed by currents.The sediment is too heavy to be picked up by the flow of the water.

Sediment Cell - Sections of the coast bordered by prominent headlands. Within these sections, the movement of sediment is almost contained and the flows of sediment should act in dynamic equilibrium.

Sediment Budget - Use data of inputs, outputs, stores and transfers to assess the gains and losses of sediment within a sediment cell.

SMP - Identifies all of the activities, both natural and human which occur within the coastline area of each sediment cell and then recommends a combination of four actions for each stretch of that coastline: Hold the Line, Advance the Line, Managed Realignment and No Active Intervention.

Subaerial Processes- The combination of mass movement and weathering that affects the coastal land above sea.

Submergent Coast- A coast that is sinking relative to the sea level of the time.

Till- Deposits of angular rock fragments in a finer medium.

Wave Quarrying- When air is trapped and compressed against a cliff which causes rock fragments to break off the cliff over time.

The Coastal System

The coast can be considered as an **open system** as it receives **inputs** from outside the system and **transfers outputs** away from the coast and into other systems. These systems may be **terrestrial, atmospheric or oceanic** and can include the **rock, water and carbon cycles**.

Whilst coasts are **open systems**, throughout this topic you will be expected to consider the coast as a **closed system** in some circumstances such as during scientific research and coastline management planning. The coastal system is impacted and impacts upon processes which occur in the **five oceans** of our planet and the **smaller seas** of which they are part of. You should be aware of the **different habitats and activities which are affected by and affect the coastal environment**

Sediment Cells

Coasts can be split into sections called **sediment cells** which are often bordered by **prominent headlands**. Within these sections, the **movement of sediment is almost contained**and the flows of sediment act in **dynamic equilibrium**.

Dynamic equilibrium refers to the maintenance of a **balance**in a natural system, despite it being in a **constant state of change**. The system has a tendency to **counteract any changes**imposed on the system in order to keep this balance, which is achieved by **inputs** and **outputs** constantly changing to maintain the balance. Dynamic equilibrium in a sediment cell is where input and outputs of sediment are in a constant state of change but **remain in balance**.

The dynamic equilibrium may be upset in the **long term** by **human interventions**, or in the **short term** it may be interrupted by **natural variations**. Within each sediment cell there are **smaller subcells**. Often the smaller subcells are used when **planning coastal management projects**.

There are many features to the coastal system and most are listed below - there is more detail on each throughout these notes. Most of the questions in your exam will **focus on how these features and processes affect the coastal system**, though this will not always be explicit in the question title. When you are learning something in this unit, always **link it back to the key features** below:

Inputs: May refer to**material or energy**inputs. Coastal inputs are not limited to but include three main areas:

- **Marine:** Waves, Tides, Salt Spray
- **Atmosphere:**Sun, Air Pressure, Wind Speed and Direction
- **Humans:**Pollution, Recreation, Settlement, Defences

Outputs: May refer to **material or energy** outputs

- Ocean currents
- Rip tides
- Sediment transfer
- Evaporation

Stores/Sinks: Refer to stores and sinks of sediment and material.

- Beaches
- Sand Dunes
- Spits
- Bars and Tombolos
- Headlands and Bays
- Nearshore Sediment
- Cliffs
- Wave-cut Notches
- Wave-cut Platforms

- Caves
- Arches
- Stacks
- Stumps
- Salt Marshes
- Tidal Flats
- Offshore Bands and Bars

Transfers/Flows: The **processes that link the inputs, outputs and stores** in the coastal system:

- Wind-blown sand
- Mass-movement processes
- Longshore drift
- Weathering
- Erosion
    - Hydraulic Action
    - Corrosion
    - Attrition
    - Abrasion
- Transportation
    - Bedload
    - In suspension
    - Traction
    - In solution
- Deposition
    - Gravity Settling
    - Flocculation

Energy: The **power and driving force**behind the transfers and flows in the system

- Wind
- Gravitational
- Flowing Water

Feedback Loops

The coastal system has mechanisms which enhance changes within a system, taking it away from dynamic equilibrium (**positive feedback**) or mechanisms which balances changes, taking the system back towards equilibrium (**negative feedback**).

Negative feedback loop - this **lessens** any change which has occured within the system. For example, a storm could erode a large amount of a beach, taking the beach out of dynamic equilibrium as there is a larger input of sediment into the system than output. A negative feedback loop will balance this excess of inputted sediment:

- When the destructive waves from the storm lose their energy excess sediment is deposited as an offshore bar.
- The bar dissipates the waves energy which protects the beach from further erosion.
- Over time the bar gets eroded instead of the beach.
- Once the bar has gone normal conditions ensue and the system goes back to dynamic equilibrium.

Positive feedback loop - this exaggerates the change making the system **more unstable** and taking it away from dynamic equilibrium:

- People walking over sand dunes destroys vegetation growing there and causes erosion.
- As the roots from the vegetation have been holding the sand dunes together, damaging the vegetation makes the sand dunes more susceptible to erosion. This increases the rate of erosion.
- Eventually the sand dunes will be completely eroded leaving more of the beach open to erosion taking the beach further away from its original state.

Sediment Sources

Rivers:

- **Most of the sediment** in the coastal zone is a result of an **input from rivers**, especially in high-rainfall environments where significant river erosion occurs. This is demonstrated in the Gulf of Mexico and the sediment flowing from a **river delta**
- Sediment may be **deposited in estuaries** which are **brackish (salty)** areas where rivers flow into the sea.

They are **important wildlife habitats**. The sediment is then **transported** throughout the coastal system by waves, tides and currents

Cliff Erosion:

- Very important in areas with **unconsolidated (uncompacted and therefore unstable)** cliffs that are eroded easily. In some areas, coastlines can retreat by **up to 10m per year**, providing a **significant sediment input**.**Most erosion occurs during the winter months** due to **more frequent storms**

Wind:

- The wind is a **coastal energy source**and can cause sand to be blown along or up a beach
- Sediment transport by winds may occur where there are **sand dunes** or in **glacial and desert environments** which provide sediment inputs

Glaciers:

- In some coastal systems such as in **Antarctica, Greenland, Alaska and Patagonia**, glaciers flow directly into the ocean depositing sediment that was stored in the ice
- This occurs when **glaciers calve**, a process where ice breaks off the glacier

Offshore:

- Sediment is transferred to the coastal zone when **waves, tides and currents erode offshore sediment sinks** such as **offshore bars**. The sediment is transported onto the beach, helping to build up the beach
- **Storm surges or tsunami waves** may also transfer sediment into the coastal zone

Longshore Drift:

- Sediment is moved along the beach, due to **prevailing winds**which alter the **direction of the waves**. This allows sediment to be transported from one section of coastline (as an output) to another stretch of coastline (as an input). This is a very important process. The **swash approaches the coast at an angle due to the prevailing winds**, transferring sediment along the beach. The **backwash pulls the sediment directly back down the beach**. The swash then transfers the sediment along the coastline and the process repeats

For example: the process of longshore drift occurred to block off the Pohoiki Boat Ramp in Hawaii when the Kilauea volcano erupted in 2018. Volcanic material was **transported along the coastline by longshore drift, leading to deposition and beach formation**. This formed a **spit** off the breakwater before eventually blocking the entire boat ramp. It demonstrates how quickly the process of longshore drift can have an impact on shaping the coastal environment.

Sediment Budgets

Sediment budgets are very similar to **carbon budgets** and have the same purpose within different systems. They use **data of inputs, outputs, stores and transfers** to assess the **gains and losses of sediment within a sediment cell**. In principle a system will operate in a state of **dynamic equilibrium** where input and outputs of sediment are equal. However, **human actions and natural variation** in the system can disrupt the state of equilibrium.

The Littoral Zone

The **littoral zone** is the area of land between the **cliff's or dunes on the coast and the offshore area that is beyond the influence of the waves**. It is therefore covered by the sea at different points in time. The littoral zone is constantly changing because of:

- **Short-term factors** like tides and storm surges
- **Long-term factors** like changes in sea level and human intervention

The word **shore** is commonly used and can be used with different terms:

- **Shore/Shoreline** - The boundary between the sea and the land
- **Offshore** - The area beyond the influence of waves
- **Onshore** - The area of land not covered by the sea, but very close to it

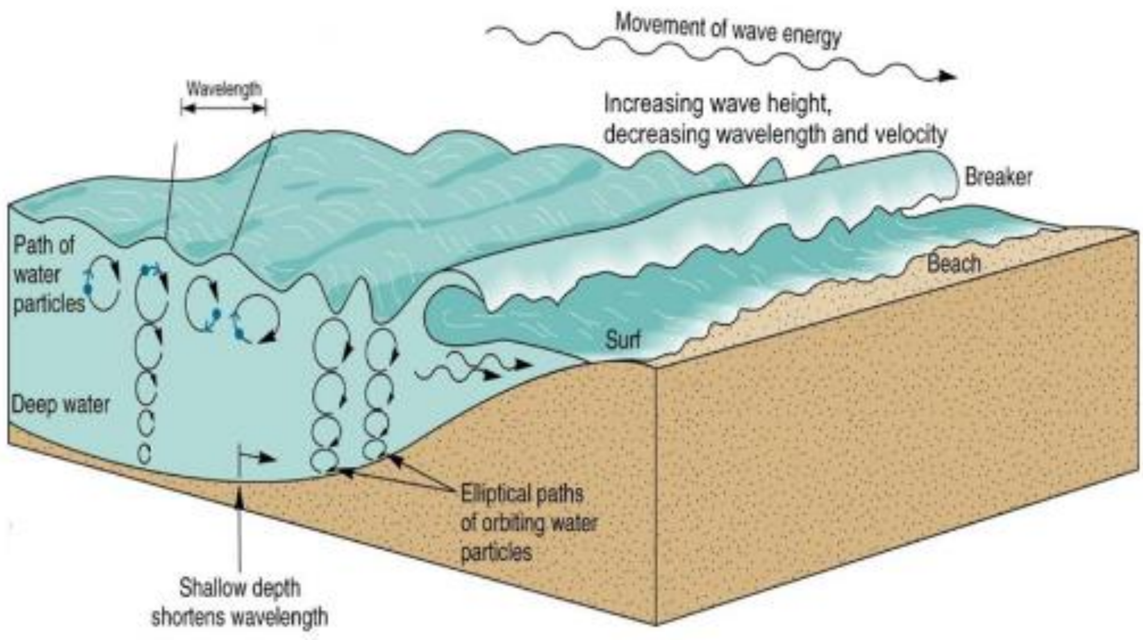
Sources of Energy at the Coast

The **sun is the primary source of energy**for all natural systems. The main energy source at the coast is from **waves which are formed offshore**, which are most commonly**generated by wind**, or less frequently **tectonic activity or underwater landslides causing tsunami waves**.

Wave Formation

The sun has a direct influence on the formation of waves, which occur when **wind moves across the surface of the water**:

- Winds move across the surface of the water, causing **frictional drag**(resistance to the wind by the water) which creates **small ripples and waves**. This leads to a**circular orbital motion of water particles** in the ocean
- As the **seabed becomes shallower** towards the coastline, the **orbit of the water particles becomes more elliptical**, leading to **more horizontal movement of the waves**
- The **wave height increases, but the wavelength (distance between two waves) and wave velocity both decrease**
- This causes **water to back up from behind the wave** until the **wave breaks (collapses) and surges up the beach**



When the wave moves up the beach, it is known as the **swash** and when it moves back down the beach into the sea, this is known as the **backwash**.

Factors Affecting Wave Energy

Strength of the Wind: Wind is essentially air that moves from an area of**high pressure to an area of low pressure**. The different pressure areas are caused by**variations in surface heating** by the sun. The larger the difference in pressure between two areas (**pressure gradient**) the stronger the winds. As waves are caused by the wind, stronger winds also mean stronger waves.

Duration of the Wind: If the**wind is active for longer periods of time**, then the energy of the waves will build up and increase.

Size of the Fetch: The**fetch is the distance over which the wind blows**and the larger it is, the more powerful the waves will be. It could also be thought of as the distance to the nearest land mass in a particular direction.

Wave Types

Constructive waves tend to **deposit material**, which **creates depositional landforms**and increase the size of beaches. **Destructive waves** act to **remove depositional landforms**through erosion, which work to decrease the size of a beach.

	Constructive	Destructive
Formation	Formed by weather systems that operate in the open ocean	Localised storm events with stronger winds operating closer to the coast
Wavelength	Long wavelength	Short wavelength
Frequency	6-9 Per Minute	11-16 Per Minute
Wave Characteristics	Low waves, which surge up the beach	High waves, which plunge onto the beach
Swash Characteristics	Strong swash, weak backwash	Weak swash, strong backwash
Effect on Beach	Occurs on gently sloped beaches	Occurs on steeply sloped beaches

The **type of waves** in a coastal environment may vary:

- In summer, constructive waves dominate but destructive waves dominate in winter
- Constructive waves may become destructive waves if a storm begins
- Climate change may increase the storm frequency within the UK
- Coastal management may affect the type of waves that occur

Negative Feedback: Beaches and Waves

The presence of **constructive waves causes deposition** on the beach, which in turn leads to the **beach profile becoming steeper**.**Steeper beaches favour the formation of destructive waves** which are then more likely to occur. The **destructive waves erode the beach**, reducing the beach profile and **leading to the formation of constructive waves**. As constructive waves occur more frequently in summer when there are fewer storms, this means that the beach profile is more gentle in summer and steeper during the winter months when destructive waves are more common. This should lead to a state of **dynamic equilibrium** though in reality this may not occur due to **external factors** such as the wind strength and direction.

Tides

Gravity is another key source of energy in coastal environments and is **responsible for tides** which occur when the **gravitational pull of the sun or moon** changes the water levels of the seas and oceans. The difference in height between the tides is known as the **tidal range** and tends to be largest in **channels such as river estuaries**. The high and low tides and therefore the **tidal range** are all impacted by the positioning of the moon and the sun.

The **highest high tide** and the **lowest low tides**occur when the sun and the moon are **in alignment** . Both of their **gravitational forces combine to effectively pull the oceans towards them** to cause the highest high tides. On the other side of the planet, this creates the lowest possible low tides. This is a **spring tide** and it creates the **largest possible tidal range**.

The **lowest high tide** and the **highest low tides** occur when the sun and the moon are **perpendicular** to each other. Both of their gravitational forces **act against each other**, so the **overall pull is minimised** at high tide, but therefore creates a higher low tide. This is a **neap tide** and it creates the **smallest possible tidal range**.

Tides affect erosion and lead to the formation of different coastal landforms.

Currents

Rip currents are powerful underwater currents occurring in areas close to the shoreline on some beaches when **plunging waves cause a build up of water** at the top of the beach. The backwash is forced under the surface due to **resistance from breaking waves**, forming an underwater current. This flows away from the shore more quickly due to beach features, such as a **gap in a sandbar**, creating a rip current. Rip currents claims lives at beaches every year, though it is possible to escape from them by swimming away from them in a direction parallel to the beach. **Riptides are different to rip currents** as they occur when the ocean tide pulls water through a small area such as a bay or lagoon. Rip currents are an **energy source** in a coastal environment and can lead to **outputs of sediment** from the beach area.

High-Energy and Low-Energy Coastlines

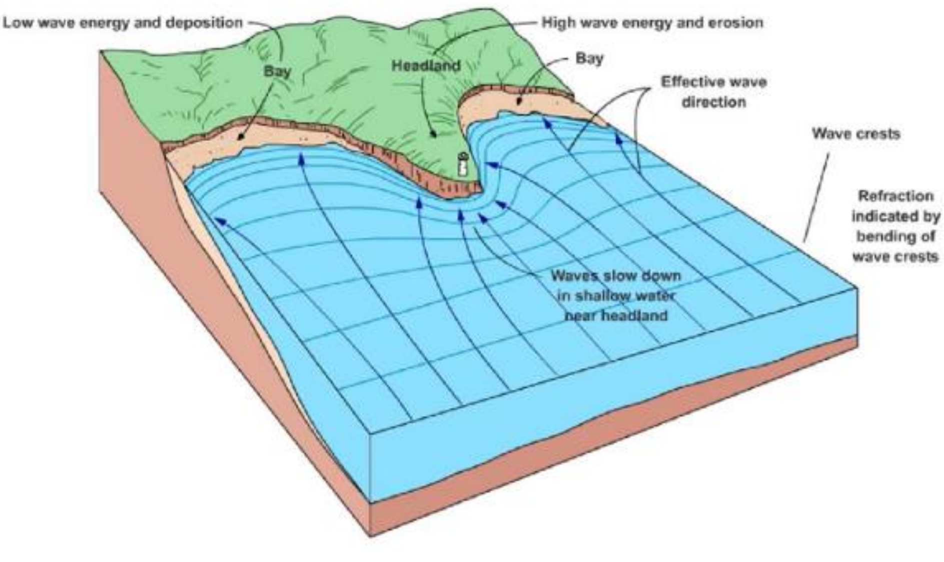
When answering questions in your exam, it is expected that you will include information about the different processes and landforms that may occur in **high and low energy environments**.

High-energy coastlines are associated with more powerful waves, so occur in areas where there is a **large fetch.** They typically have **rocky headlands and landforms** and fairly frequent **destructive waves**. As a result these coastlines are often eroding as the **rate of erosion exceeds the rate of deposition**.

Low-energy coastlines have less powerful waves and occur in **sheltered areas** where **constructive waves** prevail and as a result these are often **fairly sandy areas**. There are **landforms of deposition** as the rates of **deposition exceed the rates of erosion**.

Wave Refraction

Wave refraction is the process by which waves turn and lose energy around a headland on uneven coastlines. The **wave energy is focussed on the headlands**, creating **erosive features** in these areas. The energy is **dissipated in bays** leading to the formation of features associated with **lower energy environments** such as beaches.



Negative Feedback

Due to the different rock strengths, erosion leads to the formation of **headlands where resistant rock exists** and **bays where unconsolidated rocks and clays are dominant**. This then **increases the forces of erosion on the headlands** and **reduced erosion in the bays** as wave refraction dissipates wave energy and a beach protects the coastline behind. Eventually the **headlands are worn away**, which then again**increases erosion within the bays**. This would lead to **dynamic equilibrium** if conditions stayed constant, but of course over time they will vary.

Marine Processes

Erosion

Erosion is a collaborative process which involves the **removal of sediment from a coastline** by different types of erosion, not one type acting by itself. The main processes of erosion are discussed below:

Corrasion -Sand and pebbles are picked up by the sea from an**offshore sediment sink**or temporal store and **hurled against the cliffs** at high tide, causing the cliffs to be eroded. The shape, size, weight and quantity of sediment picked up, as well as the wave speed, affects the erosive power of this process.

Abrasion - This is the process where sediment is **moved along the shoreline**, causing it to be **worn down over time**. If a watermelon was being eroded (theoretically), corrasion would be throwing stones at it and abrasion would be rubbing the stones against the skin of the watermelon. Both will cause damage to the watermelon over time.

Attrition - Wave action cause **rocks and pebbles to hit against each other**, wearing each other down and so becoming round and eventually smaller. Attrition is an erosive process within the coastal environment, but has little to no effect on erosion of the coastline itself.

Hydraulic Action - As a wave crashes onto a rock or cliff face,**air is forced into cracks, joints and faults** within the rock. The high pressure causes the **cracks to force apart and widen** when the wave retreats and the air expands. Over time this causes the rock to fracture. Bubbles found within the water may **implode under the high pressure** creating tiny jets of water that over time erode the rock. This erosive process is **cavitation**.

Corrosion (Solution) - The**mildly acidic seawater** can cause **alkaline rock** such as limestone to be eroded and is very similar to the process of **carbonation weathering**. This is a potential link between the carbon cycle, global warming and coasts. Will increases in rainwater and ocean acidity increase coastal erosion or will the effect by negligible?

Wave Quarrying - This is when breaking waves that hit the cliff face exert a pressure up to 30 tonnes per m^2. It is very**similar to hydraulic action** but acts with significantly more pressure to directly pull away rocks from a cliff face or remove smaller weathered fragments. The force of the breaking wave **hammers the rocks surface**, shaking and weakening it and leaving it open to attack from **hydraulic action and abrasion**.

Factors Affecting Erosion

There are several factors which affect coastal erosion, which can be **marine or land based**:

- **Waves:** This is the main factor affecting the **rate and type of erosion**. As a result, most erosion occurs during the winter months when waves are more likely to be destructive and more powerful due to frequent storms
- **Beaches:** If there is a beach in front of a cliff then this will **absorb wave energy** and thus reduce the effects of erosion. Therefore if **coastal management such as groynes** are used which trap sediment, this can lead to beaches not building up in other areas. Instead it could increase the rate of erosion there
- **Subaerial Processes**: **Weathering and mass movement**processes such as landslides weaken cliffs. Rock fragments as a result of these processes may lead to increased **corrasion and abrasion**

- **Rock Type: Sedimentary** rocks like sandstone are made up of cemented sediment particles and are therefore are vulnerable to erosion, whereas **igneous and metamorphic** rocks are made up of **interlocking crystals**, making them more resistant to erosion
- **Rock Faults: Fissures, cracks and joints** are are all types of weaknesses within the rock so the more there are, the quicker erosion of the rock will occur. They also i**ncrease the rock face surface area**, further promoting erosion. Large faults within the rock can lead to the **formation of headlands and bays** due to the favourable conditions for erosion that they create
- **Rock Lithology (Rock characteristics):** As shown in the table on the next page, the type of rocks and the conditions of the rock's creation directly affects its vulnerability to erosion:

Type of Rock	Examples	Rate of Erosion	Structure of Rock
Igneous	Granite, Basalt	Very slow <0.1cm/year	Interlocking crystals which allow for high resistance to erosion
Metamorphic	Slate, Schist, Marble	Slow 0.1-0.3cm/year	Crystal all orientated in the same direction, resisting erosion
Sedimentary	Limestone	Very fast 0.5-10cm/year	Lots of faults making them weak and vulnerable to erosion

Processes of Transportation and Deposition

Coastal transportation is responsible for transferring sediment within a sediment cell and between other sediment cells. The four main processes of **transportation** are:

- **Traction** – Large, heavy **sediment rolls along the sea bed** pushed by currents. Think of a big tractor wheel moving on the ground (seabed)
- **Saltation** – Smaller sediment bounces along the sea bed, being **pushed by currents**. The **sediment is too heavy** to be picked up by the flow of the water
- **Suspension** – Small sediment is carried within the flow of the water. The **Hjulström curve** shows how **greater velocities of water are able to suspend larger and heavier pieces of sediment**
- **Solution** –**Dissolved material is carried** within the water, potentially in a chemical form. This method of transportation is an important part of carbonation weathering

Longshore (Littoral) Drift (LSD)

Longshore drift may utilise all these methods of transportation to move sediment along the beach and between sediment cells:

- Waves hit the beach at an angle determined by the direction of the **prevailing wind**
- The waves push sediment in this direction and up the beach in the **swash**
- Due to gravity, the wave then carries sediment back down the beach in the **backwash**
- This moves sediment along the beach over time
- It is one of the reasons why when swimming in the sea, you often move along the coast in a particular direction

Deposition

Deposition occurs when **sediment becomes too heavy** for the water to carry, or**if the wave loses energy**. Deposition tends to be a gradual and continuous process, so a wave won't release all its sediment at the same time. This explains why **beaches are often either sandy or rocky** and these areas are very distinct on the same beach. **High-energy coastlines** continue to transport smaller sediment, so larger rocks and shingle are deposited in these environments. **Low-energy coastlines** have much smaller sediment, which is only deposited in these areas where there is a much **lower water velocity**. As a result, specific landforms of deposition will occur. Two types of deposition are explained below:

- **Gravity Settling:** The water's **velocity decreases**so sediment begins to be deposited
- **Flocculation:** This is an important process in salt and tidal marshes. Clay **particles clump together due to chemical attraction** and then sink due to their high density

Weathering and Mass Movement Processes

Weathering

Weathering is the **breakdown of rocks**(mechanical, biological or chemical) over time, leading to the **transfer of material into the littoral zone**, where it becomes an **input to sediment cells**.

Positive Feedback: If the rate of removal of the weathered rock from the base of the cliff is higher than the rate of weathering, then this will promote further weathering as this will **increase the area of exposed rock**. This will increase the amount of erosion that occurs because this will**increase the supply of rocks** which can become part of the **erosive processes of saltation and abrasion**.

Negative Feedback: If the removal of weathered rock from the base of the cliff is slower than the rate of weathering then this will lead to a **buildup of debris at the base of the cliff**,**reducing the exposed cliff area** and therefore **reducing the rates of weathering**. It will also reduce erosion as the cliff foot will be protected from the other forces of erosion.

Mechanical (Physical) Weathering: the breakdown of rocks due to exertion of physical forces without any chemical changes taking place

- **Freeze-thaw (Frost-Shattering):**Water enters cracks in rocks and then the water**freezes** overnight during the winter. As it freezes, **water expands by around 10%**in volume which increases the pressure acting on a rock, causing cracks to develop. Over time these cracks grow, weakening the cliff making is more vulnerable to other processes of erosion
- **Salt Crystallisation:**As seawater **evaporates**, salt is left behind. Salt crystals will grow over time, exerting pressure on the rock, which forces the cracks to widen. Salt can also **corrode ferrous (materials that contains iron) rock** due to chemical reactions
- **Wetting and Drying:** Rocks such as clay **expand when wet**and then contract again when they are drying. The frequent **cycles of wetting and drying**at the coast can cause these rocks and cliffs to break up

Chemical Weathering: The breakdown of rocks through chemical reactions

- **Carbonation: Rainwater absorbs CO2**from the air to create a **weak carbonic acid** which then reacts with **calcium carbonate** in rocks to form **calcium bicarbonate**which can then be easily dissolved. **Acid rain** reacts with **limestone**to form **calcium bicarbonate**, which is then easily dissolved allowing erosion
- **Oxidation:** When **minerals** become exposed to the air through **cracks and fissures**, the mineral will become oxidised which will **increase its volume**(contributing to mechanical weathering), causing the rock to crumble. The most common oxidation within rocks is iron minerals becoming iron oxide, turning the rock rusty orange after being exposed to the air
- **Solution:** When rock minerals such as **rock salt** are dissolved

Biological Weathering: The breakdown of rocks by **organic activity:**

- **Plant Roots** - Roots of plants growing into the cracks of rocks, which exerts pressure, eventually splitting the rocks. Research **Angkor Wat** for more information on this, even though it is not coastal!
- **Birds** - Some birds such as **Puffins** dig burrows into cliffs weakening them and making erosion more likely
- **Rock Boring** - Many species of **clams** secrete chemicals that dissolve rocks and **piddocks** may burrow into the rock face
- **Seaweed Acids** - Some seaweeds contain pockets of **sulphuric acid**, which if hit against a rock or cliff face, the acid will dissolve some of the rock's minerals. (e.g. Kelp)
- **Decaying Vegetation** - Water that flows through decaying vegetation and then over coastal areas, will be acidic, thus causing chemical weathering

Mass Movement

Mass movement is the **movement of material down a slope under the influence of gravity**. Mass movement can be categorised into four main areas: **creeps, flows, slides and falls**. Mass movement processes act as an **input into the littoral zone** from the store of the land. The type of mass movement is dependent on:

- Cliff/slope Angle
- Rock Type
- Rock Structure
- Vegetation
- Saturation of Ground
- Presence of Weathering

The Different Types of Mass Movement are:

Soil Creep: The **slowest** but most continuous form of mass movement involving the movement of soil particles downhill. Particles rise and fall due to **wetting and freezing**and in a similar way to longshore drift, this causes the soil to move down the slope. It leads to the formation of **shallow terracettes**.

Solifluction: Occurs mainly in tundra areas where the land is frozen (**periglacial environments**). As the top layers thaw during summer (but the lower layers still stay frozen due to permafrost) the **surface layers flow over the frozen layers**. Forms **solifluction lobes**.

Mudflows: An increase in the water content of soil can reduce friction, leading to earth and mud to **flow over underlying bedrock**, or slippery materials such as clay. Water can get trapped within the rock increasing **pore water pressure**, which forces rock particles apart and therefore weakens the slope. **Pore Water Pressure (PWP)**is an important energy source for determining slope stability and refers to the pressure of groundwater held within soil or rock. Mudflows represent a **serious threat to life** as they can be very fast flowing.

Rockfall: Occurs on sloped cliffs (over 40º) when **exposed to mechanical weathering**, though mostly occurs on **vertical cliff faces** and can be triggered by earthquakes. It leads to **scree** (rock fragments) building up at the base of the slope. Scree is a **temporal store** which acts as an input to the coastal zone.

Landslide: Heavy rainfall leads to**water between joints and bedding planes** in cliffs (which are **parallel to the cliff face**) which can**reduce friction and lead to a landslide**. It occurs when a **block of intact rock** moves down the cliff face very quickly along a flat slope. Can be very dangerous.

Landslip or Slump: Contrary to a landslide, the**slope is curved**, so often occur in weak and unconsolidated clay and sands areas. A build up in pore water pressure leads to the **land to collapse under its own weight**. This can create a **scarred/terraced**appearance to the cliff face.

Runoff: Runoff is an example of a **link between the water cycle and the coastal system**, as the water in the form of overland flow may erode the cliffface and coastal area or pick up sediment, that then enters the littoral zone, when it is transported in the water via **suspension**. It may also be responsible for **increasing pollution** in coastal areas if it picks up waste or excess chemicals.

Vulnerability to Sub-Aerial Processes

Temperature and climate can influence the prominence of weathering. In colder climates, mechanical weathering is more common, whereas in warmer climates, chemical weathering is more common.

Coastal Landforms and Landscapes of Erosion

Caves, Arches, Stacks & Stumps

This sequence occurs on **pinnacle headlands**:

- Initially, faults in the headland are eroded by **hydraulic action and abrasion** to create small caves
- The **overlying rock in a cave may collapse**, forming a**blowhole**. The blowhole spurts water when a wave enters at the base, forcing sea spray and air out of the top
- Marine erosion **widens faults in the base of the headland**, widening over time to create a cave
- The cave will widen due to both **marine erosion and sub-aerial processes**, eroding through to the other side of the headland, creating an **arch**
- The arch continues to widen until it is unable to support itself, **falling under its own weight** through **mass movement**, leaving a **stack** as one side of the arch becomes detached from the mainland
- This was seen recently at the **Azure Window in Malta**. With marine erosion attacking the base of the stack, eventually the stack will collapse into a stump
- A **wave-cut platform** will be left afterwards

Cliff Profile and Rate of Retreat

Steep Cliffs: Most common where the **rock is strong and fairly resistant** to erosion. **Sedimentary rocks that have vertical strata** are also more resistant to erosion, creating steep cliffs. An absence of a beach, long-fetch and high energy waves also promote steep cliff development. Most commonly found in **high-energy environments**

Gentle Cliffs: Most commonly found in **areas with weaker rocks** which are **less resistant to erosion** and are prone to slumping. **Low-energy waves** and a **short fetch** will lead to the formation of a scree mound at the base of the cliff, reducing the overall cliff angle. A large beach would also reduce wave energy and prevent the development of steep cliffs by reducing erosion rates. Most commonly found in **low-energy environments**

Rate of Retreat: Dependent on the relative importance of **marine factors**(fetch, beach, wave energy) and **terrestrial factors**(subaerial processes, geology, rock strength). The cliff's most likely to retreat are those that are made of **unconsolidated rock**and sands.

Negative feedback mechanisms can help to protect and restore a coast. For example, during a storm, part of a cliff may collapse so the material produced will protect the base of the cliff from marine erosion, reducing further cliff **recession**. Alternatively, sand dunes may be eroded during a storm, meaning a loss of a sediment on land. However, the sediment produced may be deposited in **offshore bars**, which protect the coastline from further erosion by **dissipating wave energy**.

Wave-cut Notch and Platform

This sequence occurs at steep cliffs:

- When waves erode a cliff, the erosion is mostly **concentrated around the high-tide line**. The main processes of **hydraulic action and corrasion** create a **wave-cut notch**
- As the notch becomes deeper (and sub-aerial weathering weakens the cliff from the top) the cliff face becomes unstable and falls under its own weight through mass movement
- This leaves behind a **platform** of the unaffected cliff base beneath the **wave-cut notch**
- Over time the same processes repeat leading to a **wave-cut platform** to be formed, which is normally exposed at high-tide

Negative Feedback

The length of a **wave-cut platform** is limited as eventually the waves can no longer reach the cliff, reducing the erosion. Therefore the act of **erosion creating the wave-cut platform has acted to directly decrease the rate of erosion in future** - an example of **negative feedback**.

Coastal Landforms and Landscapes of Deposition

Beaches

A beach is a **depositional landform** that stretches from roughly the low tide to the high tide line and is created when sediment is deposited near the coastline when waves lose their energy. It is one of the **most important stores**in the coastal system.**Beach accretion** occurs when the beach is being built up by constructive waves, usually during the summer months. **Beach excavation** occurs in winter when destructive waves remove sediment from the beach. The effectiveness of transportation is dependent on the **angle of the prevailing wind**in relation to the land and leads to the formation of different beach types:

- **Swash-aligned**: Wave crests approach**perpendicular to coast** so there is **limited longshore drift**. Sediment doesn't travel far along the beach.**Wave refraction** may reduce the speed of high energy waves, leading to the formation of a shingle beach with larger sediment
- **Drift-aligned**: Waves approach at a significant angle, so longshore drift causes the sediment to travel far along the beach, which may lead to the **formation of a spit** at the end of a beach. Generally **larger sediment is found at the start of the beach** and weathered sediment moves further down the beach through longshore drift, becoming smaller as it does, so the **end of the beach is likely to contain smaller sediment**

There are different features within a beach. These may include **berms**, which are ridges which mark where the high tide line is at different times of the year, and as a result there may be several berms on a beach characterised by a **small ridge or change in sediment type**.**Cusps** are small **curved dips in the beach** where the swash comes in, and are slightly lower than the rest of the beach. This creates undulations in the beaches profile. **Runnells are smaller ridges** that are often found in smooth wet sand further towards the sea, caused by the tides.

Beach profiles and sediment types **vary dependent on distance from the shoreline**.**Larger sediment is found toward the top of the beach** where it has been left from winter storms. The backwash is often weaker than the swash as the water quickly percolates into the sand. As the backwash isn't as powerful the larger sediment remains at the top of the beach. Some of the smaller sediment will be moved back down the beach, giving a fairly even pattern. Often if you approach a cliff from the sea, the **sediment will become larger** in size. Scree near the cliffs as a result of mass movement processes and weathering means that **angularity increases towards the cliff**, where hydraulic action acts less frequently to round the sediment.

Spits

This is a **long narrow strip of land** which is formed when **longshore drift** causes the beach to extend out to sea, usually due to a **change in direction of the coastline**. This sediment projection can create a **salt marsh due to the sheltered, saline environment** where water flow speed is lower, allowing **deposition of finer sediments** to occur. The length of the spit depends on any changing currents or rivers, which will **prevent sediment from being deposited**. This means a **spit can never extend across an estuary**. A change in wind direction or wave direction can cause the end of the spit to curve (known as a **recurved end**). Over time, the spit may be left with multiple recurved tips, which is known as a **compound spit**. In some areas a**double spit may occur** where the spits from **opposite sides of a bay** reach out towards each other, though are unlikely to touch unless there are no changes to environmental conditions. This could lead to a **barrier beach** being formed.

Barrier Beach/Bars

A barrier beach occurs when a **beach or spit extends across a bay to join two headlands**. This traps water behind it leading to the formation of a brackish lagoon which is separated from the sea. As well as forming from present day processes, some barrier beaches may have formed due to **rising sea levels after the last glacial period**, when meltwater from glaciers deposited sediment in the coastal zone. If a **barrier beach becomes separated from the mainland, it becomes a barrier island**. They are common in areas with**low tidal ranges** and can be very large, as demonstrated by the barrier beaches that have formed in the Netherlands.

Tombolo

A tombolo is a bar or beach that **connects the mainland to an offshore island** and is formed due to **wave refraction off the coastal island reducing wave velocity**, leading to deposition of sediments. They may be covered at high tide if they are low lying.

Offshore Bars

An **offshore region where sand is deposited**, as the waves don't have enough energy to carry the sediment to shore. They can be formed when the wave breaks early, instantly depositing its sediment as a loose-sediment offshore bar. Waves may pick up sediment from an offshore bar, which then provides an **important sediment input into the coastal zone**. They may also be formed as a result of **backwash from destructive waves removing sediment from a beach**. Offshore bars may absorb wave energy, reducing erosion in some areas.

Plant Succession

A **vegetation succession is a plant community that changes over time**. On coasts where there is a supply of sediment and deposition occurs, **pioneer plants** begin to grow in bare mud and sand.

For sand dune succession, **embryo dunes** are first colonised by pioneer plants, which die and release **nutrients** into the sand, increasing the amount of vegetation able to grow within the dune. Embryo dunes and their pioneer plants alter the environmental conditions from harsh and salty, to an environment in which other plants can survive. New species of plants can now colonise the area, which will **change the environment** progressively. Marram grass is a very good example of a pioneer plant:

- It is tough and flexible, so can cope when being blasted with sand
- It has **adapted to reduce water loss through transpiration**
- Their roots grow up to **3 metres deep** and can tolerate temperatures of up to $60^{o}C$

Salt Marsh Succession

- **Algal Stage** - Gut weed & Blue green algae establish as they can grow on bare mud, which their roots help to bind together.
- **Pioneer Stage** - Cord grass & Glasswort grow, their roots begin to stabilise the mud allowing the estuarine to grow.
- **Establishment Stage** - Salt marsh grass & Sea asters grow, creating a carpet of vegetation and so the height of the salt marsh increases.
- **Stabilisation** - Sea thrift, Scurvy grass & Sea lavender grow, and so salt rarely ever gets submerged beneath the marsh.
- **Climax vegetation** - Rush, Sedge & Red fescue grass grow since the salt marsh is only submerged one or twice a year.

Coastal Vegetation

Rocks and sediment play a very important role in influencing the shape of the coastal landscape.

However, vegetation is essential in **stabilising** any landforms from further change.

Vegetation helps to stabilise coastal sediment in many ways:

- **Roots** of plants bind soil together which helps to reduce erosion
- When completely submerged, plants provide a **protective layer** for the ground and so the ground is less easily eroded
- Plants reduce the **wind speed**at the surface and so less wind erosion occurs

Sand Dunes

Sand dunes occur when **prevailing winds blow sediment to the back of the beach** and therefore the formation of dunes requires large quantities of sand and a large tidal range. This allows the sand to dry, so that it is light enough to be picked up and carried by the wind to the back of the beach. Frequent and strong onshore winds are also necessary. The dunes develop as a process of a vegetation succession:

- Pioneer species such as **sea rocket** are resistant and able to survive in the salty sand, with its roots helping to bind the dunes together
- **Decaying organic matter adds nutrients and humus** (organic material comprised of decaying plant and animal matter) to the soil allowing marram grass to grow
- Larger plants are able to colonise the area and the **climatic climax** occurs when trees are able to colonise the area

This leads to a dune structure involving different types of dunes:

- **Embryo Dunes** – Upper beach area where sand starts to accumulate around a small obstacle (driftwood, wooden peg, ridge of shingle)
- **Yellow Dunes** – As more sand accumulates and the dune grows, vegetation may develop on the upper and back dune surfaces, which stabilises the dune. The tallest of the dune succession
- **Grey Dunes** – Sand develops into soil with lots of moisture and nutrients, as vegetation dies, enabling more varied plant growth
- **Dune Slack** – The **water table** rises closer to the surface, or water is trapped between hollows between dunes during storms, allowing the development of moisture-loving plants (e.g. **willow grass**)
- **Heath and Woodland** – Sandy soils develop as there is a greater nutrients content, allowing for less brackish plants to thrive. Trees will also grow (willow, birch, oak trees) with the coastal woodland becoming a natural windbreak to the mainland behind

Estuarine Mudflats and Saltmarshes

Deposition occurs in river estuaries because when the flow of water from the river meets with the incoming tides and waves from the sea, causing **water flow to virtually cease**, so the water can no longer carry its sediment in suspension. They may also occur in sheltered areas such as **behind a spit** or other areas where there are **no strong tides or currents** to prevent sediment deposition and accumulation.

As most of the sediment is small, this leads to a **build up of mud**, which over time builds up until it is above the water level. **Deposition occurs as a result of flocculation**. Pioneer plants colonise this area, leading to more sediment becoming trapped. This colonises the transition zone between high and low tide. A **meadow** is formed as sections of the salt marsh rise above the high tide level, leading to the **climatic climax of the vegetation succession** when trees begin to colonise the area.

Stability of Depositional Landforms

Depositional landforms consist of **unconsolidated sediment** making them vulnerable to change. During major **storms** large amounts of sediment can be eroded or transported elsewhere, removing a landform from one region of the sediment cell. Depositional landforms rely on a **continuous supply** of sediment to balance erosion, which may see some landforms changed as their **dynamic equilibrium shifts**.

Sea Level Change

Sea levels change in short-term period such as day-to-day or minute to minute due to factors such as **high tide and low tide**,**wind strength** and **changes in wind direction** or changes in **atmospheric pressure** (the lower the pressure, the higher the sea levels). Sea level change also occurs over long-term periods, leading to the formation of various coastal landforms as a result of the following processes:

Isostatic Change

Isostatic change occurs when the **land rises or falls relative to the sea** and is a **localised change**. Isostatic sea level change is often a result of**isostatic subsidence**(glaciers weigh down the land beneath, and so the land subsides). When the glaciers melted, this has lead to **isostatic recovery** and the coastline to **rebound and rise again** in the areas that were covered by ice. In the UK, this has caused a see-saw effect. Scotland and the north-west of England are **rising at around 1.5mm per year** as they were previously covered by glaciers, but this has caused the land in the south-east to **subside around 1mm a year**. This links into water and carbon cycles and glaciation units. In some areas of the Mediterranean, some historical ports have been submerged and other raised above the current sea level as a result of this process

Tectonic activity (such as **earthquakes** and **volcanic eruptions**) may cause land subsidence, therefore causing isostatic sea level change. This was seen in the 2004 Indian Ocean earthquake, which caused the city of **Bandeh Aceh to sink permanently by 0.5m**. (This links to the Hazards section of Geography).

Eustatic Change

Eustatic change affects sea level across the whole planet. You can remember this using***E**ustatic affects **E**verywhere*. **E**ustatic change may be due to**thermal expansion/contraction** or changes in glacial processes. Thermal expansion is the process of water expanding when it gets warmer, and so the volume of water increases leading to rising sea levels. In the last ice age, **sea levels were over 100m lower than they are currently** due as the water was stored in large ice caps as the majority of precipitation fell as snow. When the ice caps melted, this lead to rising sea levels. As a result of global warming, both processes are acting to increase sea levels with the **IPCC predicting sea level increases for 0.3m - 1.0m by 2100**. In Miami, they are currently facing significant problems, with much of the coastal strip flooding regularly during high tides as a result of rising sea levels.

Emergent Coastal Landforms

Where the land has been raised in relation to the coastline, landforms such as **arches, stacks and stumps** may be preserved. **Raised beaches** are common before cliffs which are also raised (**relic cliffs**), with wave-cut notches and similar features proof of historical marine erosion.

Submergent Coastal Landforms

Landforms of submergence occur when the **sea level rises or the coastline sinks** in relation to the sea. An easy way to imagine the effects of rising sea levels is to picture a mountainous area close to the coast and then imagine sea level rising by around 100m leading to some of the valley's being flooded. Rising sea levels leads to the following landforms:

Rias: Rias are formed when rising sea levels**flood narrow winding inlets and river valleys**.

They are **deeper at the mouth of the inlet**, with the **water depth decreasing further inland**.

Fjords: Fjords are formed when rising sea levels **flood deep glacial valleys to create natural inlets and harbours**. Fjords can be found across the world though in some countries such as New Zealand they may be referred to as sounds. They are **deeper in the middle section than they are at the mouth**, with the shallower section identifying where the glacier left the valley.

Dalmatian Coasts: This type of coastline occurs when**valleys running parallel to the coast become flooded** as a result of sea level change. This leaves a **series of narrow, long and rugged islands** and the best examples can be seen in Croatia. They may also be referred to as Pacific coasts.

Contemporary Sea Level Change

Since records began around 20,000 years ago, sea levels have always been rising from 120m below the levels which they are now at today. The graph clearly shows that sea level increase **slowed around 8,000 years ago**, and**levelled at the current height around 3000 years ago**.

Since 1880 and the industrial revolution, **sea levels have increased by around 235mm**. That may not sound significant, but it is **enough to overwhelm some sea defences**, when**combined with higher than expected storm surges**. It also affects the drainage system in coastal cities increasing the flooding risk.

The **International Panel on Climate Change (IPCC)** predicts that sea levels may rise between **0.3 - 1.0m by 2100** and the graph shown on the left shows the **different models and climate predictions** that they have created. This could **cause aquifers to be polluted in low-lying atoll islands** (coral reefs protruding from the sea) affecting the residents who live in them. It may also **inundate many coastal cities** and significantly increase the risks from tropical storms and Tsunamis. In some areas turning the coastal area into recreational land as a method of **adaptation** to climate change is proving to be a popular option.

Risks to Coastal Environments

Coastalisation is the process by which the **coast is being developed and people are moving to the coast**, increasing the number of people at risk from marine related environmental activity. It may be a **by-product of urbanisation** in which people are **moving to cities** as the **majority of large cities are coastal**. This is not a required term for the specification, but may be useful to include when discussing the risks of sea level change in future.

Storm Surges

A **storm surge is a result of the low pressure** created by large weather events such as tropical storms. It raises the sea level and therefore poses a significant flooding risk as it has the **potential to inundate flood defences**, making the other impacts of a tropical storm more potent. The risk from a storm surge may be exacerbated by:

- **Removing Natural Vegetation**: Mangrove forests are the most productive and complex ecosystem in the world. Mangroves also **provide protection against extreme weather events such as cyclones** which are very common in the Bay of Bengal. However, due to pressure for land space, **many mangrove forests are destroyed** to make space for tourism, local industry, or housing. Mangroves are an excellent method of coastal management as they can also **keep up with global sea level rises of up to eight times the current rate**. They**trap sediment leading to accretion** on the coastline, helping protect communities from the potential impacts of climate change
- **Global Warming**: As the surface of oceans get warmer, it is**predicted that the frequency and intensity of storms will increase**, and so the **severity of storm surges and flooding is also expected to increase** - there is **no agreed scientific consensus**

Consequences for Communities

Some areas of the coast may have significantly **reduced house and land prices**(as the area becomes known to be at significant risk) leading to **economic loss for homeowners and local coastal economies**. In the UK, many insurers don't provide home insurance to people living along coastlines that are at extreme risk of erosion or storm surges.

Storm surges also damage the environment by **destroying plant successions** and **damaging many coastal landforms**. Depositional landforms, due to their**unconsolidated nature**, may potentially be destroyed as was seen in 2013, when the spit 'Spurn Head' was partially destroyed by a large storm surge. If depositional features are destroyed then erosion may occur more quickly closer to the cliff face, which can increase the risk of collapse of cliffs and threats to land owners.

Environmental Refugees

Globally, **more than 1 billion people live on coasts that are at risk from coastal flooding** and **50% of the world's population currently live within 60km** of the coast (and this figure is increasing daily). Around **75% of all of the world's large cities are coastal**.

As storm surges and erosion along some coastlines are predicted to increase, so too is the volume of environmental refugees displaced internally or internationally. People may lose their homes, way of life and culture as they are **forced to migrate to avoid the rising sea levels** and the rising risk of flooding. In low-lying countries such as Bangladesh where the coastline is made up of clay sands many people may be displaced due to the potential impacts of climate change on the coast.

Coastal Management

Approaches to coastal management have changed greatly due to new knowledge and research about the positive and negative impacts that management can have on a coastline. New approaches have been created, though the specific strategies used can mostly be classified into two types - **hard and soft engineering**. Hard and soft engineering**both relate to traditional approaches to coastal management**. 'There is erosion occurring in this area, so lets build a beach or sea wall to reduce the erosion'. These approaches are a **direct solution** to the problem that is occurring.

Hard Engineering

Hard engineering is a very traditional and in many ways outdated approach to coastal management and it involves **man made structures that aim to prevent erosion**. They are often very effective at preventing erosion in the desired area, but are high cost and have a **significant environmental impact due to the use of concrete** and other man-made materials. By reducing erosion in one area of the coastline, they may act to exacerbate erosion elsewhere. Therefore their only impact is to change where erosion is occurring.

Offshore Breakwater

- Description: Rock barrier which forces waves to break before reaching the shore
- Effective at reducing waves' energy
- Visually unappealling
- Navigation hazard for boats
- Can interfere with LSD

Groynes

- Description: Timber or rock protrusions that trap sediment from LSD
- Builds up beach, protecting cliff and increasing tourist potential
- Cost effective
- Visually unappealling
- Deprives areas downwind of sediment increasing erosion elsewhere

Sea Walls

- Description: Concrete structures that absorb and reflect wave energy, with curved surface
- Effective erosion prevention
- Promenade has tourism benefits
- Visually unappealing
- Expensive to construct and maintain
- Wave energy reflected elsewhere, with impacts on erosion rates

Rip Rap (Rock Armour)

- Description: Large rocks that reduce wave energy, but allow water to flow through
- Cost effective
- Rocks are sourced from elsewhere, so do not fit with local geology
- Pose a hazard if climbed upon

Revetments

- Description: Wooden or concrete ramps that help absorb wave energy
- Cost effective
- Visually unappealling
- Can need constant maintenance, which creates an additional cost

Soft Engineering

Unlike hard engineering, soft engineering **aims to work with and complement the physical environment** by using natural methods of coastal defence. They are useful for protecting against sea-level change as well as coastal erosion.

Beach Nourishment

- Description: Sediment is taken from offshore sources to build up the existing beach
- Builds up beach, protecting cliff and increasing tourist potential
- Cost effective and looks natural
- Needs constant maintenance
- Dredging may have consequences on local coastal habitats

Cliff Regrading and Drainage

Description: Reduces the angle of the cliff to help stabilise it. A steeper cliff would be more likely to collapse

Cost effective

Cliff may collapse suddenly as the cliff is drier leading to rock falls which pose a hazard

May look unnatural

Dune Stablisation

- Description: Marram grass planted. The roots help bind the dunes, protecting land behind
- Cost effective and creates an important wildlife habitat
- Planting is time consuming

Marsh Creation

- Description: Type of managed retreat allowing low-lying areas to flood
- Creates an important wildlife habitat
- Farmers lose land and may need compensation as a result

Cost-Benefit Analysis (CBA)

This is an analysis that is **carried out before any form of coastal management takes place**. The **expected cost** of the construction, demolition, maintenance etc. of a coastal management plan is then compared to the **expected benefits** of a scheme which may include the value of land, homes and businesses that will be protected. Cost and benefits may be **tangible** (monetary value) or **intangible** (other effects such as visual impact). According to **DEFRA's**1:1 analysis, the **expected benefits have to out way the costs** for a project to go ahead.

Sustainable Coastal Management

As the negative impacts of many coastal management schemes have become clear, **sustainable integrated approaches** are becoming more widely used. It is key that you have a good understanding of these methods as they are a topic that you may include in 20 mark question answers. They are **holistic strategies**, meaning that it is recognised that all of the different sections of the coastline are interlinked and function together as a whole. Smaller sections are not considered separately, unlike with traditional methods. Aspects of managing coast in a sustainable way include:

- **Managing natural resources** like fish, water, farmland to ensure **long term productivity**
- Ensuring that there are **new jobs**for people who may face unemployment as a result of protection measures. E.g. if a decision is taken that fishing needs to decrease as currently it is above sustainable levels
- **Educating communities** about the need to adapt and how to protect the coastline for future generations
- **Monitoring coastal changes** and then using **adaptation or mitigation** as a response to the observed changes
- Ensure that **everybody is considered** when changes are proposed and then adopted

Integrated Coastal Zone Management (ICZM)

ICZM is one method of sustainable coastline management. Large sections of coastline (often **sediment cells**) are managed with **one integrated strategy**. Management occurs**between different political boundaries**, which is both beneficial and problematic as decision making is likely to be a longer process. In the UK, different councils will have to work and manage coasts together:

- The ICZM recognises the importance of the coast for **people's livelihoods**
- The ICZM recognises that coastal management must be **sustainable** whereby **economic development is important**, but is **not prioritised over protection of the coastal environment**
- The ICZM **must involve all stakeholders**, plan for the long term and try to work with natural process and not against them
- It recognises that **sediment eroded in one location may form a protective beach elsewhere** and therefore a decision to protect one coastal community may not outweigh the disadvantages of exposing another community to increased erosion
- In 2013 the EU adopted a new initiative which promotes the use of ICZM's across all of Europe's coastlines, which recognised the benefits of the ICZM strategy

Shoreline Management Plans (SMPs)

For each sediment cell in the UK, an SMP has been created to help with coastline management. Each SMP **identifies all of the activities, both natural and human** which occur within the coastline area of each sediment cell. The sediment cells are considered to be closed for the purposes of management, although in reality there will be some exchanges between the different sediment cells. SMP's are **recommended for all sections of English and Welsh coastlines by DEFRA** (governing body responsible for majority of environmental protection in the UK). Four options are considered for each stretch of the coastline:

- **Hold the Line**: Defences are used to maintain the current position of the shoreline
- **Managed Realignment/Retreat**: Defences and engineering techniques are used to allow the coastline to advance inland and create its own natural defences such as salt marshes
- **Advance the Line**: Defence are built to try and move the shoreline seawards, potentially to protect an important population centre or tourist amenity
- **No Active Intervention**: The coastline is exposed to natural processes

Different factors are considered when choosing a management option:

- **Economic value of assets** that could be protected. A known area of gas reserves may be protected, though a caravan park may not be
- The technical feasibility of **engineering solutions**. A sea wall may not be possible for a certain location
- The **ecological and cultural value** of land. For example, it may be desirable to protect historic areas and **Sites of Special Scientific Interest (SSSI)**

Conflict Over Policy Decisions

When considering coastal management their may be **winners and losers**. Winners can be classified as those who benefit **economically**(e.g. their homes and businesses are protected), **environmentally** (e.g. habitats are protected) and **socially**(community ties still remain in place, people still have jobs so less stress and worrying). **Losers** can be classified as those who lose their property, lose a job, or have to relocate elsewhere. Communities and homeowners have a **strong attachment to a place** so losing their properties and their social networks is a great loss. This will make them **financially worse off**and many people may feel lonely if forced to move and may be angered if areas are not chosen to be protected. Business owners may be angered if nothing is done to protect the area in which they have their business, which could cause them to lose profitability and regular clients. **DEFRA funding has been reduced** by the central government since 2010 so they cannot invest in coastal management in all areas and now have to prioritise their funding in the most important locations. Some people may feel aggrieved by this.

The Impact of Coastal Management on Sediment Cells

Coastal management has a variety of impacts on sediment cells and any form of intervention will cause some kind of impact. **Installing a sea wall would reflect wave energy downdrift** increasing wave energy and erosion elsewhere on the coastline. **Less erosion occurs in these areas with the sea wall**, so there is also**less sediment in the areas with increased wave energy**.**Less sediment reduces the beach size**, so the **cliff is more exposed to erosion** from the higher energy waves. Building groynes has the same effect on downdrift areas as **longshore drift** can no longer transport sediment away from one stretch of coastline.

Coastal Management Examples

There are many different management strategies used by national governments to reduce erosion, stop coastline recession or to increase their beach. However, some strategies are more successful than others and not all strategies are sustainable.

US East Coast Barrier Islands

Characteristics

- The East coast of the USA is dominated by barrier islands. These barrier islands can be found from Florida in the South all the way up to Connecticut in the North.
- Made of sand, there are 23 shifting barrier islands which each create lagoons behind them.
- There is currently ongoing debate about how these islands have formed.

Conservation

- Barrier islands are a form of defence as they dissipate wave energy and lead to waves breaking further out and so the waves hitting land are less destructive. Since the East Coast is repeatedly hit by hurricanes (forming in the Atlantic Ocean), the barrier islands are an important natural defence against storm surges.
- Most islands are open for low-impact tourism activities – hiking, fishing, bird watching. However, many restrictions are put into place to protect the nesting birds and shellfish.
- No permanent residence is permitted on the barrier islands. A previous beach resort and settlements have all been washed away, due to the shifting nature of the barrier islands.

Tuvalu

Tuvalu is a low-lying Pacific Island, which is becoming increasingly vulnerable as eustatic sea level rise continues. Most areas in Tuvalu are only 1-2m above sea level with the highest point only 4.5m above sea level. Its population have had to mitigate to the changing coastal environment or forced to migrate to New Zealand.

Problems & Mitigation Solutions

- More tropical cyclones are occurring, due to an increase in sea temperatures
  - Residents must construct cyclone shelters to avoid injury
- Flooding of low-lying settlements has resulted in the drowning of cattle
  - Farmers are forced to move further inland. May consider importing food to avoid hunger.
- Salt water encroachment has led to crop failures and loss of local water sources
  - Residents grow staple crops in concrete plots and must travel further inland to access a freshwater supply to drink from and water their crops.

Migration

Some cannot afford to mitigate or are fed up of losing cattle, crops and economic assets. Therefore, there is a growing number of environmental refugees from Tuvalu who must live in New Zealand to survive. This can result in a better standard of living, but cultural tensions can arise between the migrants and locals.

The Maldives

97% of inhabited islands in the Maldives are experiencing erosion and, as sea levels rise, an increased risk of flooding. For some time, any coastal management by the local government has not been sustainable since:

- Isolated islands are ignored as most money is spent on the capital city Male
- Sustainable management of traditional income sources (e.g. fishing) are overlooked in favour of protecting tourist and urban developments.

NGO Intervention

- NGOs have encouraged sustainable living and educated locals to change The Maldives' situation. They have been more successful than the government because they have involved and centred their efforts around the locals, rather than tourists (public participation).
- The organisation Mangroves for the Future (MMF) is educating communities about the importance of coastal mangroves as a defence against erosion and flooding, hence reducing their deforestation.
- The Global Environment Facility (GEF) has provided small grants to locals on the islands in order for them to help develop sustainable and organic farming.

Deltawerken Project – Netherlands

This is a hard engineering project which began following the 1953 Storm Surge drastically damaged the Netherlands. 1800 people died during the storm surge as well as the flooding of 10% of the Netherlands' farmland, 40000 building were damaged and a further 10,000 destroyed.

The Scheme

- A series of dams and gates constructed along rivers to control the flow of water during a storm surge.
- It also aims to reduce the length of the coastline exposed to the sea whilst maintaining safe access to the North Sea for shipping.

Sustainability & Longevity

- The cost of the project was $5 billion. However, due to sea level rise, the Dutch will need to spend more than $1 billion annually to maintain and improve defences against the rising sea levels.
- It has allowed for 4 million people to live below normal sea level, hence easing the Netherlands' population growth.
- The dams have allowed for new roads and transport connections, which drastically reduce journey times and reduce isolation for settlements.
- A number of nature reserves were lost during construction, though some have been replaced during the project.

Sample Assessment Questions

1. **Explain how the sediment cell concept contributes to the understanding of coastal systems (9 marks)**

2. **Evaluate the contribution that changes in sea level make to the formation of coastal landscapes (9 marks).**

Mark schemes

1. Explain how the sediment cell concept contributes to the understanding of coastal systems (9 marks)

Note for answer

The indicative content below is not prescriptive and candidates are not required to include all of it. Other relevant material not suggested below must also be credited. Relevant points may include:

• the processes of erosion, transportation and deposition within the coastal margin is largely contained in sediment cells or littoral cells so coastal systems are largely self-contained
• there are both onshore and offshore processes which contribute to the sediment cells, influencing the size of store
• there are 11 large sediment cells in England and Wales
• a sediment cell is generally thought to be a closed system, which suggests that no sediment is transferred from one cell to another
• the boundaries of sediment cells are determined by the topography and shape of the coastline, with a major role played by peninsulas
• these act as natural barriers that prevent the transfer of sediment from one cell to another
• in reality, however, it is unlikely that sediment cells are fully closed with variations in wind direction and tidal currents, meaning that there is some transfer between cells. Fine material is most likely to be transported between sediment cells
• there are also many sub-cells of a smaller scale existing within the major cells.

2. Evaluate the contribution that changes in sea level make to the formation of coastal landscapes (9 marks).

Notes for answers

The indicative content below is not prescriptive and candidates are not required to include all of it. Other relevant material not suggested below must also be credited. Relevant points may include:

AO1

• coastal landscapes are made up of an assemblage of landforms that have developed over time – some in the short term, e.g. beach cusps, some over a much longer term, e.g. headland and bays
• coastal landscapes are affected by the nature of the coastline before sea-level change, e.g. whether it is glaciated or not, which will affect the rate of erosion and deposition
• the topography of the coastline is important – steep as opposed to low-lying coastal regions
• the disposition of rocks, concordant or discordant, will affect the development of particular landforms
• the direction of sea-level change (i.e. positive or negative) will have significant impact on the type of landscape that develops

AO2

• submergence of coasts results from a relative rise in sea level and results is a variety of flooded valleys changing the shape and form of coastlines and, inevitably the landforms
• emergence of coasts results from a relative fall in sea level, resulting in a variety of features such as offshore bars, raised beaches and fossil cliff lines.
• coastal landscapes are a consequence of a complex history of relative change so both emergent and submerged features can be found in the same areas, e.g. Scotland with fjords and raised beaches
• sea-level change is both short term and long term with short-term changes involving a tidal range, e.g. between spring and neap tides, that has a significant impact on landform formation. Short-term sea-level changes create daily changes to some coastal landforms, especially beaches
• storm surges will also increase sea levels in the short term and have a significant impact on the creation of landforms, which can be dramatic, e.g. Hurricane Katrina
• longer-term changes are a result of a complex combination of eustatic, isostatic and sometimes tectonic movements which result in landscape changes, e.g. post-glacial sea-level rise
• sea-level changes both short term and long term suggest that coastal landforms are in dynamic equilibrium with the processes that create them.

HAZARDS

1.1 The global distribution of tectonic hazards can be explained by plate boundary and other tectonic processes.

- The global distribution and causes of earthquakes, volcanic eruptions and tsunamis.
- The distribution of plate boundaries resulting from divergent, convergent and conservative plate movements (oceanic, continental and combined situations).
- The causes of intra-plate earthquakes, and volcanoes associated with hot spots from mantle plumes.

1.2 There are theoretical frameworks that attempt to explain plate movements.

- The theory of plate tectonics and its key elements (the earth's internal structure, mantle convection, palaeomagnetism and sea floor spreading, subduction and slab pull).
- The operation of these processes at different plate margins (destructive, constructive, collision and transform).
- Physical processes impact on the magnitude and type of volcanic eruption, and earthquake magnitude and focal depth (Benioff zone).

1.3 Physical processes explain the causes of hazards

- Earthquake waves (P, S and L waves) cause crustal fracturing, ground shaking and secondary hazards (liquefaction and landslides).
- Volcanoes cause lava flows, pyroclastic flows, ash falls, gas eruptions, and secondary hazards (lahars, jökulhlaup).
- Tsunamis can be caused by sub-marine earthquakes at subduction zones as a result of sea-bed and water column displacement.
- Tropical storms are caused by warm seas, the Coriolis effect and low shear pressure and can cause storm surges, coastal flooding, high winds and landslides.
- Wildfires are caused by natural and human factors including lightning strike and arson.

1.4 Disaster occurrence can be explained by the relationship between hazards, vulnerability, resilience and disaster.

- Definition of a natural hazard and a disaster, the importance of vulnerability and a community's threshold for resilience, the hazard risk equation.
- The Pressure and Release model (PAR) and the complex inter-relationships between the hazard and its wider context.
- The social and economic impacts of tectonic hazards (volcanic eruptions, earthquakes and tsunamis) on the people, economy and environment of contrasting locations in the developed, emerging and developing world.

1.5 Hazard profiles are important to an understanding of contrasting hazard impacts, vulnerability and resilience.

- The magnitude and intensity of hazards is measured using different scales (Mercalli, Moment Magnitude Scale (MMS), Volcanic Explosivity Index (VEI) and Saffir Simpson Scale).
- Comparing the characteristics of earthquakes, volcanoes, tsunamis, storms and wildfires (magnitude, speed of onset and areal extent, duration, frequency, spatial predictability) through hazard profiles.
- Profiles of earthquake, volcano, tsunami, storm and wildfire events showing the severity of social and economic impact in developed, emerging and developing countries.

1.6 Development and governance are important in understanding disaster impact and vulnerability and resilience.

- Inequality of access to education, housing, healthcare and income opportunities can influence vulnerability and resilience.
- Governance (P: local and national government) and geographical factors (population density, isolation and accessibility, degree of urbanisation) influence vulnerability and a community's resilience.
- Contrasting hazard events in developed, emerging and developing countries to show the interaction of physical factors and the significance of context in influencing the scale of disaster.

1.7 Understanding the complex trends and patterns for disasters helps explain differential impacts.

- Tectonic disaster trends since 1960 (number of deaths, numbers affected, level of economic damage) in the context of overall disaster trends. (6); research into the accuracy and reliability of the data to interpret complex trends
- Tectonic mega-disasters can have regional or even global significance in terms of economic and human impacts. (ü 2004 Asian tsunami, 2010 Eyafjallajokull eruption in Iceland (global independence) and 2011 Japanese tsunami (energy policy))
- The concept of a multiple-hazard zone and how linked hydrometeorological hazards sometimes contribute to a tectonic disaster (the Philippines).

1.8 Theoretical frameworks can be used to understand the predication, impact and management of hazards.

- Prediction and forecasting (P: role of scientists) accuracy depend on the type and location of the tectonic hazard.
- The importance of different stages in the hazard management cycle (response, recovery, mitigation, preparedness). (P: role of emergency planners)
- Use of Park's Model to compare the response curve of hazard events, comparing areas at different stages of development.

1.9 Hazard impacts can be managed by a variety of mitigation and adaptation strategies, which vary in their effectiveness.

- Strategies to modify the event include land-use zoning, hazard – resistant design and engineering defences as well as diversion of lava flows. (P: role of planners, engineers)
- Strategies to modify vulnerability and resilience include hi-tech monitoring, prediction, education, community preparedness and adaptation. (F: models forecasting disaster impacts with and without modification).
- Strategies to modify loss include emergency, short and longer term aid and insurance (P: role of NGOs and insurers) and the actions of affected communities themselves.

Hazards Glossary - AQA Geography A-Level

Accretion Wedge- The accumulation of material at the point of subduction.

Aseismic Buildings- Buildings designed to withstand or minimise destruction during an earthquake.

Asthenosphere- The upper mantle layer of the Earth. It is semi-molten and approximately 2000km wide.

Ash- Fine particles and dust ejected during an eruption, which can remain airborne as clouds or accumulate on the ground.

Continental Crust- Crust that forms the continents of the lithosphere, on average 35km thick.

Continental Drift- The movement of tectonic plates, due to varying weights of crust. It was originally thought that convection currents caused the movement of the plates, but now slab pull is thought of as the primary driving force.

Controlled Burning- Intentionally burning vegetation with the aim of reducing fuel available for a wildfire and disrupting the fire's path.

Convection Currents- The circulation of magma within the mantle (asthenosphere). Magma is heated by radioactive processes in the core and cools at the surface, and so circulates between the two places.

Coriolis Effect- The Earth's spin affects the movement of air masses and winds, depending on a location's latitude.

Crown Fires- Wildfires that burn the entirety of a tree (from top to bottom), often the most destructive and dangerous type of wildfire.

Degg's Model- This model shows that a hazard becomes a disaster if it affects a vulnerable population.

Epicentre– The point on the surface, directly above the earthquake's origin.

Fatalism- The belief that hazards are uncontrollable, so any losses should be accepted and mitigation is unnecessary.

Fire Breaks- The felling of trees and clearing vegetation to create a gap to disrupt a wildfire's path.

Focus– The place in the crust where the pressure/seismic energy is released.

Ground Fires- Wildfires that burn through the peat and vegetation beneath the surface, making them slow but difficult to extinguish.

Hazard Management Cycle- The sequence of governance of a natural hazard: preparedness, response, recovery, and mitigation.

Hot Spot- Volcanoes found away from the plate boundary, due to a magma plume closer to the surface.

Jokulhaup- A sudden glacial flood caused by a glacier on top of or near a volcano melting due to the heat from the eruption.

Lahar- A flow of mud and debris.

Lithosphere- The upper crust of the Earth (average thickness = 100km).

Love Waves- A surface earthquake wave with horizontal displacement.

Mid-Ocean Ridge- Parting oceanic plates at a constructive plate boundary creates a ridge, with new land at the base of the oceanic valley.

Moment Magnitude Scale- A measure of an earthquake's energy released, considered the most accurate measure.

Oceanic Crust- Crust, usually thinner than continental crust, that forms the sea floor. It is on average 7km thick.

Paleomagnetism- The alternating polarisation of new land created. As magma cools, the magnetic elements within will align with the Earth's magnetic field, which can alternate over thousands of years.

Park's Model- A model describing the decline and recovery of a country over time, following a natural disaster.

Partial Melting- Elements within the lithosphere have different melting points, and so rock is partially melted, partially solid.

Primary Waves- An earthquake wave causing compressions within the body of rock.

Pyroclastic Flow- A mixture of gases and rock fragments, at high temperatures travelling at rapid speeds.

Rayleigh Waves- A surface earthquake wave causing both horizontal and vertical displacement.

Richter Scale- A logarithmic measure of earthquake's intensity.

Secondary Waves- An earthquake wave causing vertical displacement within the body of rock.

Seismic Waves- The energy released during an earthquake, in the form of Primary, Secondary, Love and Rayleigh Waves.

Slab Pull- The force contributing to the movement of tectonic plates. Slab pull is due to the weight of the plate.

Subduction- Oceanic plate is forced below continental plate, due to the oceanic plate being more dense than the continental plate.

Surface Fires- Wildfires that only burn the leaf litter, and so are the easiest kind to extinguish.

Tropical Storm- A low pressure system of spiralling winds (due to the Coriolis Effect). Also called hurricanes, cyclones, and typhoons depending on the location they occur in.

Tsunami- Initial vertical water displacement (often from a submarine earthquake) creates waves, with large destructive power.

Volcanic Explosivity Index (VEI) - A measure of the magnitude of a volcano's eruptions.

Volcanic Island Arc- A series of volcanoes (often in the shape of an arc) that are formed consecutively, as a tectonic plate moves across a magma plume.

Wadati-Benioff Zone- A region of the subducting plate, most affected by pressure and friction, where most destructive margin earthquakes originate.

Wildfire- A large, uncontrolled fire that quickly spreads through vegetation.

Hazards

The Concept of Hazard

A **hazard** is a potential threat to **human life** and **property** caused by an event. Hazards can be human caused or occur naturally (natural hazards). An event will only become a **hazard** when it is a threat to **people**. E.g. if a hurricane hit an uninhabited desert island it would not be classed as a hazard.

Hazards should not be confused with **natural disasters**. A disaster will only occur when a **vulnerable population**(one that will be significantly disrupted and damaged) is exposed to a hazard. Degg's model is a good representation of this concept. If the population is not vulnerable, the hazard will not have a significant effect, thus the event will not be **disastrous**.

There are three major types of geographical hazard:

Geophysical	**Atmospheric**	**Hydrological**
hazards caused by **land processes**, majorly tectonic plates (e.g. volcanoes)	hazards caused by **atmospheric processes** and the conditions created because of these, such as weather systems (e.g. wildfires)	hazards caused by **water bodies** and **movement** (e.g. floods)

Hazards can also be classed as a mixture of these geographical processes. For example, a tropical storm could be classed as an hydrological-atmospheric hazard as both of these processes contribute to the hazard. Hazards that are both atmospheric and hydrological are sometimes classed as **hydrometeorological hazards**.

Hazard Perception

People have different **viewpoints** of how **dangerous** hazards are and what **risk** they pose. These perceptions are dependent on **lifestyle factors** which include **economic**and**cultural**elements. Note that these are the economic and cultural factors of **individual people** rather than an entire population's views.

Wealth - The financial situation of a person will affect how they **perceive** hazards. Wealthier people may perceive a hazard to be **smaller** as they are less**vulnerable** (e.g. they have the ability to evacuate with transport access, build stronger houses etc.) However, wealthier people may also view a risk as **greater** as there is more risk of**property damage** and **financial loss**than someone less wealthy. This is, of course, dependent on the person.

Experience - Someone who has**experienced more hazards** may be more likely to understand the **full effects** of a hazard. There are also studies suggesting that people who have experienced hazards are likely to have an **optimistic** and **unrealistic** outlook on future hazards, almost like a **'lightning never strikes the same place twice'** mentality. R. Kates describes this in his journal.

Natural Hazard in Human Ecological Perspective: Hypotheses and Models, 1971.

Education -A person who is more educated about hazards may understand their full **effects** on people and how **devastating** they can be and have been in the past. Those who are less educated may not understand the full extent of a hazard and may not evacuate etc.

Religion and beliefs - Some may view hazards as put there by **God** for a reason, or being part of the **natural cycle of life** etc. so may not perceive them to be negative. In contrast, those who believe strongly in **environmental conservation** may perceive hazards to be a huge risk to the natural environment, especially hazards that are becoming more frequent due to global warming.

Mobility - Those who have**limited access** to escape a hazard may perceive hazards to be greater threats than they are. Whether they are in a **secluded location**, or if they are impaired with a **disability**or **illness**, those who cannot easily leave an area quickly may feel more at risk.

Human Responses to Hazards

Hazards can be responded to in a **passive** way (making no effort to lessen a hazard) or in an **active** way. **Fatalism** is a passive response to a hazard.

- **Fatalism:** The viewpoint that hazards are **uncontrollable** natural events, and any losses should be **accepted** as there is nothing that can be done to stop them.

Active responses to hazards are any strategy used to overall contribute to a lower hazard risk.

- **Prediction:** Using**scientific research** and **past events** in order to know when a hazard will take place, so that **warnings** may be **delivered** and **impacts** of the hazard can be **reduced** . In some cases, hazards may also be**prevented** when predicted early enough (e.g. predicting wildfires from climatic red flags).
- **Adaptation:** Attempting to **live with hazards** by adjusting **lifestyle choices** so that vulnerability to the hazard is lessened (e.g. earthquake proof houses).
- **Mitigation:** Strategies carried out to **lessen the severity of a hazard** (e.g. sandbags to offset impact of flooding).
- **Management: Coordinated strategies** to reduce a hazard's effects. This includes prediction, adaptation, mitigation.
- **Risk sharing:** A form of**community preparedness**, whereby the community **shares the risk** posed by a natural hazard and **invests collectively** to mitigate the impacts of **future hazards**

New Zealand is an example of where risk sharing has worked. As a **multi-hazard** environment, New Zealand is under threat from earthquakes, tsunamis, volcanoes, and weather-related hazards. The cost of these hazards are huge; the Canterbury Earthquake (2010) alone cost the country 20% of it's national GDP. There are now attempts to share the risk by insurance investment, so strategies can be put in place **before** the disasters rather than investing more in a clean up.

Aspects of Hazards and How They Affect Human Responses

Every hazardous event varies in terms of its location, frequency, and strength. These **aspects** of a natural event create different types of hazards, and influence how people respond to these hazards.

Incidence: **Frequency** of a hazard. This is not affected by the strength of a hazard, it is just how often a hazard occurs.

Low incidence hazards may be**harder to predict** and have less **management** strategies put in place, meaning the hazard could be more catastrophic when it does eventually occur. Also, low incidence hazards are usually (but not always) more **intense** than high incidence hazards. For example, there are only **36 recorded earthquakes**since 1500 that were a magnitude of **8.5 or higher**, but **millions of earthquakes** that are too weak to be recorded are thought to happen **every year**.

Distribution: where hazards **occur** geographically.

Areas of high hazard distribution are likely to have a lot of management strategies, and those living there will be **adapted** to the hazardous landscape because it dominates the area more so than in places with low hazard distribution.

Intensity:the **power** of a hazard i.e. how strong it is and how damaging the effects are

Magnitude: the size of the hazard, usually this is how a hazard's **intensity is measured**

High magnitude,**high intensity** hazards will have**worse effects**, meaning they will require more **management**, e.g. more mitigation strategies will be needed to lessen the effects and ensure a relatively normal life can be carried out after the hazard.

Magnitude and intensity are **not** interchangeable terms and it is important that this is recognised. The magnitude is usually **definable** and can be a **number**- this **does not change**. Intensity, however, is the effects on the **person**, and can change dependent on the **distance** from the hazard or the **management strategies** combating high magnitude risks.

An effective way to remember this is through a **television broadcast** analogy. The **magnitude** is the **signal being sent out**and the frequency of the television transmission; the **intensity** is how well it is being **received by the person**. Even if the quality (intensity) on your end is poor and grainy, the broadcast (magnitude) is always going to be on the same frequency.

Level of development: economic development will affect how a place can **respond** to a hazard, so a hazard of the same magnitude may have very different **effects** in two places of contrasting levels of development.

Even if the hazard is identical, an area with a **lower level of development** is less likely to have **effective mitigation strategies** as these are costly. Therefore, the effects of a hazardous event is likely to be much more catastrophic in a less economically developed area.

However, there are many high income countries that are not as **prepared** for natural hazards as they should be, meaning they lack the **management strategies** for an event. This is especially true in **multi-hazard environments** where resources are spread thinly over a variety of hazards.

In **Canada** where **wildfires** have been increasing over the last few years (as a result of climate change), less **money** and **resources** have been available for **earthquake** and **tsunami preparation**. Even detailed evacuation routes and tsunami sirens are not available in popular tourist beaches such as Vancouver Island or Pacific Rim National Park. **Text message systems** are available to act as a warning system to suggest people to evacuate, but many people switch their phones off at night, reducing the effectiveness.

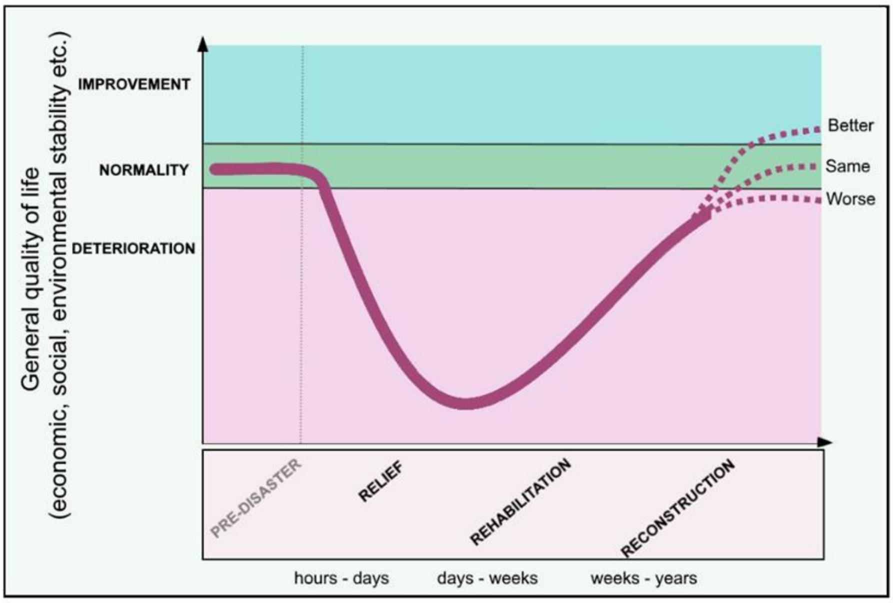
Overall, level of development may not have the biggest part to play in a hazard, and it is more to do with how these countries use their development for mitigation.

The Park Model

The Park Model is a **graphical representation** of human responses to hazards. The model shows the steps carried out in the **recovery** after a hazard, giving a rough indication of **time frame**.

- The **steepness** of the curve shows how **quickly** an area **deteriorates** and **recovers**.
- The **depth** of the curve shows the **scale** of the **disaster**(i.e. lower the curve, lower the quality of life).

***The Park Model* of Human Response to Hazards**



Stage 1 - Relief

(hours-days)

- **Immediate** local **response** - medical aid, search and rescue
- Immediate appeal for **foreign aid** - the beginnings of global response

Stage 2 - Rehabilitation

(days-weeks)

- **Services** begin to be restored
- **Temporary shelters** and **hospitals** set up
- **Food and water** distributed
- **Coordinated foreign aid** - peacekeeping forces etc.

Stage 3 - Reconstruction

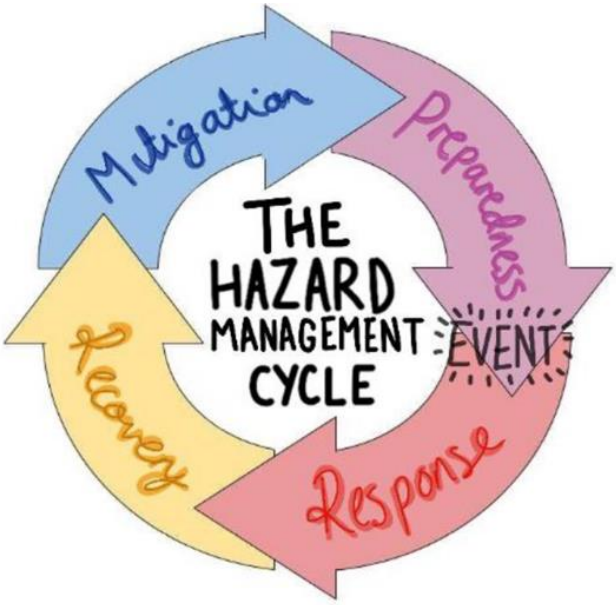
(weeks-years)

- **Restoring** the area to the same or better quality of life
- Area back to **normal** - ecosystem restored, crops regrown
- **Infrastructure** rebuilt
- Mitigation efforts for **future event**

The model also works as a **control line** to compare hazards. An **extremely catastrophic hazard** would have a **steeper curve** than the average and would have a **slower recovery time** than the average, for example. This has been indicated by the blue line.

The Hazard Management Cycle

The Hazard Management Cycle outlines the stages of responding to events, showing how the same stages take place after every hazard.



Preparedness	Response	Recovery	Mitigation
Being **ready** for an event to occur (public awareness, education, training)	**Immediate action** taken after event (evacuation, medical assistance, rescue)	**Long-term responses** (restoring services, reconstruction)	Strategies to **lessen effects of another hazard** (barriers, warning signals developed, observatories)

Evaluating the Effectiveness of Models

Hazard models are useful, but the **unpredictability** of hazards makes the models less effective at accurately representing human responses to hazards. It may be useful to ask some questions when evaluating how effective these models are:

- Can they be **applied** to every hazard? Are some hazards more complicated and require a more **complex model**? It may be useful to apply each of your case studies to these models and see how they compare.
- Does the model take any **aspects of hazards** into account such as **level of development**?
- Is there any **timeframe**? Do the models accurately lay out the time taken for a full response and how this changes due to **aspects of the hazard** such as intensity?
- Could the model be **less vague**/ include more steps that can be applied to all hazards?
- Does the model present hazards **currently**? Are there alterations that could be made to account for hazards affected by **climate change**? Will the model eventually not represent human responses at the time (e.g. could the cycle stop because hazards will occur more frequently than the mitigation strategies will occur)?

Plate Tectonics

Structure of the Earth

Inner core

- Solid ball of iron/nickel
- Very hot due to **pressure** and **radioactive decay** (contains elements such as uranium that give off heat when they decompose)
- This heat is responsible for **Earth's internal energy**, and it spreads throughout

Outer core

- Semi-molten
- Iron/nickel

Mantle	Asthenosphere	Lithosphere
Mainly solid rock, and the rocks are high in silicon. However, the very top layer of the mantle is semi-molten magma, which is known as the **asthenosphere**. The **lithosphere** rests on top.	**Semi-molten** layer constantly moves due to flows of heat called **convection currents**. Movements are powered by **heat from core**. **Lithosphere** above.	Broken up into **plates**. Majority of the lithosphere is within mantle. The top of the lithosphere is the **crust**which is the land and sea we live on.

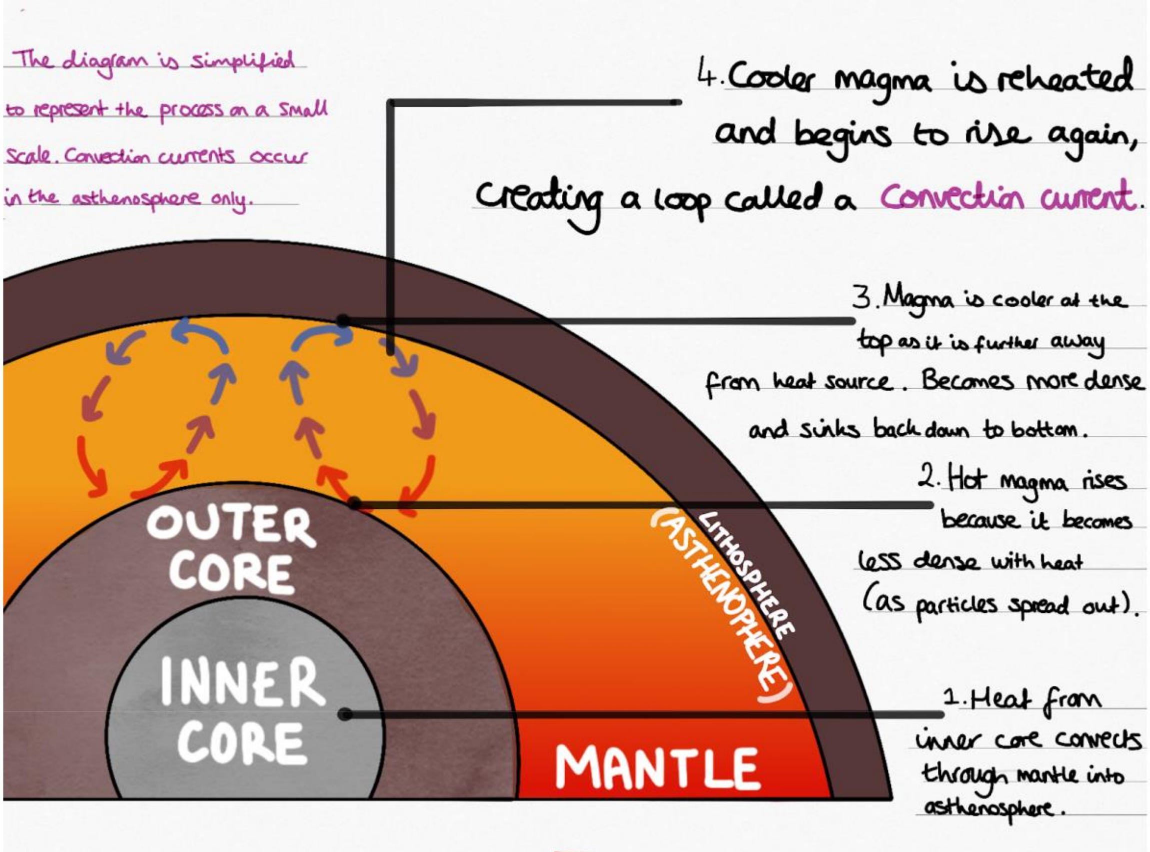
Crust

- The thin top of the lithosphere
- **Oceanic crust** is **dense** and is destroyed by **plate movement, continental crust** is **less dense** and is **not destroyed.**

Plate tectonic theory

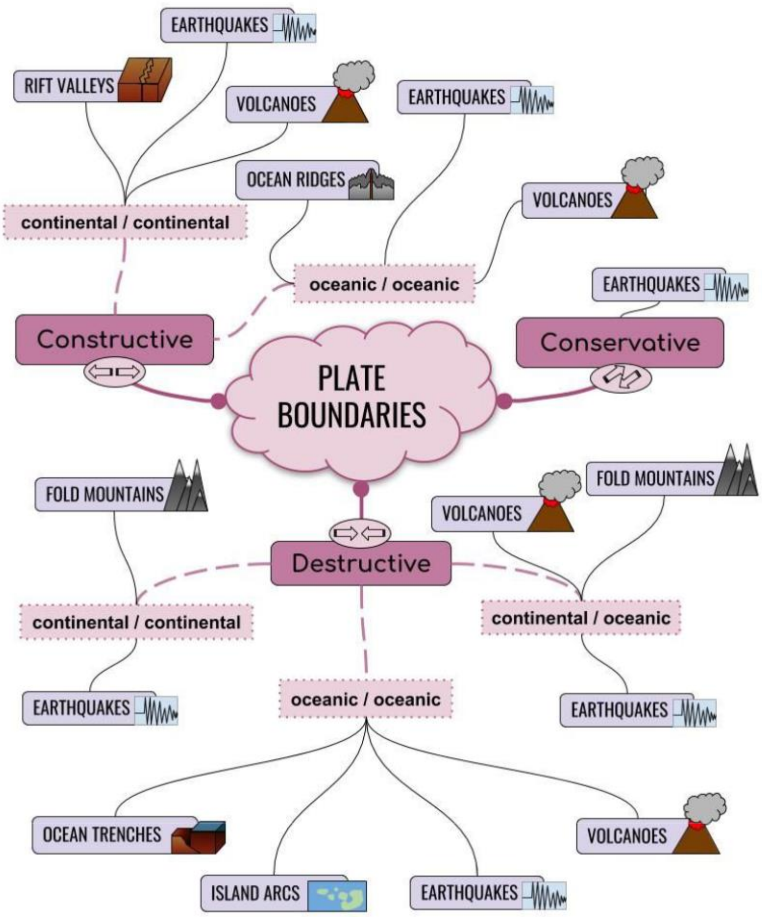
The lithosphere is broken up into **large slabs of rock**called **tectonic plates**.

These plates **move** due to the **convection currents** in the asthenosphere, which push and pull the plates in different directions. Convection currents are caused when the less dense magma rises, cools, then sinks. The edges of where plates meet are called **plate boundaries** (or plate margins).



Different Plate Boundaries

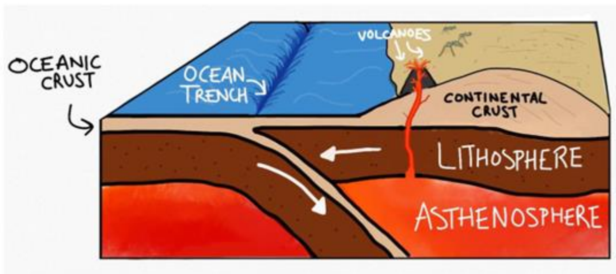
At plate boundaries, different plates can either move **towards each other** (**destructive** plate margin), **away from each other** (**constructive** plate margin), or **parallel** to each other (**conservative** plate margin). Different landforms are created in these different interactions. This spider diagram outlines what landforms and processes occur at the boundaries.



Destructive plate boundaries

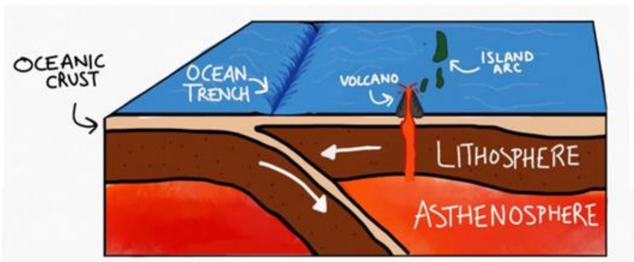
Continental and oceanic:

- Denser oceanic plate **subducts** below the continental.
- The plate subducting leaves a deep **ocean trench**.
- **Fold mountains** occur when sediment is pushed upwards during subduction.
- The oceanic crust is melted as it subducts into the asthenosphere.
- The extra magma created causes **pressure** to build up.
- Pressurised magma forces through weak areas in the continental plate
- Explosive, high pressure volcanoes erupt through the continental plate, known as **composite volcanoes**.



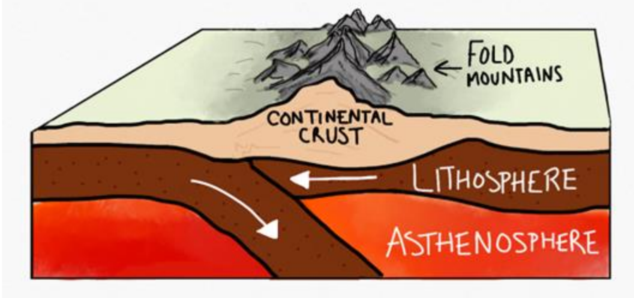
Oceanic and oceanic:

- Heavier plate **subducts** leaving an ocean trench. Fold mountains will also occur.
- Built up pressure causes **underwater volcanoes** bursting through oceanic plate.
- lava cools and creates new land called **island arcs**.



Continental and continental:

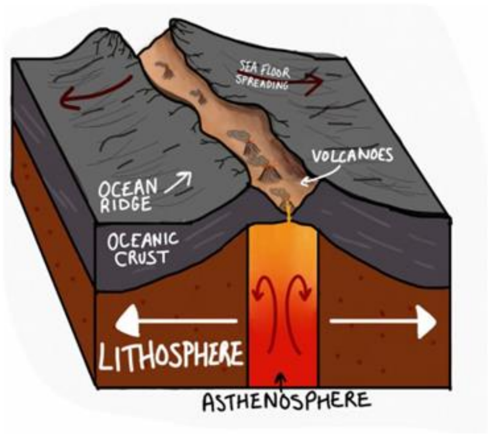
- Both plates are not as dense as oceanic so lots of **pressure builds.**
- Ancient oceanic crust is subducted slightly, but there is **no subduction of continental crust.**
- **Pile up** of continental crust on top of lithosphere due to pressure between plates.
- **Fold mountains** formed from piles of continental crust.



Constructive plate boundaries

Oceanic and oceanic:

- Magma rises in between the **gap left by the two plates separating**, forming new land when it cools.
- Less explosive underwater volcanoes formed as magma rises.
- **New land** forming on the ocean floor by lava filling the gaps is known as **sea floor spreading**(as the floor spreads and gets wider).

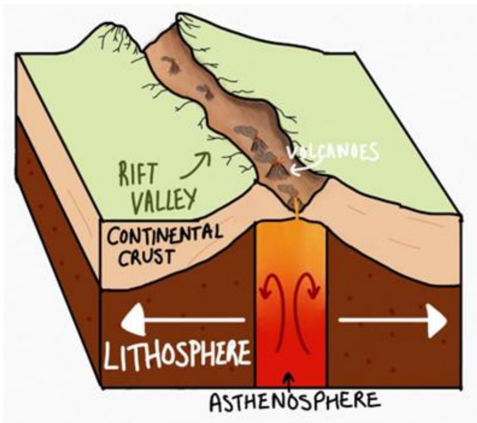


Evidence

There is sufficient evidence to prove plate movement, and **sea floor spreading** (theorised by **Harry Hess** in the 1940s) provides some of this proof. **Paleomagnetism** is the study of rocks that show the magnetic fields of the Earth. As new rock is formed and cools the magnetic grains within the rock align with the magnetic poles. Our poles (North and South) **switch** periodically. Each time these switch the new rocks being formed at plate boundaries **align in the opposite direction** to the older rock. On the ocean floor either side of constructive plate boundaries, Geologists observed that there are **symmetrical bands**of rock with **alternating bands of magnetic polarity**. This is evidence of sea floor spreading.

Continental to continental:

- Any land in the middle of the separation is forced apart, causing a **rift valley**.
- Volcanoes form where the magma rises.
- Eventually the gap will most likely fill with water and separate completely from the main island.
- The lifted areas of rocks are known as **horsts** whereas the valley itself is known as a **graben**.



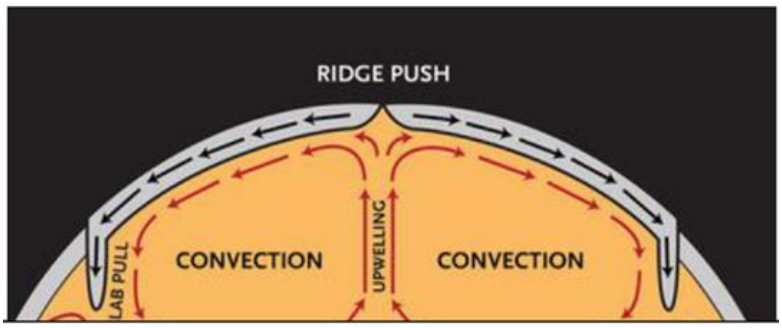
There are further forces influencing how convergent boundaries occur -

Ridge push:

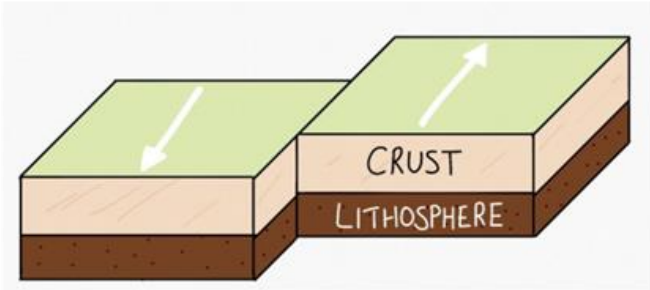
The **slope** created when plates move apart has **gravity acting upon it** as it is at a **higher elevation** . Gravity pushes the plates further away, widening the gap (as this movement is influenced by gravity, it is known as **gravitational sliding**).

Slap pull:

When a plate **subducts**, the plate sinking into the mantle**pulls the rest of the plate**(slab) with it, causing further subduction.



Conservative plate boundary



Between any crust, the **parallel plates** move in **different directions** or at **different speeds**. No plates are destroyed so no landforms are created. When these plates move, a lot of pressure is built up. On oceanic crust, this movement can displace a lot of water. On continental crust, **fault lines** can occur where the ground is cracked by the movement.

Hotspots

Hotspots are areas of volcanic activity that are **not related to plate boundaries**. Hot**magma plumes** from the mantle rise and **burn through** weaker parts of the crust. This can create **volcanoes and islands**. The plume stays in the same place but the**plates continue to move**, which sometimes causes a **chain of islands** (such as Hawaii).

Volcanic Hazards

As previously mentioned, volcanoes occur on plate boundaries where **plates melt** and **magma erupts** through a plate. Alternatively, they may occur on hotspots too.

The hazards associated with volcanoes are not just lava; there are a number of hazards caused either directly from the eruption or as a secondary effect:

- **Lava flows** - lava can flow quickly or slowly depending on its **viscosity**. Silica makes lava **viscous** and slow, which is common in **explosive** eruptions.
- **Lahars** (mudflows) - caused by a number of reasons, usually by melting ice at high latitudes
- Glacial floods (**jökulhlaups**) - when temperatures are high from magma, glaciers or ice sheets at high temperatures quickly melt and a large amount of water is discharged
- **Tephra** - any type of rock that is ejected by a volcano
- **Toxic gases** - released during some eruptions, even CO_2 can be toxic as it can replace oxygen as it is heavier
- **Acid rain** - caused when gases such as **sulphur dioxide** are released into the atmosphere
- **Nuées ardentes**/pyroclastic flows - clouds of burning hot ash and gas that collapses down a volcano at **high speeds**. Average speeds of around 60 mph but can reach 430 mph.

The Ring of Fire is an area of high volcanic and earthquake activity located in the Pacific, and the majority of large volcanoes occur within this 25,000 mile belt.

Vulcanicity is measured using the **Volcanic Explosivity Index(VEI)**. The more powerful, the more **explosive**. The scale is logarithmic from VEI 2 and onwards. Multiple features are considered when calculating the VEI, including how much tephra is erupted, how long it lasts, how high the tephra is ejected etc.

Intense high magnitude eruptions are **explosive** whereas calmer, lower magnitude eruptions are **effusive**.

Frequency of eruptions varies per volcano. Volcanoes are classed as either **active, dormant or extinct.** An estimated **50-60 volcanoes erupt each month**, meaning volcanic eruptions are always frequent (and some volcanoes erupt constantly). Usually, a higher frequency eruption means the eruptions are **effusive** whereas low frequency means the eruptions are **explosive.**

Volcanic eruptions are regular in that the eruptions on **each type of boundary** are similar (e.g. eruptions on destructive boundaries will regularly be explosive)

Sometimes eruptions may be irregular and not fit patterns.

Regularity of eruptions can help estimate when eruptions will take place (i.e. every 10 years). Seismic activity, gases releasing, elevation etc. can all indicate an imminent eruption, but there is no **definite** predictions to a volcanic eruption.

	TYPE OF VOLCANIC HAZARD			
EFFECT	**Environmental**	**Economic**	**Social**	**Political**
Primary	- **Ecosystems damaged** through various volcanic hazards - Wildlife killed	- **Businesses** and industries destroyed or disrupted	- People **killed** - **Homes destroyed** from lava/pyroclastic flows	- **Government buildings** and other important areas destroyed or disrupted
Secondary	- Water acidified by **acid rain** - Volcanic gases contribute to **greenhouse effect** (global warming)	- **Jobs lost** - Profit from **tourism** industry	- **Fires** can start which puts lives at risk - **Mudflows**or **floods** - Trauma - Homelessness	- **Conflicts** concerning government response, food shortages, insurance etc.

Hazards can be responded to by **preventing**them directly, being **prepared** for the next hazard, **mitigating** the effects, or completely **adapting**your lifestyle to limit the hazard's effects.

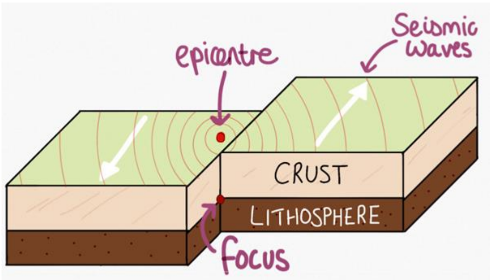
Seismic Hazards

Plates do not perfectly fit into each other, meaning they do not move in **fluid** motions. At all boundaries, plates can become stuck due to the **friction between plates**.

You can try this by moving **one palm** of your hand **against the other**, and it is clear that at some points there is more friction between irregularities and bumps, causing the hands to become stuck slightly.

When the plates are stuck, the **convection currents** in the asthenosphere continue to push, which builds the pressure. It builds so much that it cannot be sustained and the plates eventually **give way**. All of this pressure is released in a sudden movement, causing a **jolting motion** in the plates This jolt is responsible for **seismic** movement spreading throughout the ground in the form of **seismic waves**(or shock waves).

The **focus** is the point underground where the earthquake originates from. The **epicentre** is the area above ground that is **directly above** the focus.



The Ring of Fire accounts for 90% of the world's Earthquakes (shown in the diagram as the Circum-Pacific belt).

The Alpine-Himalayan belt accounts for 5-6% of the world's earthquakes.

Seismicity is measured using a logarithmic richter scale, which is a measure of the strength of seismic waves.

The **Modified Mercalli Intensity Scale**is also used, which is a rate of the destruction caused (originally the Mercalli scale when developed in 1884, but the name was changed after 1931 when it was modified). Unlike the Richter scale, the Mercalli scale has a definite end at 12 (XII as it is in roman numerals). The Mercalli scale is **subjective**, meaning sometimes it is disputed as it is dependent on human development being present rather than the strength of the seismic waves.

The magnitude of the earthquake is also dependent on the **depth of focus**. Conservative boundaries have the **shallowest** boundaries, meaning they are closer to the epicentre and the seismic waves are stronger. Destructive boundaries usually have deeper focuses, meaning the seismic waves are spread over a larger area before they reach the epicentre. This is dependent on the earthquake.

Earthquakes are frequent around the world and occur **every day** at boundaries.

Hundreds of smaller magnitude earthquakes that cannot be felt by humans occur every day, whereas the larger earthquakes are less frequent.

- Earthquakes follow no pattern and are **random** so there is irregularity between events.

Earthquakes are almost impossible to predict. **Microquakes** may give some indication but the magnitude cannot be predicted as how strong they are is **random**.

Hazards caused by seismic events:

- **Shockwaves** (seismic waves) - When two plates move side by side, friction builds up and pressure increases; this pressure is stored as **potential energy**, it cannot move so it just builds up. When the pressure becomes too much, the plates eventually move. All of the energy that has been built up must go somewhere, so it is transferred into **kinetic energy**, which is released and vibrates throughout the ground. The further away from the focus, the weaker the shockwaves, as the energy is transferred into the surroundings.
- **Tsunamis** When an oceanic crust is jolted during an earthquake, all of the water above this plate is **displaced**.

The water travels fast but with a low **amplitude** (height).

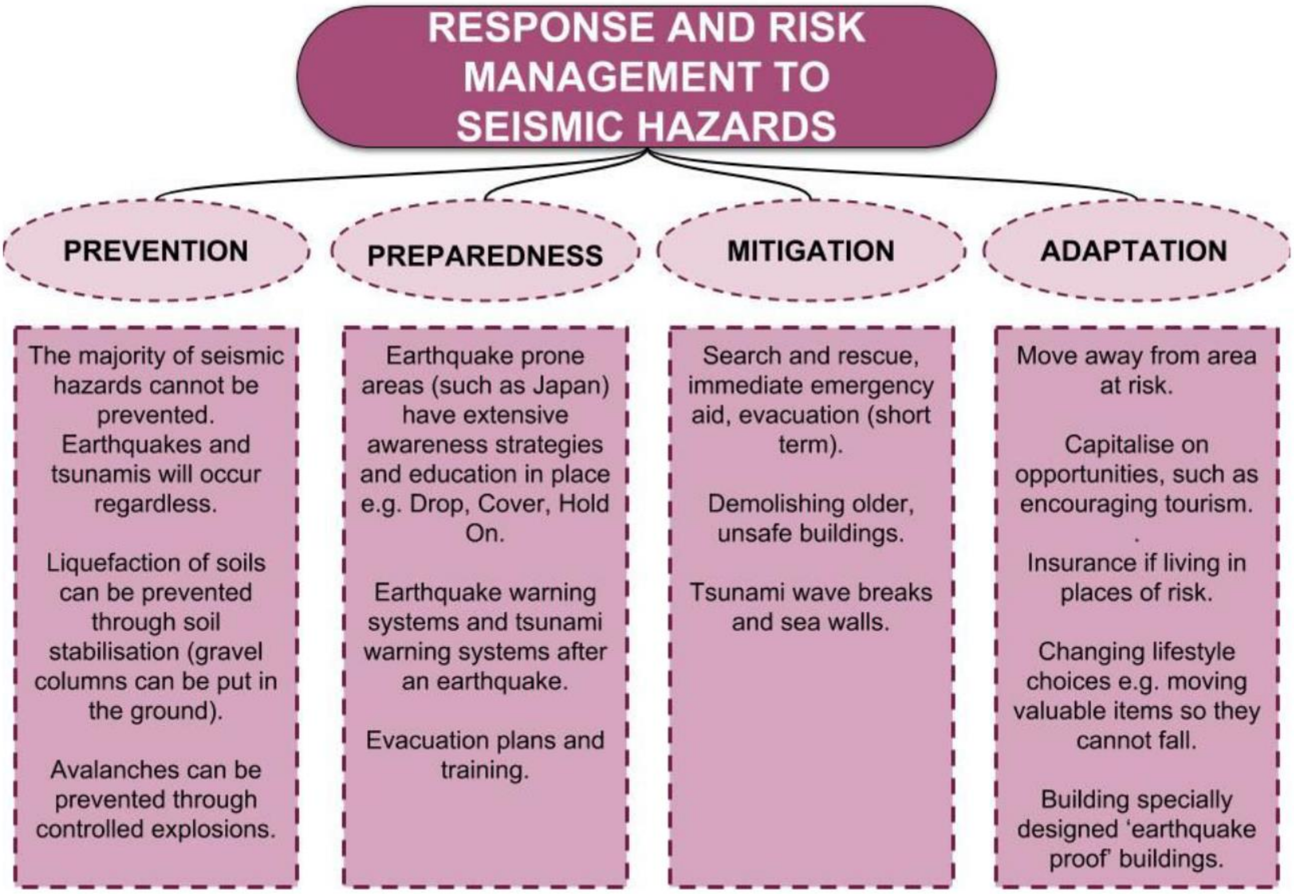
As it gets closer to the coast, the sea level decreases so there is friction between the sea bed and the waves.

This causes the waves to slow down and gain height, creating a wall of water that is on average 10 feet high, but can reach 100 feet.

Liquefaction - When soil is saturated, the vibrations of an earthquake cause it to act like a liquid. Soil becomes weaker and more likely to **subside** when it has large weight on it.

- Landslides and avalanches - Movement in soil or snow will cause it to become unstable.

	TYPE OF SEISMIC HAZARD			
EFFECT	**Environmental**	**Economic**	**Social**	**Political**
Primary	- Earthquake can cause **fault lines** which destroy the environment - Liquefaction	- Businesses destroyed	- Buildings **collapse**, killing/injuring people and **trapping**them.	- Government buildings destroyed
Secondary	- **Radioactive materials** and other dangerous substances leaked from power plants - Saltwater from tsunamis flood **freshwater** ecosystems -Soil **salinisation**	- **Economic decline** as businesses are destroyed (tax breaks etc.) - High **cost of rebuilding** and insurance payout - Sources of income lost	- Gas pipes **rupture**, starting fires which can kill - Water supplies are contaminated as pipes burst, spreading **disease** and causing floods - Tsunamis which lead to **damaging flooding**	- Political unrest from food shortages or water shortages - Borrowing money for international aid - Can be initial chaos and '**lawlessness**' e.g. looting



Storm Hazards

A **tropical storm**is a **low pressure**, spinning storm with high winds and torrential rain.

There are certain **conditions** for a tropical storm to form and develop:

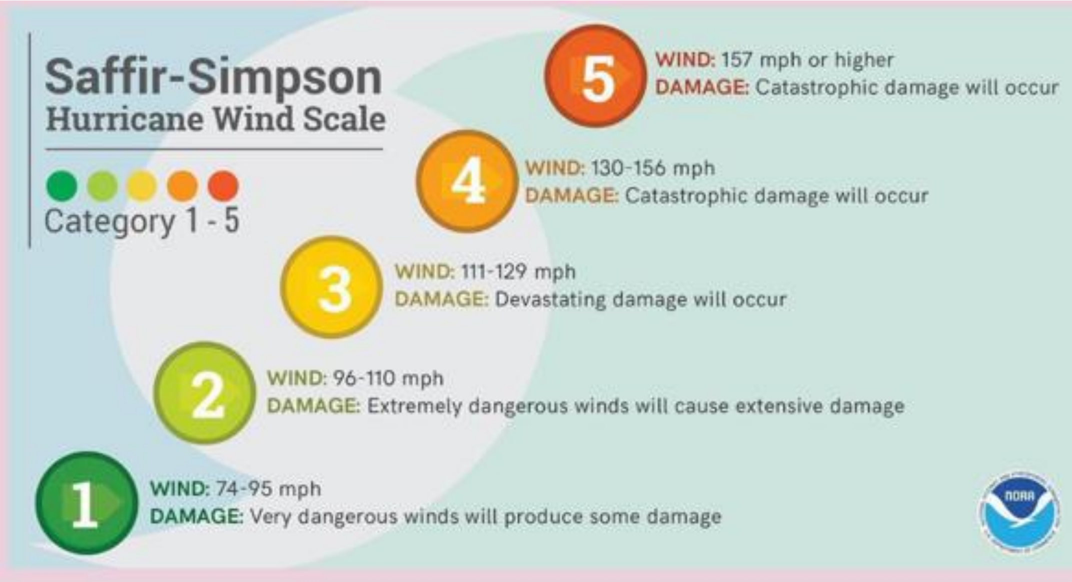
- **Temperature:** Ocean temperatures must be around **26 - 27°C**and at least 50 metres deep. Warm water provides the storm with **energy**.
- **Air pressure:** Must be in areas of **unstable air pressure**- usually where areas of high pressure and low pressure meet (**convergence**) - so that warm air rises more readily and clouds can form (this air must also be humid for cloud formation). Warm air rises because it is **less dense** than cold air.
- **Wind shear:** Winds must be present for the **swirling motion** to form, but not too strong or the storm system will be **ripped apart** in the early stages.
- **Rotation:** Tropical storms only form around the equator, but no less than **5° on either side**. The **Coriolis Effect**is the effect of the **Earth's rotation** on weather events. The storm spins because the Earth is spinning; but there is **no Coriolis Effect at the equator**, hence why these storms will only form a certain distance away from it.
- **A trigger:** a pre-existing thunderstorm, a spot of very high sea surface temperature, an area of low pressure and many other factors can act as a **trigger** for a storm to develop, which will only further develop when the **other conditions are present**.

Formation

- **Warm, moist air rises**, leaving an area of **low pressure below**. This causes warm air from surrounding areas of higher pressure to **move into this low pressure area**and rise too. Overall, **warm air is constantly rising**and accumulating in the atmosphere.
- When the warm air rises, it **cools**, condensing into **thunderstorm clouds**.
- The whole system is spinning due to the **Coriolis effect**. In the **southern**hemisphere, the storms spin **clockwise**; in the **northern**, **anticlockwise**.
- The **constant additions of energy** from the warm air causes the storm to spin faster and generate higher wind speeds. At **39 mph** the storm can be classed as a **tropical storm**.
- The **eye** of the storm is in the centre. This is an area spanning around **30 miles wide**that is of **extremely low pressure** (can be 15% lower pressure than areas outside of the storm). Cool, dry air (cool from the higher altitudes and the moisture has been transferred into the system) descends in the eye, causing the weather to be relatively **calm and cloud free**. The more intense the storm, the clearer the eye.
- Surrounding the eye is the **eyewall**, the most **intense and powerful**area of the storm. **Warm, moist air rapidly rises** here, with extremely **high winds and torrential rain**. When winds reach **74 mph**, it becomes a hurricane/cyclone/typhoon.

- When the tropical storm reaches a coast, the **low pressure and high winds** will cause a large amount of sea water to be **taken into the system** and then released as a high wave called a **storm surge**.
- When the storm reaches **land**, it no longer has a **supply of energy**(warm, moist air from the sea) and the eye eventually **collapses**. Heavy rain can persist for days.

- Measured on the **Saffir-Simpson Scale**(A scale of 1-5) based on wind speed and thus power of the storm.



Tropical storms form in the Northern Hemisphere from June-November, and the Southern Hemisphere from November-April. The majority of tropical storms do not develop into strong storms and do not reach land. Tropical storms that are **higher magnitude** and reaching land are thought to be increasing in frequency. Tropical storms are **irregular** because although they occur in the **same areas**, their path does not follow a set route - the route taken is **dependent on the storm** and the climatic conditions.

Tropical storms form **away from land** meaning **satellite tracking**of cloud formations and movement can be tracked and the general route can be predicted. These projected path of Hurricane Florence estimates to the hour when the hurricane will hit. The first picture tracks 5 days in advance, the second picture is the day after. Note how the tracking changes within 24 hours.

The closer the hurricane gets, the easier it is to predict. Storm surges can also be predicted based on the pressure and intensity of the storm.

From past storms and climatic trends, the **probability** of a storm hitting an area can also be predicted. Scientists have predicted how many years it will take for a tropical storm to hit certain areas.

Hazards caused by tropical storms:

- **High winds** - over **300km/h**and therefore very strong. Hurricane winds are strong enough to blow a house down, and also blow heavy debris at high speeds, which can obviously cause damage and injure anyone who comes into contact.
- **Flooding** - coastal/river flooding from **storm surges**and **heavy rain**. River flooding also sends more floodwater to other places, which can cause areas outside of the tropical storm's path to flood also.
- **Landslides** - due to soil becoming **heavy**when wet with high levels of rain
- **Storm surges** - Large **rise in sea levels**caused by low pressure and high winds, pushing water towards the coast

	TYPE OF STORM HAZARD			
EFFECT	**Environmental**	**Economic**	**Social**	**Political**
Primary	- Beaches **eroded** -Sand displaced - Coastal **habitats** such as coral reefs are destroyed	- Businesses destroyed - **Agricultural land** damaged	- **Drowning** - **Debris**carried by high winds can injure or kill - Buildings destroyed	- Government buildings destroyed
Secondary	- River flooding/ **salt water** contamination - **Animals displaced** from flooding e.g. alligators -Water sources **changing course** from blockages	- **Rebuilding**and **insurance** payout - Sources of income lost - Economic decline from sources of income destroyed	- Homelessnes - **Polluted water** supplies spread disease - Food shortages from damaged land	- Issues paying back international aid - Pressure for government to do more about **global warming**

Wildfire Hazards

Wildfire: A large, **uncontrolled**fire that quickly spreads through vegetation.

Conditions favouring intense wildfires

Vegetation Type

Thick, close together vegetation allows fires to spread **quickly**and easily. **Trees and thick bushes** lead to more intense wildfires; grasslands do not burn as intensely. Vegetation with **flammable oils**- like eucalyptus - causes more intense fires also.

Fuel Characteristics

Vegetation should be **dry**to allow it to catch. **Finer** vegetation causes fires to spread **quicker**, but larger,**thicker** forms of vegetation burns for longer and more intensely.

Climate and Recent Weather

Wildfires can occur anywhere in the world, but the most common areas wildfires occur in are located on this map (from 2010).

Wildfires occur in a climate that has **enough rainfall to have sufficient plant growth**, but considerable dry spells and droughts to **dry out the fuel**. Areas with **dry seasons**such as California allow for intense wildfires. **Wind** also causes fires to spread quicker.

Many **climatic events** can make wildfires grow more intense and extend wildfire seasons. The **Santa Ana Winds** and **Diablo Winds** in California, for example, cause more wildfire damage.

El Niño (warm phase) and **La Niña** (cold phase) are also climatic events that are thought to affect wildfire prevalence. The effects of these phenomena vary throughout the world, but in California El Niño is thought to provide warmer, wetter seasons to grow vegetation, and La Niña's dryer seasons create more wildfires.

Recent temperature increases have caused an **increase** in the number of **wildfires**and an increase the **length of wildfire seasons**.

"Forest fires in the western US have been occurring nearly five times more often since the 1970s and 80s. Such fires are burning more than six times the land area as before, and lasting almost five times longer."

There are also arguments that despite climate change, wildfires are not increasing everywhere. Studies have shown that this is somewhat true; between 1998 and 2015 globally burned area declined about 24 percent. However, this may also be down to **agricultural productivity** and **land use change** as there are less areas that **can** be burned, i.e. less forestry.

Fire Behaviour

Fires spread quickly on **hills** as the heat rises. Fire can also **'jump'** across rivers and into areas due to **lit debris** which causes it to **spread**. Wildfire does not just spread in one way; there are three main types of wildfire burning.

- **Crown fires** burn the entire tree from **bottom to top**, which is classed as the most dangerous and destructive type of fire.
- **Surface fires** only burn the **leaf litter**, meaning they are easy to extinguish.
- **Ground fires** burn at the dry peat or vegetation **beneath the surface**, and move slowly through the dried underground. Due to them being underground, they can be difficult to put out and can actually continue to burn throughout the year if the weather conditions allow it.

Causes of Wildfires

Wildfires can be caused **naturally** or by **humans**. The majority of the time, wildfires are caused by human activity. Humans may start fires **accidentally** or through **arson**.

Natural causes include lightning (being the biggest cause), volcanoes and even spontaneous; **Human causes** can be lit cigarettes, barbeques, agriculture, train lines and more.

	HAZARD			
EFFECT	Environmental	Economic	Social	Political
Primary	- **Air pollution** from ash -**Water pollution** -Habitats destroyed in fire -**Toxic gases** released in burning	- Businesses destroyed - Agricultural land damaged - Cost of **fighting fires** (firefighters, helicopters, water)	-People killed or injured in fires - Homes destroyed - People go **missing** during evacuations	- Government buildings destroyed
Secondary	- Removing **invasive species** and stimulating seed **germination** - **Migration** patterns of animals affected -Increased **CO_2** from fires could heighten the greenhouse effect	- High cost of rebuilding and insurance payout - Sources of income lost - Discouraging visitors, losing **tourism** sector -**Planes**cancelled	-Homelessness - Food shortages from destroyed agricultural land - **Health problems** such as asthma from **smoke inhalation**	- Borrowing money for international aid - Pressure for government to do more about global warming due to increased frequency

Risk Management

Prevention and Preparedness

In the current climate, wildfires overall will never be eradicated entirely. However, **public awareness** can prevent the ignition of wildfires and prepare people for wildfires. In areas of risk, campaigns teach people the dangers of leaving fires burning in forest areas through barbeques or cigarettes. **Smokey Bear**is a 70 year-old U.S. mascot used to **provide information**on preventing wildfires, with the intention of becoming a well-known figure so that people would recognise the risks.People can be **prepared**by having evacuation plans, emergency services training and drills, and a personal emergency plan (with food supplies, water, a place to stay etc.).

Warning systems are also a good way for people to be prepared. Broadcasted weather warnings (or ‘Red Flag Warnings’ as they are commonly referred to as) warn people when the perfect conditions for wildfires are occurring - e.g. hot, dry, upcoming lightning storms. This means people may wish to evacuate and campfire bans can be put in place. **Thermal infrared satellite imagery** shows where wildfires are occurring so that people can stay away from these areas. Therefore, **evacuation zones**can be set up for areas in high risk, and people can be evacuated.

Fire danger signs are used in fire-prone areas

Mitigation

Immediate responses to wildfires are mainly concerned with protecting those **directly** at risk and **extinguishing** the fire

Like all hazards, wildfires will need search and rescue teams, immediate aid, and evacuations. To immediately **mitigate** the effects, the fire must be **extinguished** or **diverted**. Firefighters are dispatched on ground to spray water onto the fire. Water and flame retardants are also sprayed onto large areas using aircrafts

Long-term mitigation strategies work to reduce the impacts of wildfires before they occur. **Controlled burnings** are burnings created on purpose to remove flammable materials so that less fuel is available. These burnings are strictly monitored so that they are contained and easily extinguishable. **Fire breaks** (gaps in trees) are also created to limit spread.

Those who live in areas at risk can also do their part in **mitigating** the effects of wildfires by **ensuring their homes do not contribute** to wildfire spread. This guide from the Smokey Bear campaign outlines the steps you can take to lower the risk created by your home and its surroundings. This includes removing flammable materials from the vicinity so that in the event of a fire, your house is less likely to contribute to the spread of the wildfire.

To limit the effects of **toxic gases** and **material** that contaminates the ecosystem, homes can also be built using materials that will not produce as harmful substances when burnt.

Adaptation

Many who live in fire-prone areas must **adapt** and live with the consequences of wildfires. The expenses of **insurance** and clean-up as well as staying educated become part of everyday life.

With wildfires on the increase though, **globally** we may have to adapt **our** lifestyles in order to stop contributing so significantly to **CO_2 levels**, heightening

the greenhouse effect. If temperatures continue to increase, it may lead to **unprecedented** changes in wildfire patterns that may otherwise be avoidable with more eco-conscious decisions to reduce CO_2 emissions.

There is the argument that perhaps we should not intervene in wildfires at all, which can be classed as a **fatalistic outlook**. Many people believe it is not worth the **money or resources**to extinguish wildfires if they are only going to start again, and some should just be left to burn. There are also **ecological benefits** of having wildfires burn, which supports the idea that we should adapt to wildfires and let them burn. Wildfires **eradicate disease** and **stimulate seed germination.**

Sample Assessment Questions

1. Assess the importance of governance in the successful management of tectonic mega-disasters. (9 marks)

2. Explain why the number of reported earthquakes has increased since 1965 (4 marks)

Mark schemes

1. Assess the importance of governance in the successful management of tectonic mega-disasters. (9 marks)

Notes for answers
The indicative content below is not prescriptive and candidates are not required to include all of it. Other relevant material not suggested below must also be credited. Relevant points may include:
AO1
• mega-disasters are large-scale disasters on either an areal scale or in terms of their economic and human impact
• they pose serious problems for successful management to minimise impact and mitigate the impact of the disaster
• they need often require international management both short term and longer term
AO2
• extreme events are likely to pose serious challenges for any governance, however well-planned, e.g. the 2011 Japanese tsunami
• extreme events are by their nature unpredictable (1- in a 1000-year events) and so prediction is difficult and prevention is impossible, sometimes secondary and tertiary outcomes occur, e.g. Fukushima
• disaster management, pre-, during and after the event, can have a significant impact on losses, e.g. comparison of Japanese tsunami with Indian Ocean, Boxing Day tsunami
• strong governance can lead to very effective management of immediate disaster recovery, e.g. Sichuan earthquake in China, as well as the development of longer-term education and community preparation strategies
• however, management is expensive and with long return intervals there are strains on budgets that may affect levels of investment, e.g. San Francisco and 'the big one'
• democratic governance is also often driven by short-term budgetary constraints which make saving money on management measures very tempting, given that it is expensive
• governance is important but it has limitations such as the affordability of prediction and prevention measures, especially in the management of mega-disasters immediately after the event, e.g. Haiti, therefore, other factors such as level of development are likely to be more important.

2. Explain why the number of reported earthquakes has increased since 1965 (4 marks)

Notes for answers
For each reason, award **1** mark for identifying a reason for the increase in the number of reported earthquakes, and a further mark for an appropriate expansion. For example:
• increase in the number of recording stations (1) which means
more earthquakes are detected which previously might have been missed in remote areas (1)
• higher population densities (1), which leads to more reporting because areas are better 'covered' (1)
• better (more reliable and accurate) detection equipment (1) so smaller magnitude earthquakes are detected which previously might have been missed (1).
Accept any other appropriate response.

Physical Geography Topics

1. Name one stage of the hazard management cycle. (1)
2. Explain two strategies that are used to modify vulnerability to volcanic hazards. (4)
3. Using a named location, explain how hydrometeorological hazards can contribute to a tectonic disaster. (6)
4. Assess how prediction can contribute to the management of tectonic hazards. (20)
5. Explain two reasons why the number of reported earthquakes has risen since 1960. (4)
6. Explain the causes of tsunamis. (6)
7. Assess the significance of earthquake hazard profiles in relation to the effectiveness of management strategies. (9)
8. Identify one process that occurs only at destructive plate boundaries (1)
9. Explain two secondary hazards caused by earthquakes (4)
10. Explain the tectonic hazards that may result from volcanic activity (6)
11. Assess whether development and governance are the most important factors in understanding the scale of tectonic disasters (20)
12. Define what is meant by disaster (1)
13. Explain two reasons how a government might influence a community's resilience. (4)
14. Explain why some earthquakes generate secondary hazards. (6)
15. Assess the factors that contribute to increased impacts from some tectonic hazard events. (6)
16. Explain the reasons why volcanoes are more likely along some plate margins than others (4)
17. Assess the contribution of plate-tectonic theory to our knowledge of the Earth's structure (9)
18. Explain the causes of one earthquake. (6)
19. Assess the relative importance of the hazards associated with destructive plate margins. (20)
20. Explain the hazards cause by one volcanic eruption. (6)
21. Assess the range of hazards caused by explosive volcanic eruptions. (9)
22. Explain the formation of a tsunami. (6)
23. Assess the severity of the various impacts of a tsunami. (9)
24. Assess the reasons why, even within a country, some people are more vulnerable to hazards than others. (9)
25. Assess the relative importance of the concept of vulnerability in understanding hazards impacts. (20)
26. Explain the impacts of one major tectonic disaster. (6)
27. Assess the extent to which a country has been able to meet the pressures placed upon it by a major disaster. (9)
28. Explain why some disasters are economically costly, while others are more costly in terms of human lives. (6)
29. Assess the statement that 'we are living in a more hazardous world'. (20)
30. Assess the vulnerability of one named country to natural hazards. (9)
31. Assess the extent to which hydro-meteological hazards can produce very similar impacts to hazards with tectonic causes. (20)
32. Explain the value of Park's hazard-response curve in understanding the management of the impacts of tectonic hazards. (6)
33. Assess the usefulness of theoretical frameworks in understanding the prediction, impact and management of tectonic hazards. (20)
34. Assess the value of hazard-mitigation strategies. (9)
35. With reference to earthquake waves, explain two reasons why it is difficult for buildings to remain intact during an earthquake event. (4)
36. Explain the link between plate boundary type and the strength of earthquake waves (4).
37. Explain the geographical criteria that can be used to decide if a tectonic event is a hazard, disaster or mega-disaster. (6)
38. Explain the correlation between the magnitude and intensity scales used for measuring earthquakes and their secondary hazards. (4)
39. Compare the tectonic hazard impacts in developed countries with those in developing / emerging countries. (6)
40. Explain how emergency planners and engineers may help to modify the impacts of a tectonic hazards. (6)
41. Explain why insurance companies may be interested in encouraging the accurate prediction of, and effective preparation for, a tectonic hazard. (4)
42. Assess the reasons why earthquakes create more disasters than volcanic eruptions (9)
43. Assess the relative importance of the physical characteristics of volcanic eruptions in creating risk for people (20)
44. Explain two process in the formation of offshore bars. (4)
45. Explain how geological structure affects the development of coastal landforms. (6)

46. Assess the importance of lithology in influencing the rate of coastal erosion. (9)
47. State one coastal depositional landform (1)
48. Explain two local factors that increase flood risk for low-lying islands. (4)
49. Explain the physical processes involved in a sediment cell system. (6)
50. Assess whether storm surges pose an increasing risk for some coastlines. (9)
51. State one factor that affects coastal sediment transport (1)
52. Suggest one reason why the wave frequency differs at two locations (3)
53. Explain two coastal depositional processes (4)
54. Explain the factors that create an erosional coastline (6)
55. Assess whether sustainable management schemes are always the most appropriate for managing the risks to coastlines (20)
56. Name one erosion process that occurs at a coast (1).
57. Assess the importance of mass movement in influencing the rate of coastal recession and landform change. (20)
58. Evaluate the extent to which all coastlines can be protected using sustainable management approaches. (20)
59. Explain how geological structure influences the development of coastal landforms. (9)
60. Using examples, explain the characteristics of high-energy coastlines. (6)
61. Referring to examples, explain the problems of classifying coastlines. (6)
62. Explain the relationship between geology and coastal form along one named stretch of coast. (6)
63. Assess the extent to which rates of coastal recession and stability depend on lithology. (9)
64. Compare constructive and destructive waves. (4)
65. Explained how different wave types result in different beach profiles. (6)
66. Explain two processes or erosion that increase in importance during storms. (6)
67. Assess the importance of different erosion processes in the development of cliff features. (9)
68. Explain the characteristics of a 'drift-aligned' stretch of beach. (6)
69. Assess the relative importance of depositional processes along a named stretch of coast. (20)
70. Assess the relative importance of different methods of mass movement along one stretch of coast. (9)
71. Explain the difference between eustatic and isostatic change. (4)
72. Assess the contribution of geologically recent eustatic changes to the UK's coastal landscapes. (9)
73. Assess the relative importance of factors which have led to rapid coastal erosion along a stretch of coastline. (9)
74. Explain the physical and human causes of one flood in a developing country. (8)
75. Evaluate the influence of a country's level of development in determining the impacts of coastal flooding. (9)
76. Assess the effectiveness of hard-engineering approaches designed to protect the coast from erosion. (9)
77. Evaluate the effectiveness of coastal-management strategies along a stretch of coast. (9)
78. Assess the effectiveness of holistic strategies used to protect a stretch of coast from erosion. (20)
79. Explain how geology is an important influence on the shape (morphology) and features of a coastline. (6)
80. Explain how vegetation can bring stability to low-energy coastlines (6)
81. Explain the difference between low-energy and high-energy coastal environments. (6)
82. Explain why coastal processes may vary from day to day. (6)
83. Explain the formation of a cuspate foreland. (6)
84. Explain how local factors may increase the risk of coastal flooding. (6)
85. Explain the impact of storm surges on lowland coastal areas. (6)
86. Explain the possible social impacts of coastal recession on coastal communities. (6)
87. Explain why UK Government coastal management policies vary from place to place (6)
88. Assess the benefits of soft engineering approaches when managing threatened coasts (9)
89. Evaluate the threats for lowland coastal areas arising from future sea level rise (20)
90. Assess the severity of the various impacts of tsunami. (9)
91. Evaluate the relative importance of the human and physical geography of the coasts and the characteristics of the tsunami event in determining its impact. (20)
92. Evaluate this statement: 'The hazard risks along the Californian Coasts are mainly the result of physical processes'. (20)