CIE Geography A-Level

1: Hydrology and Fluvial Geomorphology

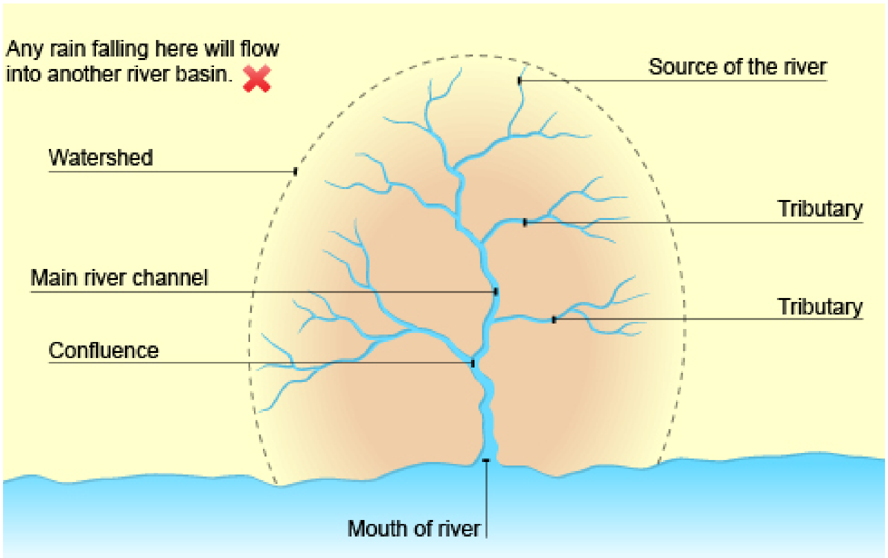
Detailed Notes

The Drainage Basin System

Natural systems are composed of:

- **Outputs** - Where matter or energy leaves the system
- **Stores** - Where matter or energy builds up and is stored in the system
- **Flows** - Where matter or energy moves in the system

A **drainage basin** can be classified as a natural system. A drainage basin is the area that is **drained by a river and any tributaries** (a tributary is a smaller stream that flows into and contributes to a larger river). The **boundary of the drainage basin** is called the **watershed**; if any water drains outside the watershed, it is classified as being within another drainage basin.



(Source:www.tes.com/lessons/IANrONFgHmPOdg/copy-of-rivers)

In **the drainage basin system,** there are outputs, stores, and flows:

Outputs

Evaporation: The change in state of water from **liquid to gas**. Evaporation occurs in the drainage basin system when water is heated by **solar energy**, causing it to evaporate into a **gas** and rise into the atmosphere. Water is **leaving** the system here, which is why evaporation is an **output**.

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.

River 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)**. Water leaves the basin through streams which drain the basin. These may flow as **tributaries** into other rivers or directly into lakes and oceans.

Stores

Interception: Water (e.g. **precipitation**) that is **intercepted** by plants' **branches** and **leaves** before reaching the ground. This water is stored **short-term**.

Soil Water: Water that is stored in the **upper levels of the soil**, which is **utilised by plants**.

Surface Water: Water stored in **puddles, ponds, lakes etc**. Dependent on the size of these stores, they can last from hours to millions of years.

Groundwater: Water that is stored in the **pore spaces of rock** or lower soil.

Channel Storage: Water that is stored in a river's **channel**.

Flows

There are two major types of flows: **above ground** flows and **below ground** flows.

Above Ground Flows

Throughfall: Water flows from **leaves and foliage** onto the **ground**. This is especially prominent in areas with a large **canopy** that receives a lot of **rainfall**, like a rainforest, but will occur whenever precipitation falls onto plants and trees.

Stemflow: Intercepted water stored on plants and trees flows down a **stem** onto the **ground**.

Overland flow: Water flows above the ground, as **sheetflow** (lots of water flowing over a large area), or in **rills** (small channels similar to streams, that are unlikely to carry water during periods where there is no rainfall). Overland flow will occur when water cannot **infiltrate** the soil.

Channel flow: Water that moves through **established channels**, like streams or rivers. Naturally, channel flow is fed by **two sources**: **overland flow** (i.e. precipitation that flows over the ground, rather than infiltrates the soil), and **groundwater flow** (groundwater flow contributes to channel flow where a **channel intersects the water table** - this will be explored further).

Below Ground Flows

Infiltration: The movement of water from **above ground into the soil**. Infiltration is affected by multiple factors, including:

- Permeability of soil
- Relief
- Rate of precipitation
- Saturation levels of soil

Percolation: Water flows 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.

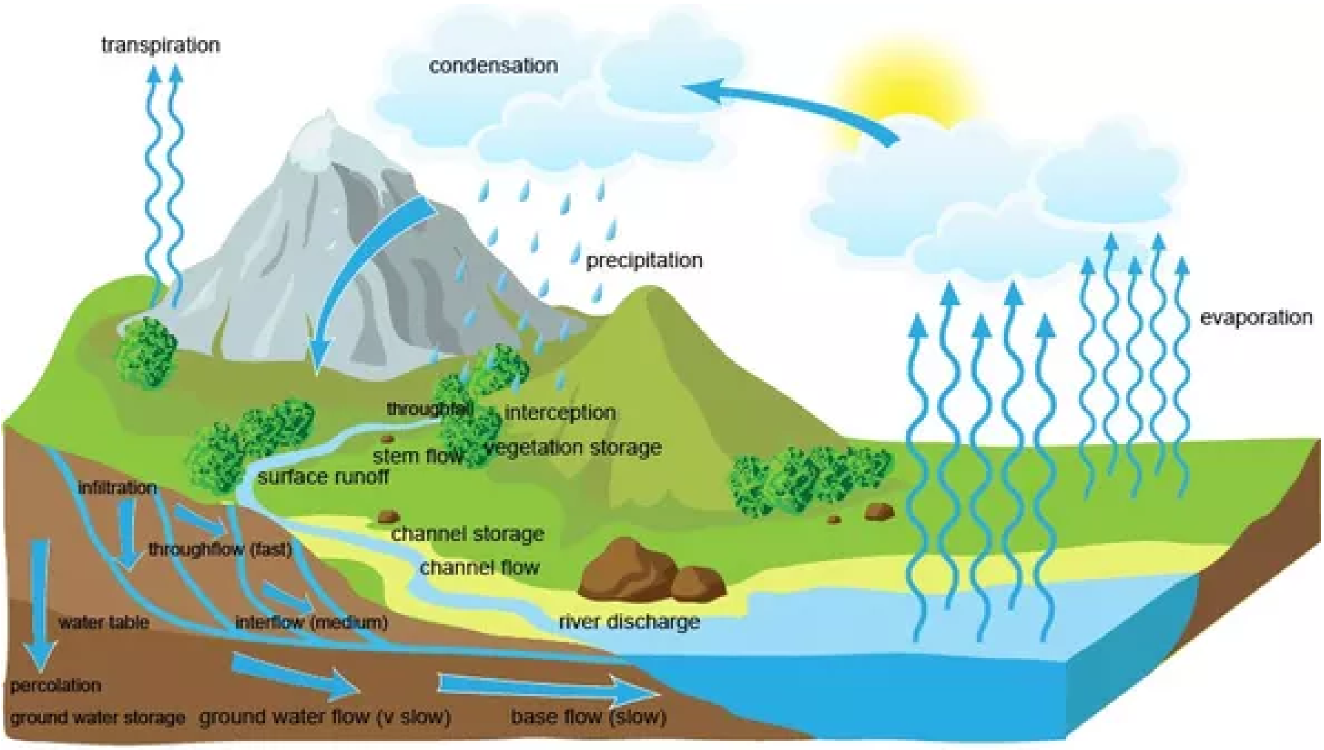
Throughflow: Water flows **through the soil** and into **streams or rivers**. Speed of flow is dependent on the **type of soil**, e.g. **clay soils** will have a slower flow rate than **sandy soils**.

Groundwater Flow: Water **flows through permeable rocks**, below the **water table**, and may also flow as springs. Groundwater **maintains water levels elsewhere**, which will be discussed further in the 'Underground Water' section.

Baseflow: The baseflow is the **level of channel flow** when there is **no overland flow,** (i.e. when **no precipitation has fallen**).

This means baseflow is made up of **any groundwater** that contributes to **channel flow** (refer back to the **two sources of channel flow**: overland flow and groundwater flow - baseflow is the level where there is **no precipitation** contribution, hence **only** groundwater flow is contributing to the **channel flow**).

In short, baseflow is the ‘normal’ or **base** level of water in a river, when there is no **contribution from precipitation**.



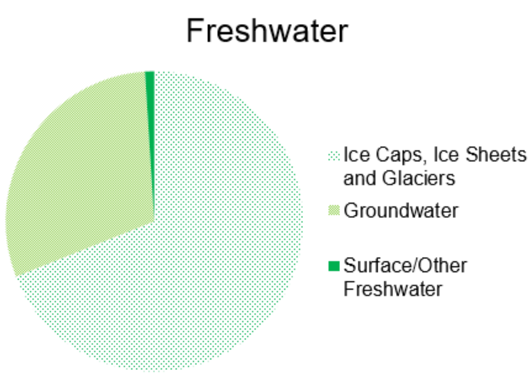
(Source:www.alevelgeography.com/drainage-basin-hydrological-system/)

Underground Water

Underground water makes up a large amount of the **Earth’s water stores**, in fact it accounts for around **30% of all the Earth’s freshwater**.

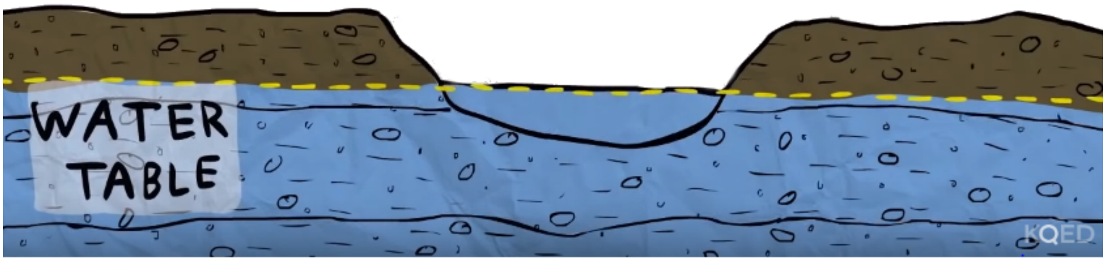
Groundwater is classified as any water underground, meaning it can be held in **soils** or in **between rock spaces**.

Aquifers are underground water stores. On a global scale they are unevenly distributed. **Shallow groundwater aquifers** can store water for up to **200 years**, but **deeper fossil aquifers**, formed during wetter climatic periods, may last for **10,000 years**.



The Water Table

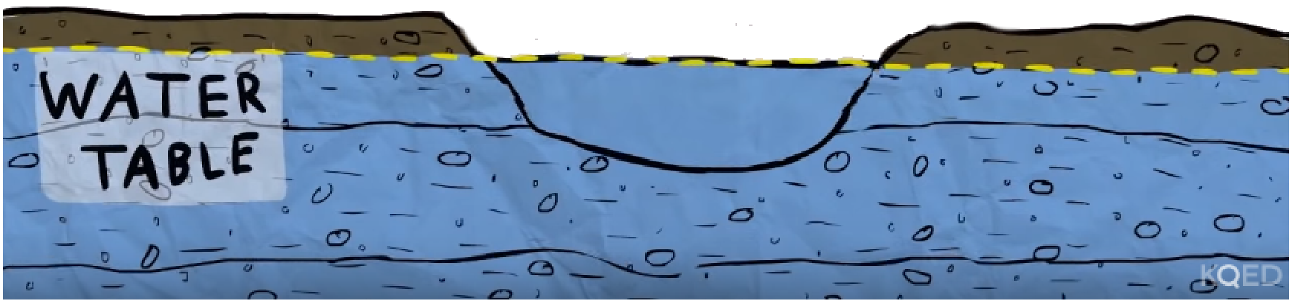
The **water table** is the **level** at which the **pore spaces and fractures in the ground become saturated**, meaning above the water table is **unsaturated soil**, and below the water table is **saturated soil**.



If the **surface dips below the water table**, **groundwater** will fill the surface space to become surface water.

If the surface water **dries up**, groundwater will continue to **replenish the area** that is underneath the water table.

The water table can **rise/fall**, and surface water **will rise/fall accordingly**. For example, in this diagram the water table has risen, causing surface water levels to rise.



(Source:www.youtube.com/watch?v=oNWAerr_xEE)

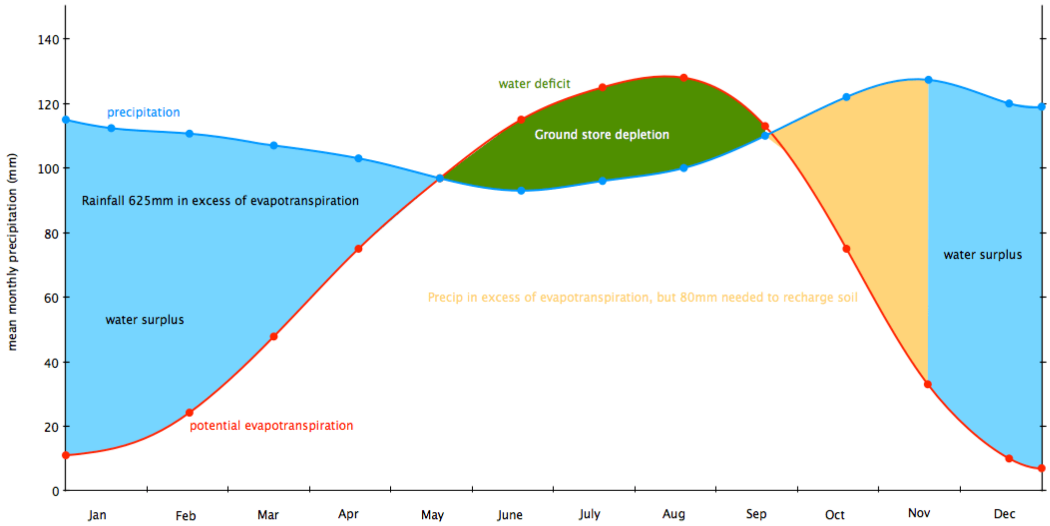
Groundwater Recharge

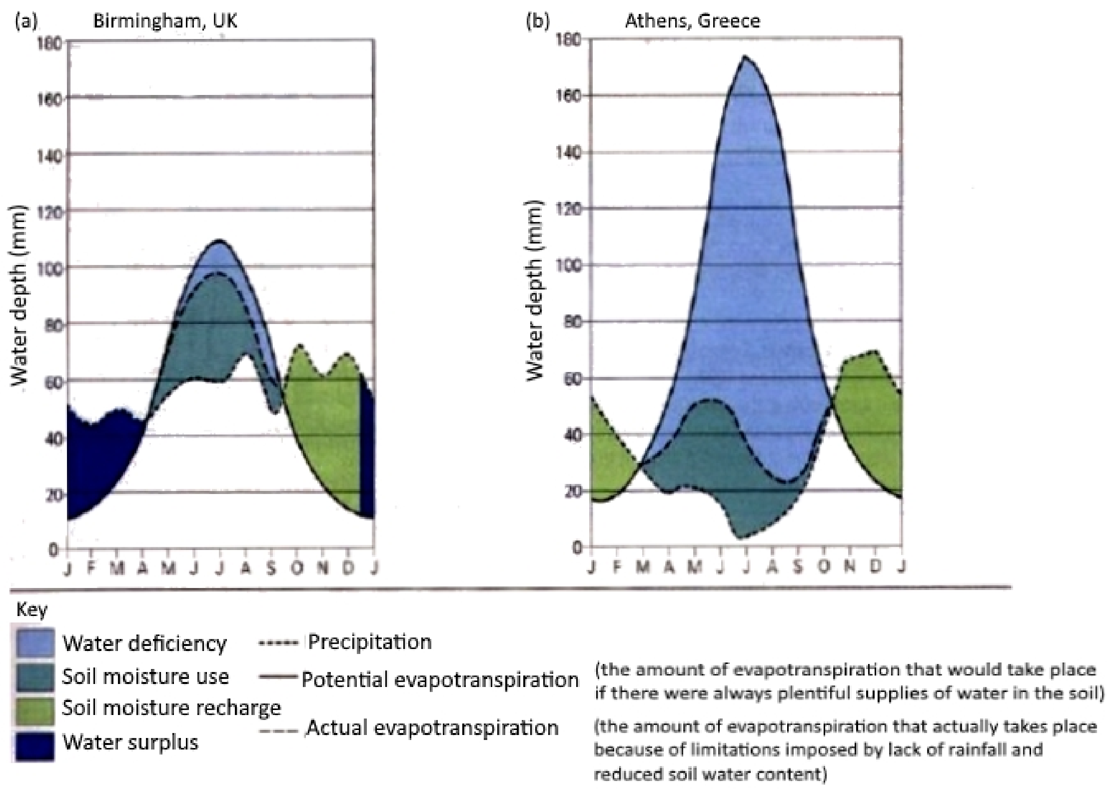
When groundwater levels deplete (by human **extraction**, or by groundwater **replenishing surface water levels**) groundwater can be **recharged**.

Groundwater levels fall when groundwater is being **used more**. For example, in hotter temperatures, there is less rainfall (summer), so more surface water bodies are drying up and therefore groundwater will **somewhat replenish** these stores. When groundwater is utilised, this can cause the **water table** to fall, as there is **no water replenishing the used groundwater**.

Groundwater is **recharged** by:

- Precipitation **infiltrating** the ground until it reaches groundwater. When **precipitation is higher**, and **evaporation is lower**, such as in winter, groundwater levels will be **recharged**.
- Surface **water bodies** (such as lakes and rivers) **seeping** into groundwater stores.





The type of precipitation affects the **amount of groundwater recharge**. In storm events, large amounts of rainfall quickly **saturates the ground** to its **field capacity** (no more water can **infiltrate** the soil) increasing **overland flow**. Storm events are therefore **less effective at recharging water stores than prolonged rainfall**.

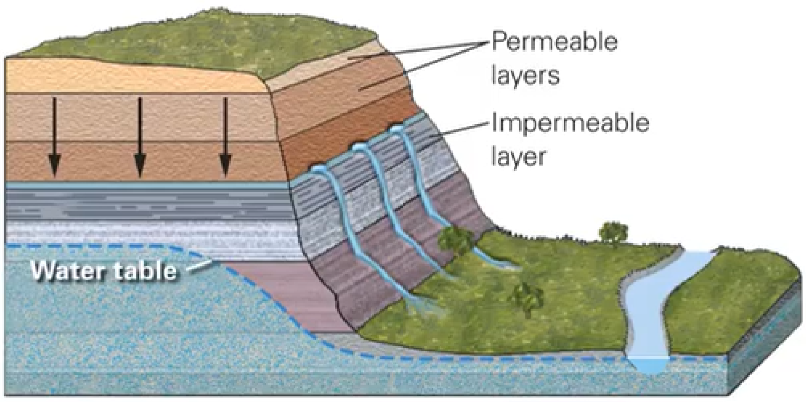
- If 20mm of rain fell evenly over the course of 24 hours, this would **infiltrate the soil and percolate into the groundwater stores as well**, with low **overland flow**.
- In 1 hour, if 20mm of rain fell, there would be **less water infiltrating the soil and percolating into the rocks**, reducing the **replenishment of groundwater stores**, but increasing overland flow.

Springs

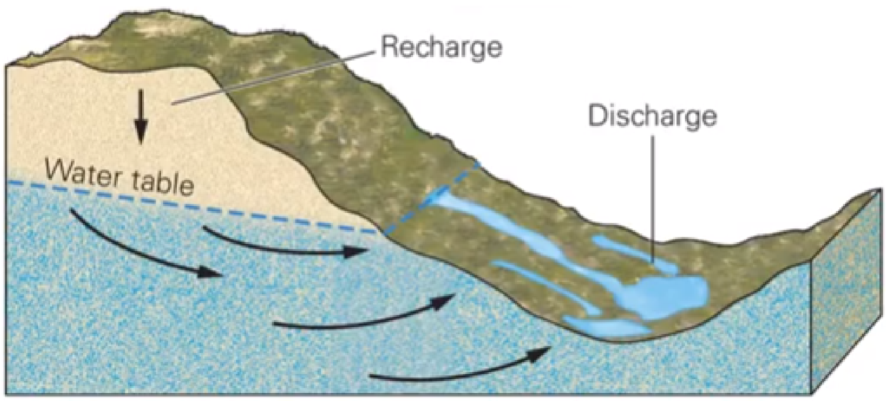
A spring is a **natural outlet of groundwater**, i.e. it is any place where groundwater flows out onto the surface.

Springs can form for a number of reasons, but the main reasons a spring forms is due to either:

1. **Permeable rock** meeting **impermeable rock**, causing the infiltrated water to build up and eventually escape as a **spring**.



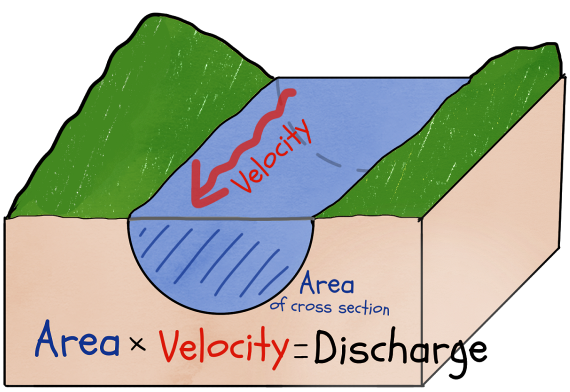
2. Where the **water table meets the surface** (especially on a hill), causing the discharge of groundwater.



(Source:www.youtube.com/watch?v=TIY_C1sSTdU)

Hydrographs

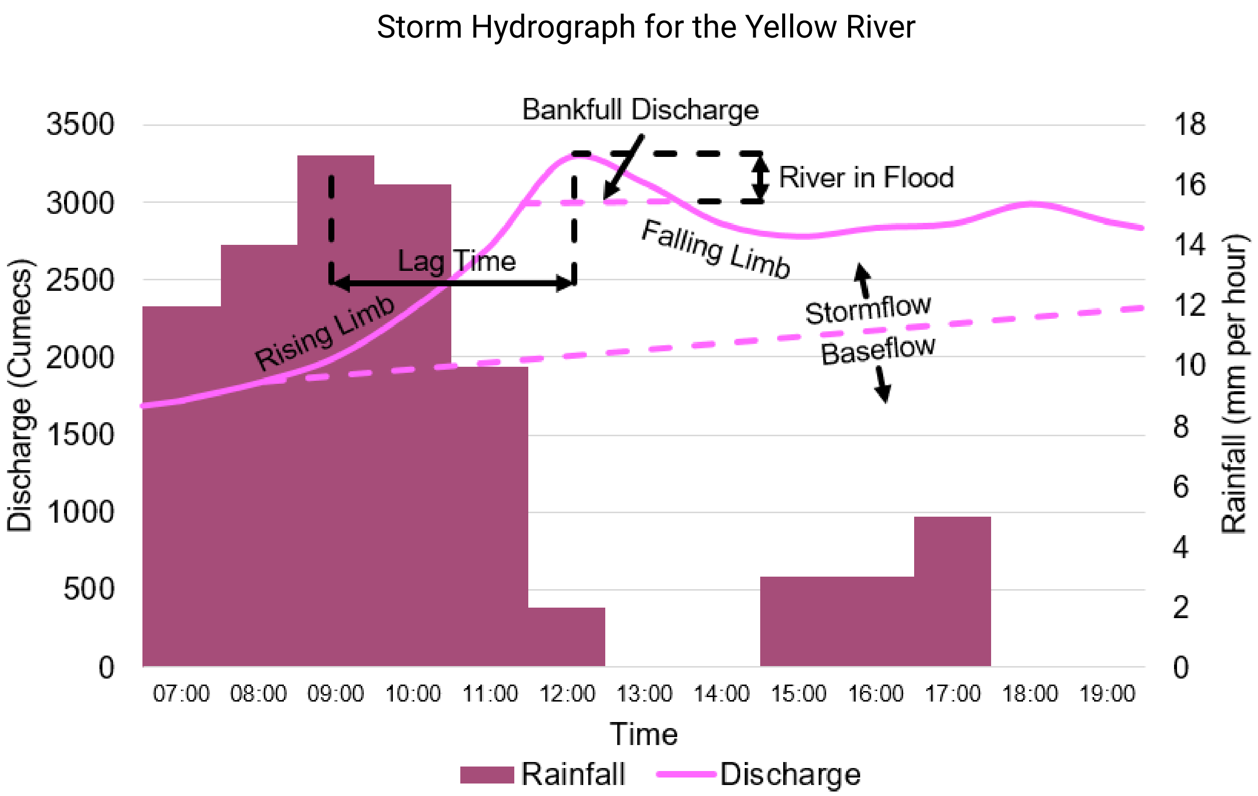
A hydrograph is a graph that shows how **river discharge** changes over time. **Discharge** is the **volume of water in a river at a given point**, measured in **cubic metres per second**. This combines the **speed of the river in a given direction** (velocity) with the **area of a cross sectional point** (area) to show how **much water** is travelling through an area, and how **fast** it's doing so.



A hydrograph may show how a river channel changes in response to a **storm event** (storm hydrograph) or it may show the changes of a river channel **over a year** (annual hydrograph).

Storm Hydrographs

Storm hydrographs show how a **storm event** (with consequent higher precipitation levels in the drainage basin) alters the discharge of a river. The hydrograph can be used to identify several components of a flood.



- **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 **baseflow and stormflow.**
- **Rising Limb:** The line on the graph that represents the **discharge increasing**.
- **Falling Limb:** The line on the graph that represents the **discharge decreasing**.
- **Lag Time:** The time between **peak rainfall** and **peak discharge.**
- **Baseflow:** The level of water that the river holds **without** contributions by overland flow. This is the 'normal' discharge line (without precipitation).
- **Stormflow:** This is the **additional water** in the river bank during a storm, 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. When the discharge goes above the line labelled above, it is in **flood**.

Storm hydrographs can usually be separated into **flashy hydrographs** or **subdued hydrographs**.

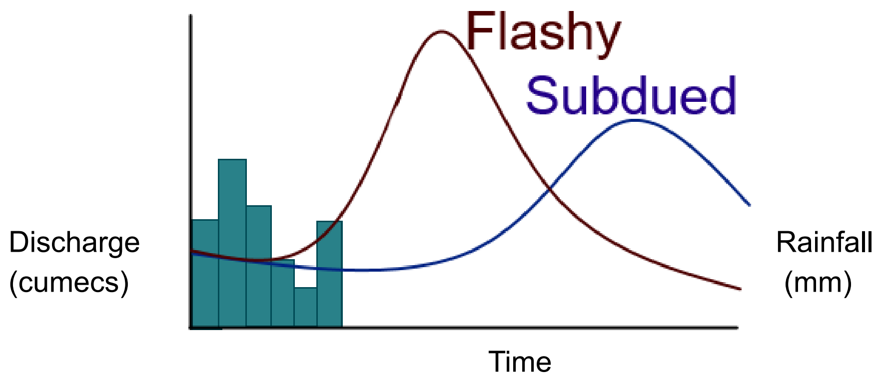
Flashy Hydrograph: Short lag time and **high peak discharge**, most likely to occur during a storm event, with favourable drainage basin characteristics

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

Features of Flashy and Subdued Hydrographs

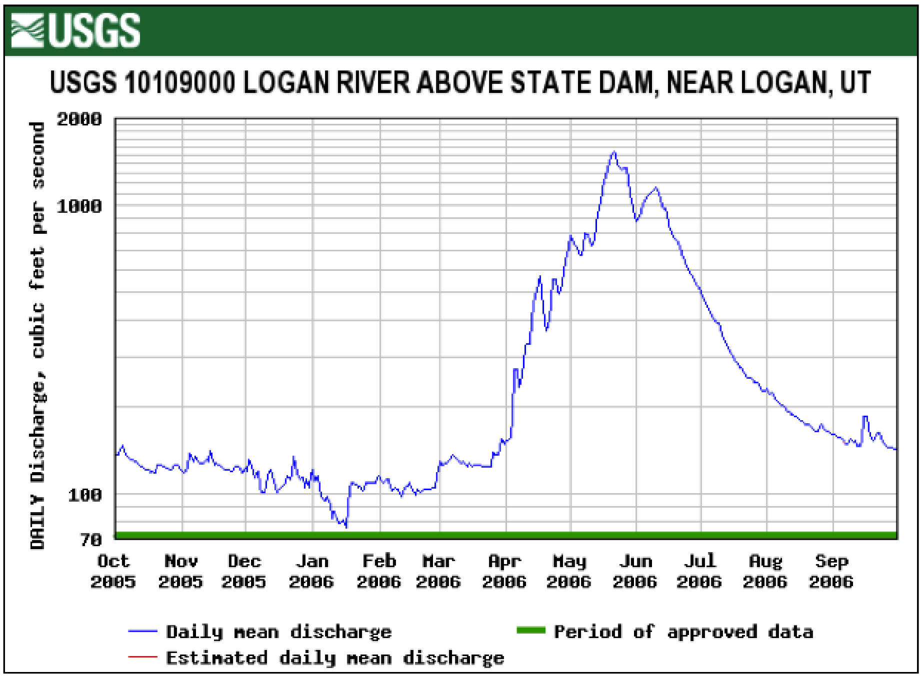
Flashy:
- Short lag time
- Steep rising and falling limb
- Higher flood risk
- High peak discharge

Subdued:
- Long lag time
- Gradually rising and falling limb
- Lower flood risk
- Low peak discharge



Annual Hydrographs

Annual hydrographs show how discharge changes over **a year**. The discharge is usually an average, such as a daily or weekly average. Annual hydrographs allow **different trends** of a river to be seen, such as seasonal variations.



(Source:serc.carleton.edu/integrate/teaching_materials/water_science_society/student_materials/865)

Influences on Hydrographs

Hydrographs vary in different ways (as seen by **flashy/subdued hydrographs**, and the **variation in discharge** on an annual hydrograph). These variations are influenced by a number of factors, mainly concerned with the **climate** the river is in, and the **drainage basin** the river is part of.

CLIMATE

Precipitation

Precipitation varies with the **climate**, and these **variations affect hydrographs**. Overall, **more precipitation will lead to a flashier storm hydrograph**, and will also create higher levels of **discharge** on an annual hydrograph.

Storm events influence hydrographs due to the **fast and heavy rainfall** falling in **short periods of time**. When **above average amounts of precipitation fall** in short periods of time, there is not enough time for **the water to infiltrate**, and instead it flows into the **channel**. **Bankfull discharge** is reached quickly and any discharge **above that line** on the hydrograph flows outside the river channel.

The **type of precipitation** also affects **discharge in a river**. If water falls as **snow**, for example, it can be stored as **surface water** for longer. Therefore, it would take longer to **reach the channel**, affecting the **lag time**.

Temperature

Temperature has a direct relationship with **evaporation**. When temperatures are **higher**, water particles have **more energy**, meaning they are more likely to **evaporate**.

Therefore, in **warmer climates** or in **warmer seasons**, **water** stored in **soil**, **bodies of water**, **on trees** etc. evaporates, meaning **more water can be stored in them before they reach their capacity**. When precipitation does fall (dependent on the type of precipitation), more of it can **infiltrate the ground** or be **stored**, meaning less water **overall** reaches the river. Therefore, **the overall discharge** will be lower.

Antecedent moisture

Antecedent moisture is the **pre-existing level of moisture** within soil before precipitation. The level of moisture in the soil affects the amount of **infiltration**, which therefore affects **hydrographs** (as infiltration has a direct affect on river discharge).

- Highly saturated soils have **a lot of water already stored**, meaning the soils will reach their **field capacity** sooner, and water will flow as **overland flow** instead. Thus, there will be **more water** flowing as **channel flow** rather than **through flow** or **infiltration**.
- If antecedent moisture is very low in soils, the soils may become too dry for water to **infiltrate** as soils can **structurally deteriorate**. This means more water **flows as overland flow** and into channels, increasing discharge.
- Higher levels of overland flow leads to higher levels of channel flow, therefore increasing the **discharge in a river**. This leads to a **flashier hydrograph** - one with higher discharge levels as well as a quicker lag time.

Seasonal Variations

Precipitation and temperature change depending on the season, and these changes have different **effects** on the drainage basin. For example:

Spring and Summer

- More vegetation growth, meaning **more interception by vegetation** and more **transpiration**. Therefore, soil saturation content is **lower** and potentially more water can **infiltrate** into below ground stores.
- Precipitation is usually **lower** in many regions, therefore leading to **less saturated soil** as well as **less water** flowing as **channel flow**.
- If precipitation becomes **very low**, the ground may become **hard** and less permeable. This leads to more **overland flow** as the water cannot infiltrate, potentially leading to **high discharge**, especially during storm events.

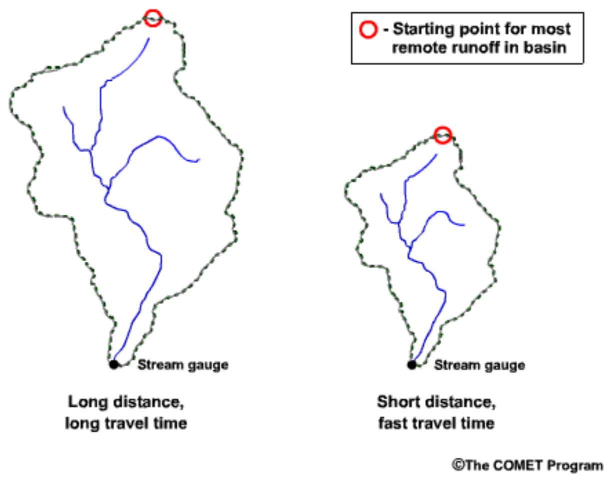
Autumn and Winter

- **Less vegetation growth** and cooler temperatures. This leads to less interception as well as less transpiration, leading to more **overland flow** and therefore **higher discharge.**
- **Soil** may be more **saturated**, leading to more **overland flow** and higher river discharge.
- Frozen ground may be **impermeable and lead to overland flow**. **Snow** takes time to melt, therefore leading to a **longer lag time** and more opportunity for water to **infiltrate** the ground. slowing down the processes that occur within the water cycle.

DRAINAGE BASIN CHARACTERISTICS

Size of Drainage Basin

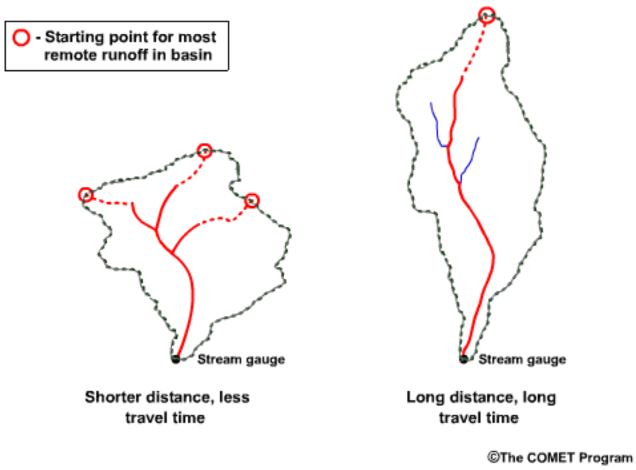
The **size** of the drainage basin affects **discharge** in a river. In **larger drainage basins**, overland flow has **more distance to cover** before it reaches a river, potentially leading to a **longer lag time**. Furthermore, large basins cover **more area**, therefore there is potentially **more water in this area** to flow into the river, leading to a **higher peak discharge**.



Shape of Drainage Basin

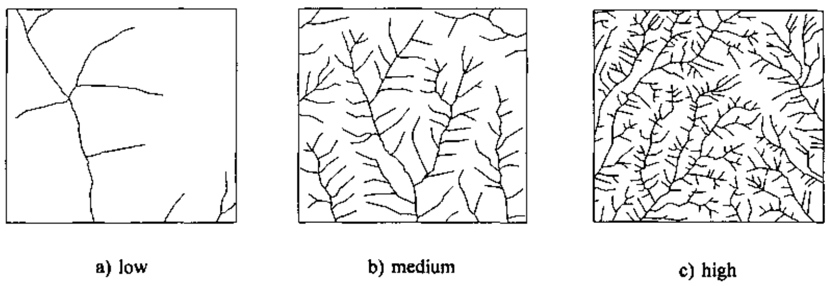
In **circular** drainage basins, different **starting points of overland flow** are likely to be **similar distances** apart, meaning they are more likely to **join the river at a similar time**. This leads to a **large quantity of water** concentrating into an area in a **short space of time**, therefore increasing **peak discharge** as well as **shortening the lag time**.

In contrast, in an **oval drainage basin** of a similar area, the starting points of **overland flow** will be different distances apart, meaning they will arrive **at different times**. Due to this, the lag time will be **longer**.



Drainage Density

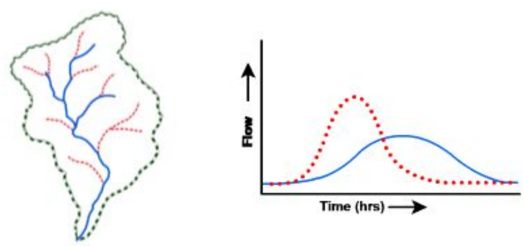
The **drainage density** is the **total length of all rivers and streams** in a drainage basin divided by the **total area of the drainage basin**. The drainage density is an **indicator** of how well the drainage basin is **drained**.



(Source: http://sageography.co.za)

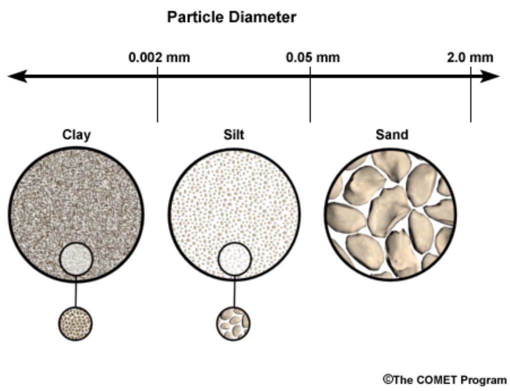
In a drainage basin with a **high drainage density**, there are **more streams and rivers** carrying water, meaning the peak discharge is **high** and it is reached **quickly**, meaning there is a short lag time. As well as this, the amount of rivers mean the water is **drained quickly**, leading to a steep **falling limb**.

In areas of **low stream density**, overland flow is more likely to **infiltrate** rather than make its way into channels, therefore lengthening the lag time and lowering the peak discharge, as there is less water draining into the river.



Porosity and Permeability of Soils

Particles with **larger pores** will allow water to **infiltrate faster**, as there is **more space available for water to enter**. Therefore, in periods of **intense, heavy rainfall**, sandy soils - for example - will infiltrate more water than clay soils, and drainage basins with **sandy soils** would have a **more subdued storm hydrograph** as there is less **overland flow**.



The **porosity** of clay soils is higher than that of **sandy soils** as overall there is **more space** in between each soil particle, therefore clay soils can hold more water **overall**. In periods of **lighter rain** (when there is time for water to infiltrate the clay soil), overland flow may be higher in areas with **sandy soils**, leading to higher river discharge.

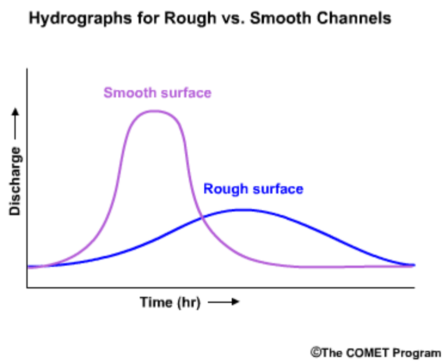
Rock Type

Similarly to **soil type**, **rock type** also affects **drainage**, therefore affecting **river discharge** within the drainage basin.

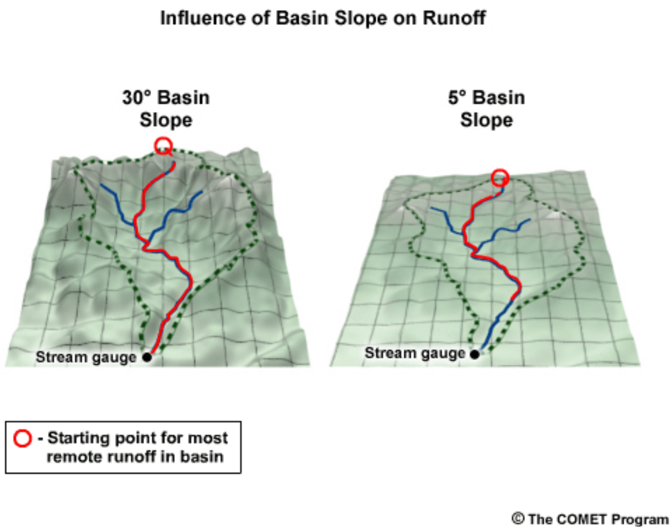
Permeable rocks such as sandstone infiltrate **more water** than **impermeable rocks** as there are **spaces** for water to seep into. Therefore, drainage basins with **permeable rock** will have **less overland flow**, leading to **less discharge**. Furthermore, water stored in soil **on top** of the rocks can **percolate** into the rocks below, making the soil **less saturated** and therefore more capable of **holding water**.

Topography and Relief

A **rough**, **jagged** topography reduces the **velocity** of water, as the flow of water is interrupted with **bumps**, **rocks**, debris etc. In contrast, a smoother topography allows water to move **quickly**. Therefore, in areas with jagged topography, peak discharge is usually lower due to **slower overland flow**.



A **steeper slope** allows water to **travel faster** as the force of gravity is **stronger**. As well as this, water therefore has **less time to infiltrate**, and more of it flows as overland flow. This makes the lag time **quicker** and the peak discharge **higher** (a flashier hydrograph).



Vegetation

A **well vegetated** drainage basin encourages surface water to **drain into the ground** rather than flowing as **overland flow**.

Tree and plant roots create **passages** for water to **infiltrate** into the **lower layers of soil**, meaning less water flows as **overland flow** and therefore less water goes into the river channel. Furthermore, vegetation decreases **soil moisture content** as **vegetation takes up water** and releases it into the atmosphere through **transpiration**. This process is more significant in forested areas, rather than **grassy** fields, for example.

Land use

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.**
- Overall, this leads to a **flashier hydrograph**, with a shorter lag time and higher peak discharge.

Agriculture:

- **Livestock** can trample the ground **reducing infiltration** as the pore spaces are lost.
- **Ploughing increases infiltration** by creating a looser soil, which decreases overland flow. 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**, therefore affecting the water table and therefore allowing more **water** to enter channels before the river is in flood.

Urbanisation:

- **Roads and buildings** have **impermeable surfaces**, **reducing infiltration** and **increasing overland flow**. This **reduced lag time** and **increases the peak discharge.**
- **Urban drainage** reroutes large amounts of water to different areas, meaning water **outside the natural drainage basin** can flow into a river, increasing peak discharge.

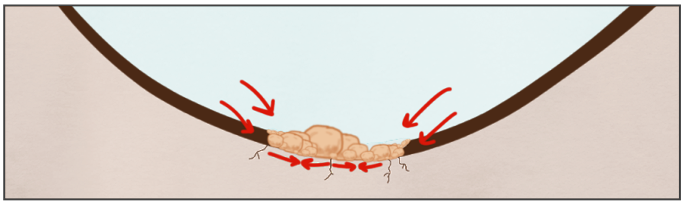
River Channel Processes

River channels are influenced by a number of **processes**, affecting the shape and flow of a river.

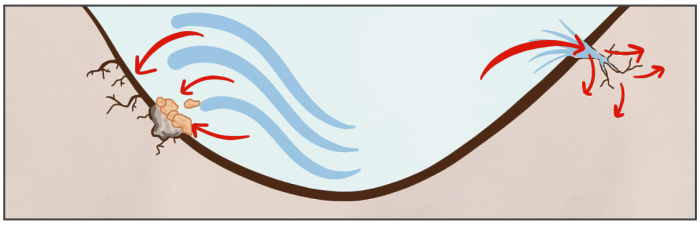
Erosion

Erosion is the **process** of the **wearing away of soil and rock**. In a river channel, both the **force of water** as well as **fragments of rock** cause the river bank to wear away in certain areas over time. There are four main types of erosion in a river channel:

- **Corrasion:** This is the process of rocks **scraping and grinding** (known as **abrasion**) along the river channel, causing soil and rock to wear away. This usually causes the river bed to deepen and widen, and is especially prominent when a river is flowing **with high velocity** (like during a flood) as it has enough **energy** to carry larger rocks.



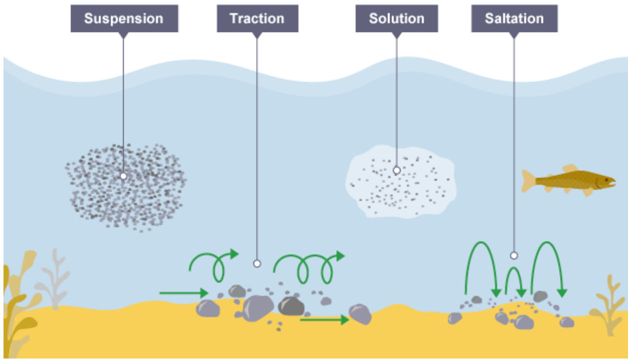
- **Solution:** This is the process of **water dissolving** parts of rock/soil that makes up the river channel. Solution is most prominent when the river channel is made from **water soluble rocks**, such as **chalk, gypsum, or limestone**. Water can slowly wear away at the river channel over time through this process.
- **Hydraulic Action and Cavitation:** These processes are concerned with the force of **water** eroding the river channel. **Hydraulic action** is the sheer **force of water** can cause **rocks to fragment off** when the channel is hit (left). **Cavitation** is where water forces its way into **small cracks**, causing the air in these spaces to be **compressed and put under pressure**, widening the cracks and fragmenting the rocks (right).



Transportation

A river's **load** is the sediment and materials transported by a river. The load is transported in different ways, dependent on its **size**:

- **Traction:** The movement of larger rocks and pebbles through water **rolling them along the river bed**. As the rocks are heavier, they cannot be **carried by water** within the channel as the river does not have enough energy.
- **Saltation:** Pebbles are **bounced along the riverbed**.
- **Suspension: Small pebbles** and material are **carried** (suspended) within the water, rather than rolling/bouncing along the river bed.
- **Solution: Soluble materials** are carried within the water.



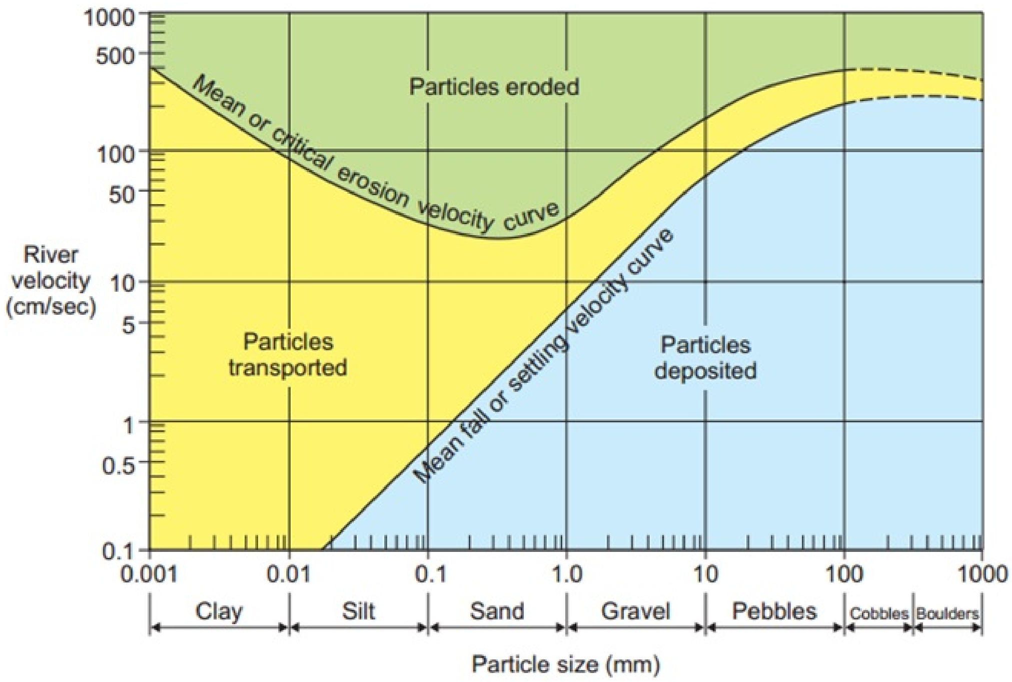
(Source: https://www.bbc.com/bitesize/guides/zq2b9qt/revision/2)

Deposition and Sedimentation

Deposition is where the **river drops its load** when the river **no longer has enough energy to carry the load**. Deposition may occur when a **river becomes shallower** or when the **volume of water decreases**.

The Hjulström Curve

The Hjulström Curve is a **graph** that shows how the **velocity** of a river affects the river's **material**. The relationship between **material size and velocity** is presented, and the graph shows whether the material will be **eroded, transported, or deposited** based on its **size** and the river **velocity**.



(Source: https://www.thegeoroom.co.zw/hydrology/hjulstrom-curve.php)

The main points to take from this graph are:

- The graph is **logarithmic**
- The **critical erosion velocity curve** (the top curve) is the **minimum velocity needed** for the material to be **picked up** and then **eroded**. The velocity must reach this line for the material to be transported **initially**, but once the velocity **exceeds** this line (in the **green** area), there is a likelihood that the particle will be **eroded**.

For example, a particle that is 0.1mm will not be picked up until the velocity of the river has reached 30cm/sec (the critical erosion velocity curve).

However, if the velocity then falls below 30cm/sec after the 0.1mm particle has been picked up, the particle will still be transported until the river velocity reaches 0.6cm/sec (the settling velocity curve), at which point it will be deposited.

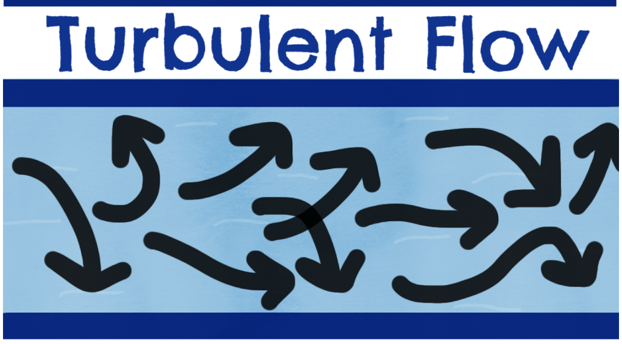
I.e., if the particle is in the yellow area, it will continue to be transported until it reaches the blue area, but it must meet the critical erosion velocity *initially* to be picked up.

- Overall, the **critical erosion velocity curve** shows the relationship between **material size** and the **energy** (velocity) needed to **transport** and **erode** it. In general, the **larger the material size**, the more energy needed to transport/erode, therefore the **higher the velocity needed**. This is not true of **clays** and **silts**, because these **bond together**, meaning it is harder to break the particles up to **transport/erode them**. (notice how the **critical erosion velocity** is much **higher** for these smaller particles than sand)
- The **settling velocity curve** is the point at which the material **no longer has the energy** required to be transported, meaning it is **deposited**. If the velocity falls below this line into the **blue** area, there is a likelihood that the particles will be **deposited**. The larger the material, the higher velocity needed to keep the particles transporting.
- There is no **settling velocity** for **clays and silts**, as once they are transported, they will continue to be transported, and will not be **deposited**.

River Flows and Channels

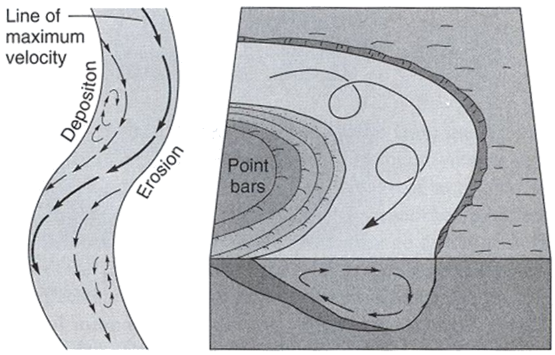
Rivers flow differently throughout their course, and there are different types of channels.

- The flow of water in parallel streams
- No cross currents or swirls
- One directional, orderly flow



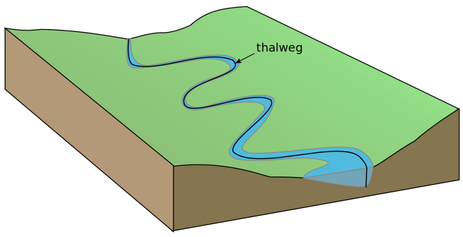
- Disorderly flow
- Changes in velocity (speed and direction)
- Can be caused by friction, especially when river channels are irregular
- Eddies (swirling reverse currents) common in this flow.

Helicoidal Flow

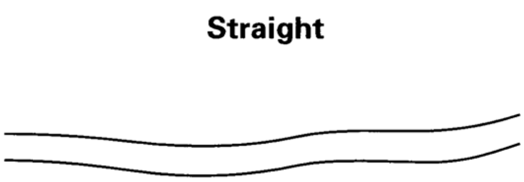


- **Corkscrew** movement of water (spiral)
- Occurs in bends in the river channel called **meanders**
- Responsible for the erosion and deposition in a meander

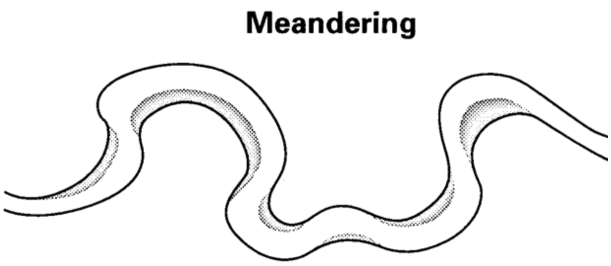
Thalweg: This is the line of **fastest flow** (maximum velocity) within a river. This is also the **deepest point** within the river channel (as **erosion** is greatest when stream flow is fastest)



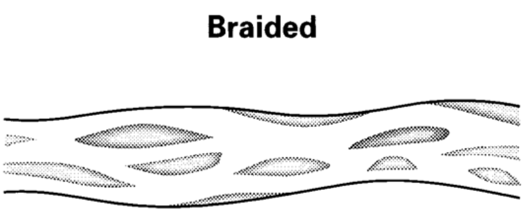
Channels



- Mainly in the **upper course** of the river
- Single, straight channel
- **Vertical erosion** is prevalent
- **Thalweg** moves from side to side



- **Middle and lower course** of the river
- Series of **bends** and curves from side to side
- Deposition on the inside of the bend
- Erosion on outside of the bend



- Large **deposits of sediment** within the channel, causing multiple channels separated by islands of sediment
- Usually occur where discharge **fluctuates**
- River deposits when it loses energy
- Do not usually occur in the **upper course**

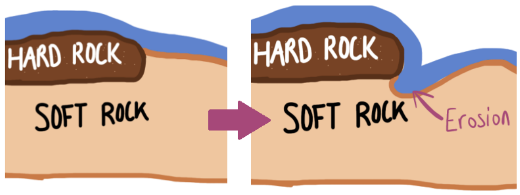
River Landforms

Waterfalls

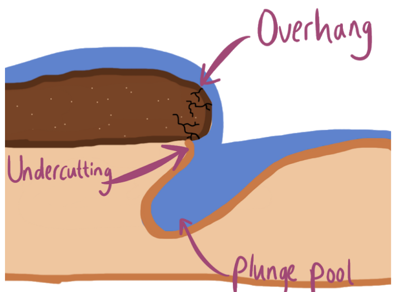
(Source:www.yorkshire-dales.com/ingleton/thornton-force)

Thornton Force, The Yorkshire Dales

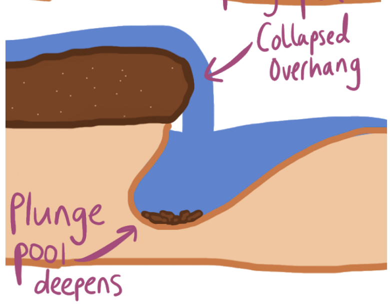
In an area where **a river flows over an area of hard rock and soft rock**, the soft rock erodes more **quickly**. This causes the soft rock to erode away beneath and underneath the hard rock, creating a **step**.



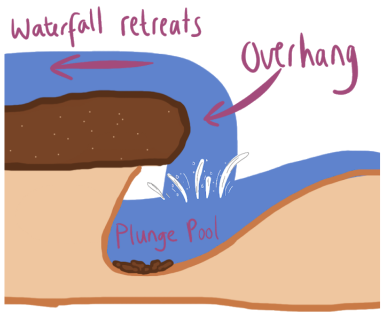
Over time, the soft rock continues to erode further, **undercutting the hard rock**. The hard rock is not eroded as quickly, leaving it suspended in the air as an **overhang**. The **rotational movement of the water** quickens erosion, creating a **deep plunge pool**.



Due to the force of gravity, the **unsupported overhang** collapses. The broken up rocks fall into the **plunge pool**, which act as **tools for erosion** and further **deepens** the plunge pool. Erosion also continues to **undercut underneath the hard rock**, creating an overhang again.



The continual process of the **overhang collapsing** causes the waterfall to **retreat upstream** over time. The **plunge pool continues to deepen**, and the **hard rock continues to be undercut** to create an overhang.

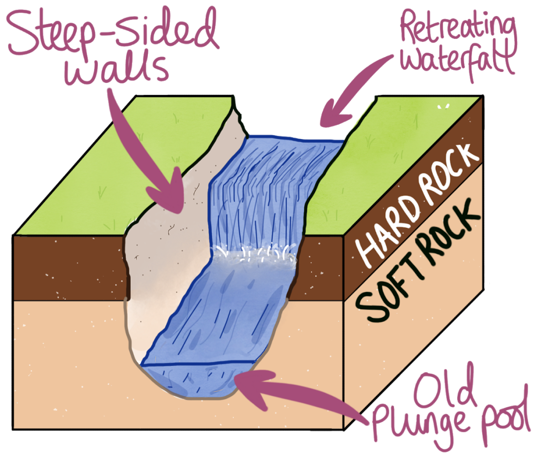


Gorges

(Source:www.flickr.com/photos/syromaniac)
Tiger Leaping Gorge, China

A gorge is a **steep sided, narrow valley** with a river flowing through it.

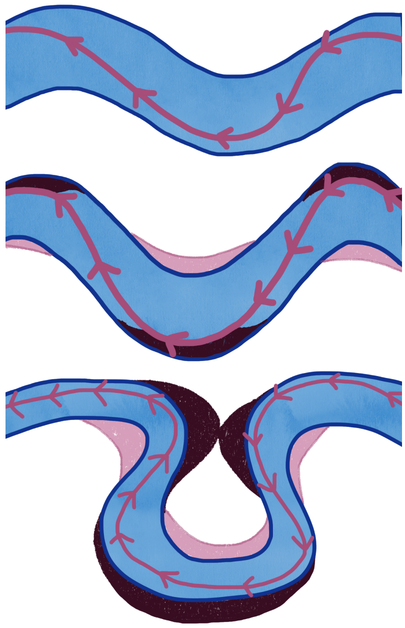
A gorge is formed when a **waterfall continually retreats over time**. The **back of a waterfall wall** and the **channel floor** is eroded, whereas the valley sides are not, leaving a **deep gorge** when the waterfall retreats upstream.



Meanders

Cauto River, Cuba

The **thalweg** is located on the outside bend of a river. This is the line of fastest flow.



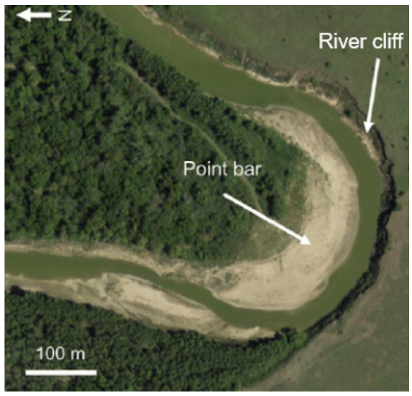
Erosion is stronger on the **outside of a bend**, as this is where the river is at its **highest velocity**. The river channel is at its **deepest** here, meaning there is less **friction**.

Deposition is more prominent on the **inside of a bend**, as this is where the river is at its lowest velocity. Therefore, it has **less energy** to carry the material and instead **deposits** it. The river channel is at its **shallowest here**, causing the water to be slower due to **friction**.

Over time, erosion causes the **outside bends to get closer**, until only a **small area of land remains** (called the **neck**).

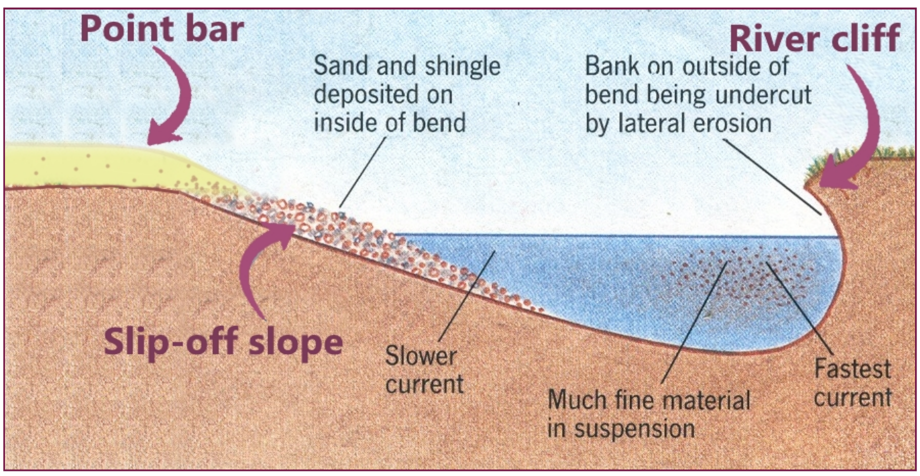
Cross-section of a meander

Within the river channel of a meander, different **landforms** occur as a result of the **erosional and depositional processes**.

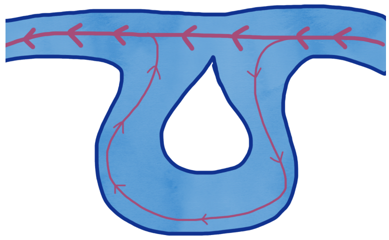


River cliff: A cliff created when the bank is **undercut** by erosion on the **outside of the bend**.

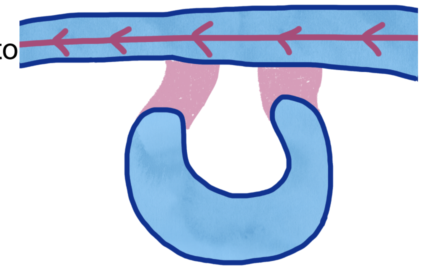
Point bar: A **deposit** of fine sediment, such as sand, on the river bank **inside of a meander bend**. The point bar usually changes position as the meander changes shape, leaving a mark where it once was.



Oxbow Lakes



When a river is in **flood** and it **breaks its banks**, the river will flow along the **shortest available course**. In some meanders, this will be **across the neck**, cutting off the meander.



Eventually, the meander bend becomes fully cut off due to **deposition**. This forms an oxbow lake.

Bluffs

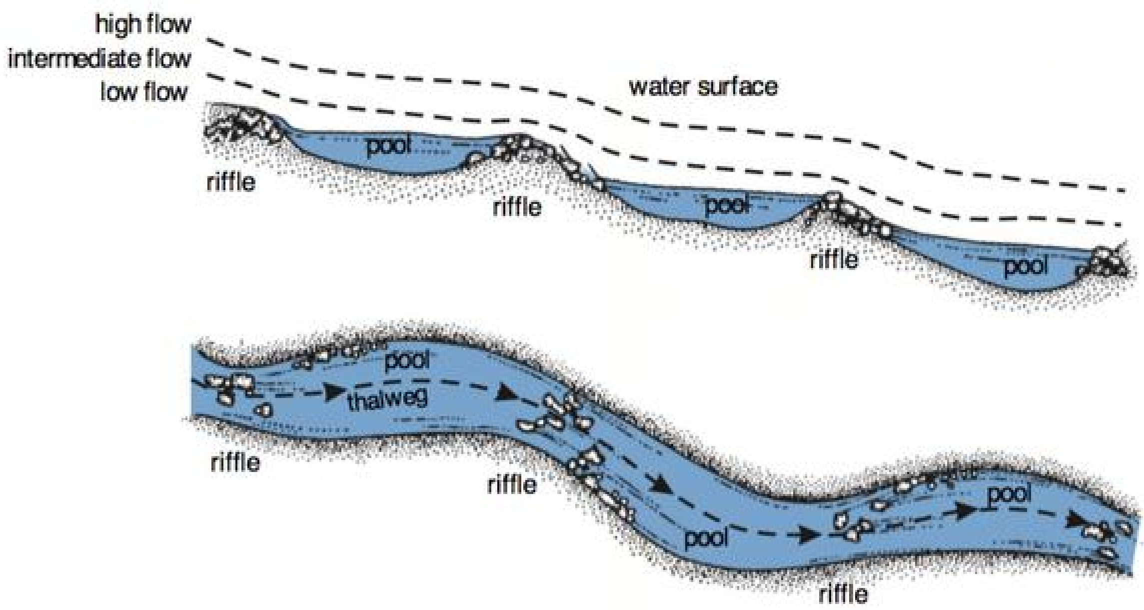
(Source: National Geographic)

Pecos River, Texas

A bluff is a **large, rounded cliff** on the side of a river.

- Bluffs are formed on the **outside bend of a meander**, where **erosion** is dominant.
- The water **erodes** the **lower section of the river bank**, causing the upper section of the river bank to become **unsupported** and therefore **unstable**.
- Eventually, the **unsupported upper part of the bank collapses**, causing a steep bluff to be left.
- Bluffs also occur when water in the outside bend of a meander erodes a **steep valley wall**. This occurs on a **wide flood plain**, when a meander (over thousands of years) shifts from side to side to reach the valley wall.

Riffle & Pool Sequences



(Source: https://content.ces.ncsu.edu/natural-stream-processes)

Riffle-pool sequences are **alternating patterns of shallow and deeper water** in a river channel, common in rivers with **gentle slopes**.
These are formed because a **river tends to adjust its course of flow** to **efficiently** transport its load downstream (using as little energy as possible).

Riffle: The **higher**, **shallower** area of the sequence, characterised by deposits of material.
Pool: The **lower**, **deeper** area of the sequence.

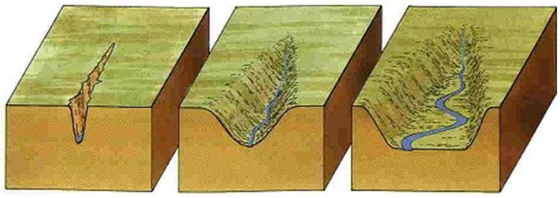
Floodplains

(Source:riverwatch.eu/wp-content/uploads/2014/09/Lonjsko-Polje-Goran-Safarek-11.jpg)

Sava River, Europe

A floodplain is a **large, flat area of land** near a river, that forms due to **erosion** and **deposition**.

Over time, meanders can **erode a v-shaped valley** into a wider, **flat valley** shown below.



When a river is in **flood**, the sediment that is transported **within the river** leaves the channel and **spreads out** onto the river bank.

The water **loses energy** when it is no longer flowing through its channel, meaning the sediment is **deposited** onto the flat plain.

Over time this deposition **builds up**, making it higher. The soil is usually very **fertile**.

Levees

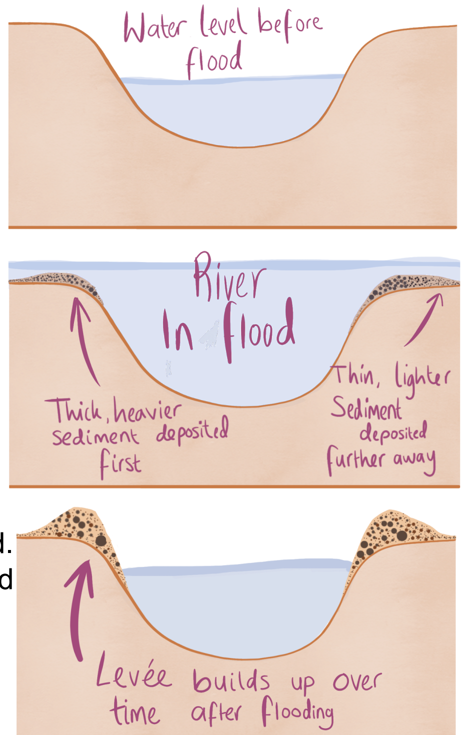
River Brue, Southern England

Levees are **natural embankments** along a river that build up due to **repeated flooding**. They create **raised edges** on the river bank, making it less likely for the river to **break its banks**.

When a river floods, the **sediment** being **transported** in the river floods onto the **floodplain**.
The **heavy, coarse material** is deposited first (closest to the river channel), because it requires the **most energy** to be transported.

The **finer, light sediment** (such as sands and silts), require less energy to be transported, so it can be transported and **deposited** further away from the channel. This creates a **tapered shape**.

Over time, the levee becomes larger and more well-formed. River levels can be **higher** without breaking the bank and flooding; the levees act as **natural flood defences**.



Deltas

(Source: NASA)

Dvina River, Russia

Deltas form at the **mouth** (end) of a river, where the river carries a **large amount of sediment**. When a river meets **a body of water** (a lake or an ocean) there is a large **difference** in velocity between the **high velocity river** and the **low velocity water body**. This causes the river to **mass deposit** sediment, causing a series of **sediment islands** with smaller **streams** and rivers flowing through them.

The Human Impact

Many **human activities** and **modifications** can **impact a river**. This may be a **physical modification to a river**, such as a dam, or it may be a **secondary effect**, such as **greater channel flow** levels due to urbanisation increasing **interception** rates.

Land-use Changes

Humans modify the land **surrounding a river**, which - in turn - affects a variety of flows in the **hydrological system**.

Deforestation & Afforestation

Deforestation is the **removal of trees** by felling, burning, or other means of removal. Deforestation affects the drainage basin in **multiple ways**:

- **Evapotranspiration decreases:** The lack of trees causes **less water to be evaporated into the atmosphere** via transpiration. Therefore, there is more water **on/in the ground** that can **flow** into a river.
- **Infiltration rates decrease**: although there is less **plant material** blocking water from **infiltrating into the soil**, tree roots play a **vital part** in allowing water to infiltrate. They provide natural **gaps** within the soil to allow water to enter and **percolate** into groundwater stores. Without trees, ground can become **less permeable**, increasing overland flow.
- **Interception decreases:** Trees and their leaves can **intercept** precipitation. Without these trees, the precipitation that **would have been intercepted** instead falls straight onto the ground, where it either **infiltrates** the soil, or **flows as overland flow**.
- **Channel flow increases:** As overland flow increases due to a number of reasons (less transpiration, less infiltrated, and less interception), more water flows **into** the river channel. This **increases discharge** and can make it more likely for a river to flood, especially when precipitation is higher.

Afforestation is the **planting of trees** in an area **without trees**. Afforestation has the **opposite effect** of deforestation (more interception, less overland flow, more transpiration etc.). Afforestation may work to **decrease channel flow**, causing **lower river levels**.

Urbanisation

In general, urbanisation usually causes **larger flows** into the river channel:

- **Roads and buildings** have **impermeable surfaces** and are likely to have **drains**, which **reduces infiltration rates** but **increases overland flow**.
- **Deforestation and lack of trees/greenery** decreases **transpiration**, which therefore leaves more water in the catchment area.

Water Abstraction

Abstraction is the **removal of water** from a water body, such as a river, lake, reservoir, or groundwater store. This is usually done in order to **meet water demands** for drinking water, sanitation etc.

Water abstraction may be **unsustainable** (i.e. the **abstraction rate** is higher than the **replenishing rate**, causing a **deficit of water**) which can cause changes in the river and its catchment area.

- Water levels can **deplete**, both on the surface and **groundwater levels.**
- This can affect **channel flow** and **discharge**, and may cause more **deposition**.
- The water table may fall when groundwater is overexploited, meaning there is less **groundwater seepage** into **above ground water stores**, which may cause above-ground water levels to fall.

A dried up well, caused by lowering groundwater levels.

Water Storage

Water can be stored **above ground** by **dams and reservoirs**. This form of **unnatural** water storage affects the catchment area and flows in different ways:

- Dams directly **stop and control** channel flow, as they provide a **barrier** in the way of a river channel
- Reservoirs behind dams can **raise the water table** underground, and can affect **soil saturation** if not properly managed. This may lead to a **lowering of the water table** in other areas as the water that would normally be **flowing** in other areas is instead being stored in the reservoir.
- Reservoirs are usually **very large**, meaning a lot of water can enter the **atmosphere** through evaporation and increase cloud formations in the area, affecting **precipitation**.

(Source:https://www.ice.org.uk)

River Flooding and Management

Causes of Flooding

River flooding occurs when a river **bursts its banks**, causing water to **spill out of the river channel** onto the area surrounding it. This can occur due to a number of reasons:

- **Heavy rainfall** in a short space of time, causing large amounts of **overland flow** to overwhelm the river channel.
- **Prolonged periods** of rainfall, leading soils to be so **saturated** that water can no longer infiltrate and flows as **overland flow**.
- **Impermeable surfaces**, either caused by **impermeable materials** such as impermeable rock or caused by **structurally compromised soil** (e.g. very dry soil or frozen soil).
- Melting snow or glaciers contributing to **channel flow**.

Flooding has many **impacts** on the **environment**, the **economy**, and **people**:

- Water and sediment leaves the river bank and spills onto the **floodplain**, which can **waterlog plants** and put wildlife in **danger**.
- Floods can transport **materials** (e.g. building materials, sediment, general waste, chemicals etc) and deposit them in **clean water supplies**, potentially causing **more** environmental damage, especially to **aquatic life**.
- Powerful floods can **damage buildings**, potentially destroying **infrastructure**, people's **homes**, and **businesses**. Water can enter buildings and **destroy it**, but also the sheer **force of water** can be enough to **damage and destroy structures**, especially bridges.
- Many **social issues** arise from flooding, such as **homelessness**, emotional **trauma**, **poverty**, **disease**, as well as **injury or death** as a result of the floods.
- The **economy** can be damaged from flooding as businesses are forced to close from flood damage. Furthermore, money is spent on **flood defences**, **insurance pay out**, and **clean up**.

Cockermouth High Street in November 2009, after a storm that flooded 2,239 properties.
(Source: www.bbc.co.uk)

New self-closing flood defences put in place in 2013 to reduce the effects of flooding. (Source: www.theguardian.com)

Predicting Flood Risk

Modern technology has made it possible to **calculate the risk of river flooding** before the flooding is an imminent risk. Flood risk can be calculated in advance:

- The **probability of a flood** of a certain size can be predicted based on **past flooding** records. This is known as a flood recurrence interval, which is discussed in more detail below.
- Floods can be **modelled** using software and other equipment, to predict how **different circumstances would affect flooding**. For example, the **slope**, **topography**, **precipitation** rates, soil **moisture** content, and many other aspects that affect flooding can be **modelled**. Using these models, the **risk** of a flood can be calculated.

Flood risk can be predicted to be low, medium, or high, and these predictions are very important decisions such as **construction work** or **insurance policies**. This map shows the predicted flood risk for the whole of the UK (flood-warning-information.service.gov.uk/long-term-flood-risk/map.)

Flood Recurrence Intervals

Flood recurrence intervals are a method of **presenting the probability of a flood of a given size** in an area. Recurrence intervals are in **years**, e.g. a flood may be described as a **50 year flood** or a **100 year flood**. A **100 year recurrence interval**, for example, is described as a '100 year flood'.

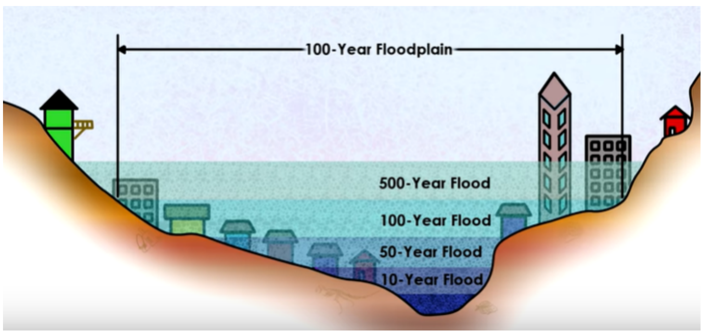
It is important to recognise that if a flood is described as a **100 year flood**, this **does not mean** the flood will occur **once every 100 years**. The term can be **confusing and misleading**, as it can imply that the flood is a **once every 100 year event**, but this is not the case.

What the term '100 year flood' does mean is that there is a **1% chance of a flood of this size occurring any given year** (i.e. there is a 1/100 chance of a flood this size occurring any given year). If a flood of that size does occur one year, there is still the **exact same probability** (1%) that a flood of the same size will occur in the next year. The **higher the recurrence interval**, the less **likely** it is for a flood of that size to occur. For example:

- A recurrence interval of **10 years** means there is a **1/10 chance** of a flood that size occurring any given year (**10%**), meaning it will be a **smaller** flood.
- A recurrence interval of **1000 years** means there is a **1/1000** chance of a flood that size occurring any given year (**0.1%**), meaning it will be a **larger flood**.

This **video** explains the concept of a 100 year flood in more detail:
(https://www.youtube.com/watch?v=mEY64UpYj0M)

Flood recurrence intervals are important when **assessing the risk of flooding in an area**. If the recurrence interval is longer, the probability of a flood of a given size is smaller, therefore there is hypothetically **less risk of a flood in that area**.



(Source: www.youtube.com/watch?v=EACkiMRT0pc)

River Flooding Management: Prevention and Amelioration

The **effects** of a river flood can be **limited** through certain **strategies**. Flows can be **physically altered** in order to **control flooding**, or the effects of **flooding** can be **mitigated** through different means.

Forecasts and Warnings

Flood forecasting uses **precipitation forecasts** to estimate the level of flooding risk in an area. **Streamflow data** and **models of streamflow routes** can calculate **the areas most at risk** when heavy precipitation is forecasted, meaning **warnings** can be issued **days before**. Early warnings are **vital** in the preparation for flooding, as people can **take action by evacuating, moving valuables, sandbagging etc.**

In the UK, the **Met Office** issues flood alerts (amber) flood warnings, and severe flood warnings (all red) to people may act accordingly. An **amber** flood alter means '**be prepared**', whereas a severe flood warning means '**danger to life**'.

<table>
<tr><th colspan="2">HARD ENGINEERING
Physically altering a river and its channel through building structures or using machinery.</th></tr>
<tr><td>Dams

The Masudagawa Dam in Japan, built for flood control (Source: https://www.ctc-n.org)</td><td>Dams physically obstruct a river's natural course, leading to the build up of a reservoir behind a dam if channel flow is large enough. Some dams are built for the purpose of flood control, whereas others are built for water storage.

Dams are effective at preventing flooding as the river can no longer flow as there is an obstruction in the way. It is only if the dam fails or if the dam is opened up in a controlled way that water can get through.

There are several issues associated with dams. These include dams being very expensive to build, the displacement of settlements, disruption of wildlife etc.</td></tr>
</table>

Channel Straightening  The Kissimmee River in Florida, which was straightened for flood control. The straightening of the channel has led to multiple environmental issues due to the faster water flow, and projects are underway to reintroduce oxbow lakes to slow the river flow.	**Straightening** is where bends and irregularities in the river channel are **removed** using machinery, leaving a straight channel, e.g. by cutting off meanders. River channels are **straightened** so that water flows **faster through the channel**, meaning water is less likely to **overflow onto the floodplain** and instead moves quickly downstream. There can be **issues** with straightening channels, as water is just **sent further downstream** where it can cause flooding further downstream and enhance erosion (as it is high velocity).
Levees  (Source:commons.wikimedia.org)	As well as occurring naturally, levees can also be **reinforced** or **constructed** for flood prevention. Similarly to **natural levees**, artificial levees provide a **raised embankment** so that water within the **river channel** has further to rise before it can **spill out of the channel onto the floodplain**.
Diversion Spillways  (Source: https://mapio.net/pic/p-38792160/)	A diversion spillway is a **constructed channel** that allows **excess water to flow into it** when the channel is overflowing. The spillway may **direct water** to further downstream, or it may **direct water to a different river**. On many spillways, there are usually **floodgates** that control when they are opened and closed. Spillways may direct water to **areas that do not flood naturally**, which can cause environmental damage if the spillway floods.

SOFT ENGINEERING

The use of **natural, sustainable** means to reduce flooding, rather than building structures.

Floodplain and Drainage Basin Management

(www.theguardian.com)

Sustainably managing the area **around the river channel** can limit flooding risk. Management strategies include:

- **Afforestation and tree management:** Planting trees in the drainage basin area can **overall decrease surface runoff**, which reduces flooding.

  Furthermore, afforestation must be **managed properly** to avoid creating **further problems**. For example, large, unstable trees on floodplains can potentially lead to **more flooding** as they can block rivers if they fall over. Therefore, it is important to develop **strong, sturdy rooted trees** that are less likely to be damaged in floods, which can be done through strategies such as **pollarding** (pruning the branches of trees).

- **Floodplain land use management:** Floodplains are very important to rivers and the environment around them. They provide the space for excess water to **infiltrate** into the ground, as well as **naturally blocking and diverting flood water**.

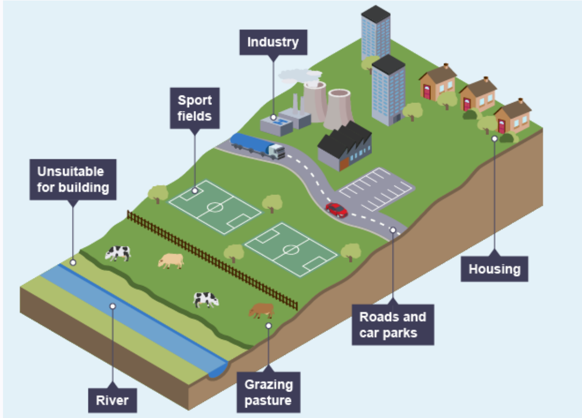
  Certain **activities** that take place on floodplains can **damage them** and limit their use as a **natural flood defence**. This can therefore **increase the risk of flooding in other areas** further away from the river. Therefore, it is important to **limit these activities** and **manage them** to reduce damage.

  Urbanisation on a floodplain can potentially be a very **damaging** form of land use on a floodplain. Not only does it **increase the risk of homes and businesses flooding** as they are so close to the river, but it also severely **decreases infiltration** by creating impermeable surfaces. **Limiting construction** on floodplains can reduce this risk.

  Agricultural land use on floodplains is thought to be **the most damaging form of land use on floodplains**. **Livestock** can **trample** soil, which reduces infiltration and affects the floodplain. Furthermore, **unsustainable farming strategies** such as **monoculture** (only cultivating one crop) or the use of **heavy machinery** can affect soils and therefore **reduce infiltration**. **Sustainable farming practices** are necessary in order to **preserve the floodplain**. In some cases, the floodplain may need to be **left to naturally restore itself**, in which case **agricultural subsidies** may be paid to farms in exchange for **limiting activity on floodplains**.

- **Floodplain mapping:** Decisions about **where to build** and **land use on floodplains** can be decided using **floodplain mapping**. Using **river flooding records** and other information concerning the floodplain, the areas **at risk of flooding** can be mapped. This information can then be used to make decisions about **construction and land use**, so that damage can be limited to both **property** and the **floodplain**.

  E.g. in areas of high risk, land use should be limited to activities that will have **low restoration costs**, such as **agriculture** or **sports fields**.



(Source:www.bbc.com/bitesize/guides/zg4tfrd/revision/4)

Wetland and River Bank Conservation

(Source: commons.wikimedia.org)

Wetlands are **ecosystems** that are **partially submerged** in water for periods of time, which limits **the availability of oxygen** and creates an environment for **aquatic plants and animals**.

Wetlands are **very important** to the river system, as they provide **environments that floodwater can inundate**, which limits flooding elsewhere. Wetlands are under **extreme threat** due to **climate change** as well as **human impacts** (such as draining to make land available for agricultural use). Therefore, strategies for wetland conservation are important to overall reduce the risk of river flooding. These strategies include:

- Banning or limiting the **drainage of wetlands**, to protect the ecosystem.
- Monitoring **changes** (such as **water level changes**, changes to **seasonal flooding**, changes to **wildlife**) so that actions may be taken to counteract these changes.
- Reintroducing species of **plants and animals** that may have been affected by past activities. By reintroducing native species, the natural balance of the ecosystem can be restored so that the wetlands can continue to serve their purpose.
- In some cases, the **conditions of wetlands** may have to be recreated, for example if there is a particularly **dry season** and the ecosystem is severely affected. Water from the river can be **pumped into the wetlands**, so that the ecosystem can continue to be **stable** until normal water levels are restored.

River banks affect **flooding**, as a damaged river bank will **not hold water** as **effectively**, therefore **increasing the risk of flooding**. River banks can be conserved in a number of ways:

- **Protecting and reintroducing vegetation** can be beneficial to a river bank. Vegetation helps to **limit erosion**, by providing a natural barrier to limit **erosional processes**. Therefore, the **structure of the river bank** is not compromised which can potentially reduce flooding. Furthermore, limiting erosion also **reduces the sediment in the water**. Over time, less sediment from the bank washes into the river and builds up **in river channels**, leaving them more clear for water to flow through.

- **Ensuring there is no waste** on the river bank is an important aspect of conservation, as **debris** or **waste** can easily enter the river from the river bank. This waste can increase **sedimentation**, **disrupt the ecosystem**, and cause many other issues that can increase flooding risk, especially **large materials** that are not **biodegradable** or have the potential to **block the river channel**. Clean up projects, such as litter picking, can be very beneficial to the river ecosystem and limit flooding.

River Restoration

River Thur before restoration

River Thur after restoration

(https://www.ctc-n.org/products/river-restoration)

River restoration refers to the process of **restoring** a river **back to its original state** before it was altered. In many cases, river restoration is necessary after **failed hard engineering techniques**, that actually **create more damage to the river system and increase flooding** further downstream. An example of river restoration is **reintroducing meanders to straightened channels**.

In many cases with river restoration, the restoration may not necessarily **reduce flooding in that particular area**, in fact it may actually **increase flooding**. However, the decision must be made whether it is more **beneficial** to limit discharge **further downstream** by restoring the river upstream. River restoration can often take place where the **land is no longer seen as valuable**, meaning it is not an issue if it is flooded.