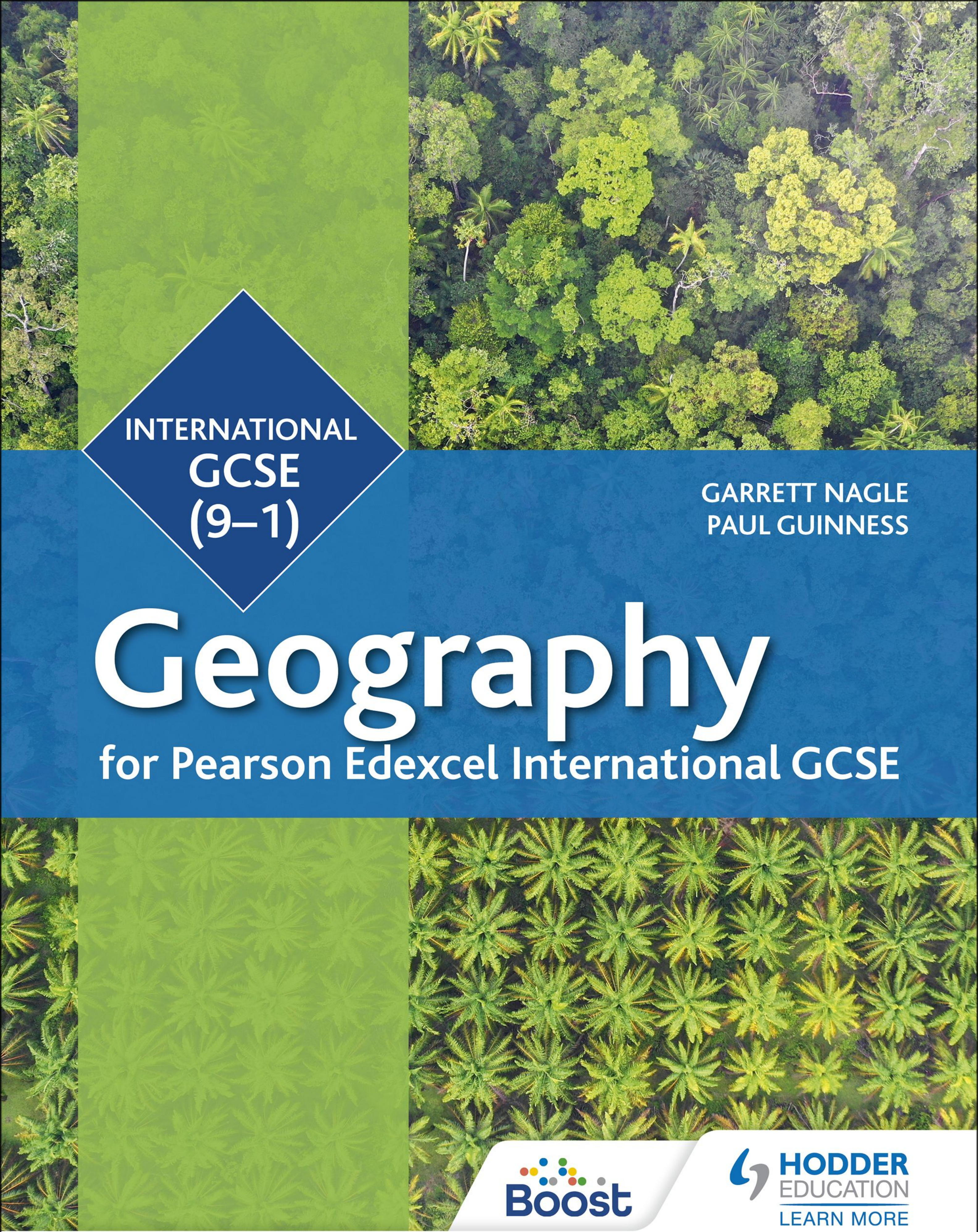

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Contents

1

River environments

Key ideas

1.1 The world's water supply is contained in a closed system – the hydrological cycle.

1.2 Physical processes give rise to characteristic river landforms.

1.3 River environments are of great importance to people and need to be sustainably managed.

1.1 The world's water supply

Key objectives

You should be able to:

- explain the characteristics, stores and transfers of the hydrological cycle
- understand the features of a drainage basin
- outline the factors affecting river regimes

The hydrological cycle

Hydrology is the study of water. The Earth's water is constantly recycled in a **closed system** called the **hydrological cycle**. A closed hydrological system means that the volume of water in the Earth's **hydrosphere** has always been the same.

Characteristics

More than 97% of the world's water is stored in oceans and seas and is saline. These water bodies make up about 70% of the surface of the Earth. Of the rest of the world's water (<3%), which is fresh water:

- just over 2% is held as ice (on both sea and land) and snow with most of this in Antarctica and Greenland
- 0.6% is held as groundwater
- 0.1% is held as surface water in rivers, lakes and surface reservoirs
- 0.001% is held in the atmosphere as water vapour and clouds at any one time.

This last figure amounts to only about 10 days' supply of average rainfall around the world.

Ice and snow

Antarctica covers an area of almost 14 million square kilometres and contains 30 million cubic kilometres of ice. The Antarctic ice sheet holds an amount of water such that if it were to melt, the sea level would rise by 70 m. The Greenland ice sheet covers 1.7 million square kilometres, which is about 70% of the surface of Greenland. Together, ice and snow account for around 69% of the Earth's fresh water.

Groundwater

About 30% of the Earth's fresh water is held as **groundwater**. At over 1.7 million cubic kilometres, the Great Artesian Basin in Australia underlies 22% of the country and is arguably the largest groundwater **aquifer** in the world.

Surface water

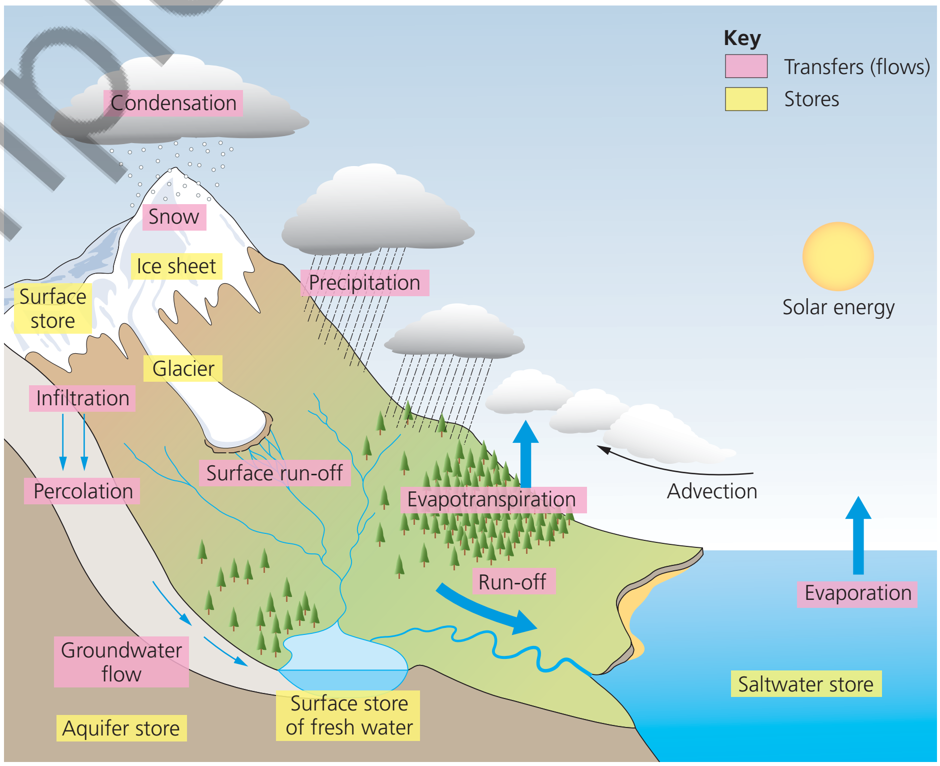
Lake Baikal in eastern Russia is the largest volume freshwater lake in the world. It is also the world's deepest lake. It covers an area of 31,500 km^2, with a maximum depth of 1637 m. In total, surface water accounts for about 1.2% of the Earth's fresh water.

▲ **Figure 1.1** Thick cloud surrounding the top of Mt Kenya, East Africa, formed by intense condensation in the atmosphere

Stores

Figure 1.2 shows that water can be held for varying periods of time in various **stores**, namely:

- in oceans and seas
- on land as rivers, lakes and reservoirs
- in bedrock as groundwater
- in the atmosphere as water vapour and clouds (Figure 1.1).



▲ **Figure 1.2** Processes, stores and transfers in the hydrological cycle

Transfers

Without **transfers** in the hydrological cycle, the world would run short of fresh water very quickly. Transfers of water occur between stores by the following processes:

- Evaporation
- Transpiration
- Condensation
- Precipitation
- Overland flow
- Infiltration
- Percolation
- Throughflow
- Groundwater flow

Water exists in three states – liquid water, solid ice and water vapour (gas). The three states are constantly interchanging through the processes of evaporation, condensation and precipitation so that water is constantly recycled between the sea, the atmosphere and the land.

Evaporation

Evaporation occurs when liquid water is changed into water vapour, which is a gas. It takes place mainly from surface water. The energy required comes from the Sun's heat and from wind. The higher the temperature, the greater the potential for evaporation, so water evaporates from a concrete or tarmac surface on a very hot day quickly compared with on a cooler day. Evaporation is also faster on a windy day compared with a calm day. Evaporation from water surfaces on land would not be enough to keep rivers and lakes full and provide the human population with drinking water. Fortunately, large amounts of water evaporated from the seas and oceans are carried by air masses onto land (advection), where condensation and precipitation take place.

▲ **Figure 1.3** Ice melting (a transfer) at the edge of Antarctica, the world's largest store of ice by far

Condensation

Condensation occurs when water vapour changes into water droplets. It happens when water vapour is cooled to a level known as the dew point**.** This is when clouds begin to form. The extent of cloud cover at any point in time is a good indication of the intensity of condensation in the atmosphere.

Clouds are therefore tiny water droplets suspended in air, while rain (precipitation) is much larger water droplets. These larger and heavier droplets can overcome rising currents in the air to reach the ground surface.

Precipitation

Precipitation occurs when water in any form falls from the atmosphere to the Earth's surface. This is mainly as rain, snow, sleet and hail. Therefore, water is constantly recycled between the sea, the atmosphere and land. The main characteristics of precipitation that affect local hydrology are the amount of precipitation, seasonality, intensity, type (for example, snow or rain) and variability.

ACTIVITY

Draw a labelled diagram to show the relationship between evaporation, condensation and precipitation.

ACTIVITY

Look at an atlas to find climate graphs for a) tropical rainforest, b) desert, c) temperate latitudes, and d) polar regions, to see the huge variations in climate around the world.

Climate graphs

A climate graph is a standard way of summarising variations in precipitation and temperature over a year for a particular location. It illustrates the average climate over a long period, usually 30 years. Precipitation for each month is shown by bars, while temperature is illustrated by a line.

Advection

Advection is the horizontal movement of water in the atmosphere. It is an important part of the hydrological cycle. Without advection, water could not be transported from the oceans to land masses.

Subterranean rivers

Subterranean (underground) rivers and streams are often found in areas of highly permeable rock such as carboniferous limestone. They appear at the surface at the boundary of permeable and impermeable rocks. Carboniferous limestone is characterised by caves, sinkholes and significant underground flows of water. Areas of carboniferous limestone generally lack surface drainage. A map of an area of carboniferous limestone will provide evidence of this. For example, you will find valleys, but they lack rivers (dry valleys).

The drainage basin system

EXAM TIP

When drawing a diagram of the hydrological cycle, ensure that you distinguish clearly between stores and transfers.

A **drainage basin** (or catchment area) is the area drained by a river and its tributaries. Some drainage basins are very small, at less than 10 km². However, the world's largest are huge – the Mississippi River and its tributaries drain over one-third of the USA (Table 1.1). While the global hydrological cycle is a closed system, the hydrological cycle of an individual drainage basin is an open system as it is open to external inputs and outputs. The system has a range of:

- **inputs** – water entering the system
- **stores** – places where water is held in the system
- **transfers (flows)** – where water is flowing through the drainage basin system
- **outputs** – where water is lost to the system.

Table 1.1 Fact file: Some of the world's major rivers

River	Continent	Length (km)	Area of drainage basin (km²)	Average discharge (m³/sec)
Amazon	South America	6,387	6,144,727	219,000
Nile	Africa	6,690	3,254,555	5,100
Mississippi/Missouri	North America	6,270	3,202,230	16,200
Yangtze	Asia	6,211	1,800,000	31,900

Note: It is difficult to make accurate measures. The figures shown here may differ from those found in other sources.

Source: Geography for CSEC, 2nd edition, Nelson Thornes, 2016

Precipitation is the input to the system. When precipitation reaches the surface, it can follow different pathways:

- A small amount falls directly into rivers as **direct channel precipitation**.
- The rest falls onto vegetation or the ground.
  - If heavy rain has fallen previously and all the air pockets in the soil are full of water, the soil is **saturated.** Since the soil is unable to take in any more water, the rain flows over the surface under the influence of gravity as **surface runoff** or **overland flow**.

- If the soil is not saturated, rainwater will soak into it through the process of **infiltration** and moves vertically down through the soil and rock by the process of **percolation**. If the rock below the soil is **permeable** (allows water into it), the rainwater will continue to soak down deeper into the rock. This water will eventually come to **impermeable** rock (which does not allow water into it). The underground water level will build up towards the surface from here. This water does not remain stationary but flows downslope under gravity. The upper level of underground water is the **water table**. Water contained in rocks is known as groundwater, and water on the move in rocks is called **groundwater flow**. Rock that holds groundwater is known as an aquifer.

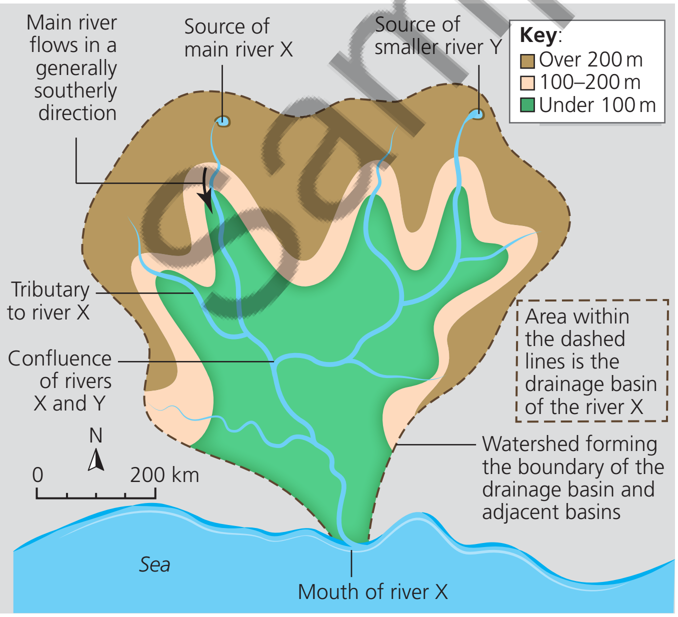
Throughflow is the movement of water through the soil.

A spring occurs when underground water emerges at the surface. This happens:

- where a permeable rock such as limestone covers an impermeable rock such as clay. Rainwater that can percolate into the permeable rock is unable to penetrate the impermeable rock below. This water will emerge at the surface as a spring, provided the water table is above surface level
- when the water table in a normally dry area reaches the surface during a period of unusually heavy rain. Such springs generally flow for only a short period of time.

Rainwater can be intercepted by vegetation. **Interception** is greatest in the summer when trees and plants have most leaves.

- Some rainwater will be stored on leaves and then evaporate directly into the atmosphere.
- The remaining intercepted water will either drip to the ground from leaves and branches or it will trickle down tree trunks and plant stems (**stemflow**) to reach the ground.



▲ **Figure 1.4** Features of a drainage basin

Vegetation takes in moisture through its root system. It loses some of this into the air through **transpiration**. Surface water is also lost by evaporation. The combination of the two is known as **evapotranspiration**.

In some countries precipitation is fairly regular throughout the year. However, in other countries there may be distinct wet and dry seasons. Here, rivers may dry up completely for many months. In deserts, small river channels may be dry for most of the year.

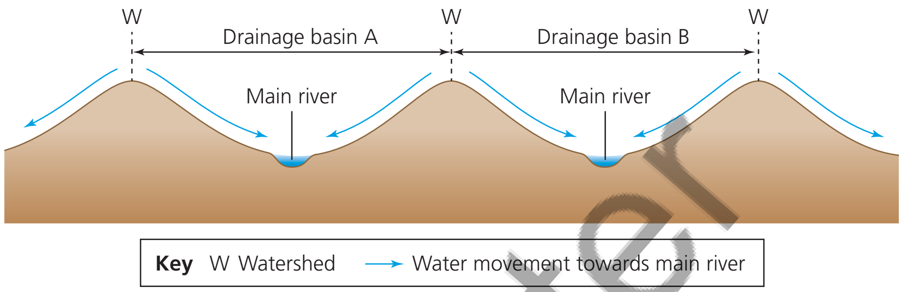
Features of a drainage basin

Drainage basins have a number of distinct features (Figure 1.4):

- The boundary of a drainage basin is called the **watershed**.
- The point where a river begins is its **source**.
- A river reaches the sea at its **mouth**.
- A tributary joins the main river at a **confluence**.
- A main river and all its tributaries form a **channel network** or river system.

Watershed

The watershed is a ridge of high land that forms the boundary between one drainage basin and other adjacent basins. (See Figure 1.5.)



▲ **Figure 1.5** Cross-section showing drainage basins and watersheds

▲ **Figure 1.6** Meltwater stream emanating from the Fox Glacier in the Southern Alps, New Zealand

▲ **Figure 1.7** Water issuing from a spring at the boundary of permeable and impermeable rock, Malham Cove, UK. This is the source of Malham Beck

The source of a river

A river is a large, natural stream of flowing water. The place where a river begins may be:

- an upland lake – the Mississippi River, the largest river in North America, begins as a stream from Lake Itasca in the US state of Missouri
- a melting glacier – (Figure 1.6). The 13-kilometre Fox Glacier in New Zealand is one of two sources of the Fox River. On a larger scale, the Gangotri Glacier in the Himalaya mountains is the source of the River Ganges in Asia
- a spring in a boggy upland area where the soil is so saturated that recognisable surface flow begins. The source of the Danube River is a spring in such an area of the Breg River in the Black Forest in Germany
- a spring at the foot of an escarpment at the boundary between permeable and impermeable rock (Figure 1.7). There are many such springs at the foot of the North and South Downs, in South East England, UK.

When small streams begin to flow, they act under gravity, following the fastest route downslope. As they take the lowest path in the local landscape, water is added to them from tributaries, groundwater flow, throughflow and overland flow.

Channel networks

Some main rivers have a large number of tributaries so that no place in the drainage basin is very far from a river. Such an area is said to have a high **drainage density**. The Amazon River receives water from more than 1000 tributaries. Where a main river has few tributaries the drainage density is low. Channel networks often form a distinct pattern due to the structure of rocks in the drainage basin.

ACTIVITY

Use a map to describe the channel network of a river in the region in which you live.

REMEMBER

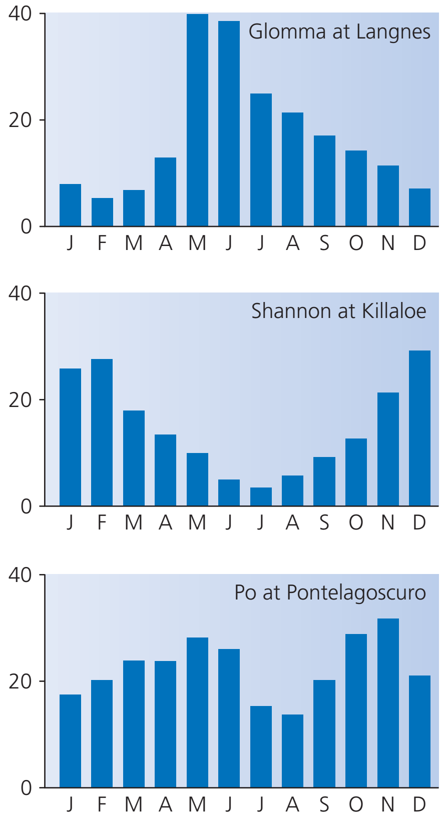
Remember that the global hydrological cycle is a closed system as it has no inputs or outputs, but the hydrological cycle of an individual drainage basin is an open system as it is open to external inputs and outputs.

Mouth of a river

A river's mouth is where it empties into another body of water – a larger river, a lake, a sea or an ocean. The majority of rivers drain into a sea or ocean, but some drain into lakes that may be far from a coastline. For example, the Volga River, Russia, the longest river in Europe (approximately 3685 km), flows into the Caspian Sea. Deltas sometimes form at the mouth of a river where the strength of tides and currents is insufficient to clear the large-scale sediment arriving from further upstream. The largest delta in the world is the Ganges Delta in Bangladesh and India.

Factors affecting river regimes

A **river flow regime** is the variation in the **discharge** of a river over the course of a year (Figure 1.8). The flow regime plays a major role in influencing the processes that shape river channels and floodplains. The regime of a river is influenced by several factors including climate, vegetation, geology, soil, land use, water abstraction, dams, etc.



Note: All the graphs show the specific discharge in litres/second per km^2

▲ **Figure 1.8** Three contrasting river regimes (bar graphs) for the Shannon, Glomma and Po

Climate

Climate is the most important factor affecting the regime of a river.

Precipitation

The type of precipitation (rain/snow) occurring is important, for example, snow in polar and high-altitude regions, and thunderstorms with convection rainfall in warm/hot continental interiors in summer. Snow and ice store precipitation in the cold winter months, which is later released with warming in spring. The amount of rainfall, rainfall intensity and duration are also important factors affecting the regime of a river.

Figure 1.8 shows the effects of climate on three contrasting river regimes:

- The River Shannon in the Republic of Ireland has a typical temperate regime with a clear winter maximum in discharge, the result of high rainfall beginning in late autumn and subsiding in the spring.
- The River Glomma in arctic Norway has a spring peak associated with snowmelt as temperature increases after the cold of winter.
- The River Po near Venice in Italy has two main peaks associated with periods of high rainfall in spring and autumn, and spring snowmelt from Alpine tributaries.

All of these examples are taken from Europe, but similar contrasts can be found in other world regions.

Temperature

Temperature has a huge effect on evaporation rates – higher temperatures lead to more evaporation from the ground, resulting in less water making its way into rivers. However, as warm air can hold more water vapour than cold air, very high precipitation and river discharge can be experienced in hot, moist climates.

Vegetation

Areas of high vegetation cover intercept more rainfall, allowing water to reach the ground more gradually compared with poorly vegetated areas. This reduces overland flow and increases the infiltration rate into the soil.

- Broad-leaved vegetation is particularly effective in intercepting rainfall because of the large surface area of the leaves.
- In winter, deciduous trees lose their leaves and therefore intercept less rainfall.

Wetlands can hold water and release it slowly into rivers. As such, they play a valuable role in regulating the movement of water in a drainage basin.

Deforestation can have a huge effect on the movement of water within a drainage basin and therefore a significant impact on the regime of a river. Removal of the tree canopy reduces interception and evapotranspiration.

This leads to increased rates of infiltration and increased amounts of water entering the river system.

Geology

The permeability and porosity of rocks and soils are major influences on drainage basins. Porous and permeable rocks allow the accumulation of groundwater, which is gradually released into rivers as **base flow**. Porosity is a measure of a rock's ability to hold water; permeability is a measure of the ease with which water can flow through the rock. A rock may be extremely porous, but if there is only limited connection between the pores, permeability will also be limited. Chalk is a good example of a porous rock, and carboniferous limestone is a good example of a permeable rock.

Soil

The more compact the soil surface, the less infiltration and the greater the overland flow.

- Sandy soils are free draining and therefore dry out rapidly, meaning less overland flow.
- Clay soils have very fine particles, resulting in few air spaces, which give this soil a high level of cohesion. As a result, clay drains poorly and feels lumpy and sticky when it is wet, meaning more overland flow.

Land use

- Forested areas are most effective in slowing the movement of water to channel networks.
- Run off is much faster in urban areas where impermeable surfaces of concrete, tarmac, bricks and tiles have replaced permeable vegetated surfaces.
- Where open spaces, such as parks and commons, exist in urban areas the soil is often heavily compacted due to high recreational use.
- Urban drainage systems, such as pitched roofs, gutters, water downpipes and drains, are designed to remove surface water as quickly as possible.

Water abstraction

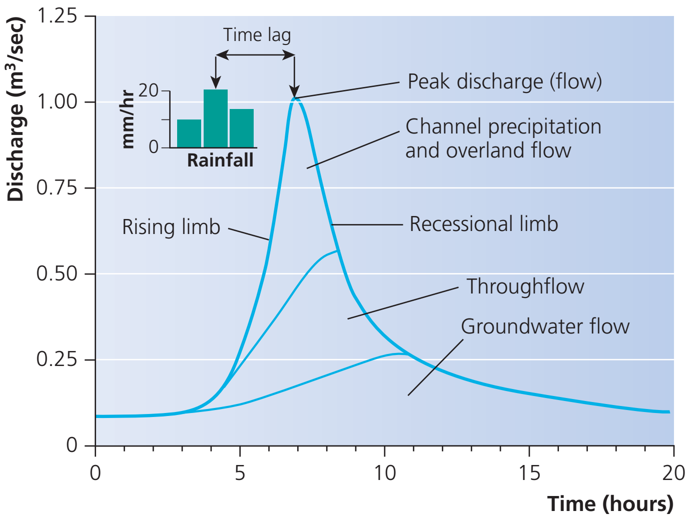
Water abstraction is the removal of groundwater from water sources on the surface or underground. It occurs along most rivers of a significant size. Water is abstracted for human consumption, irrigation and other uses. Abstraction directly changes surface water flows and indirectly lowers groundwater levels. As abstraction increases, groundwater flow is reduced, sometimes to a very low level indeed. In some parts of the world where groundwater is a major source of water supply, water tables have fallen dramatically.

Dams

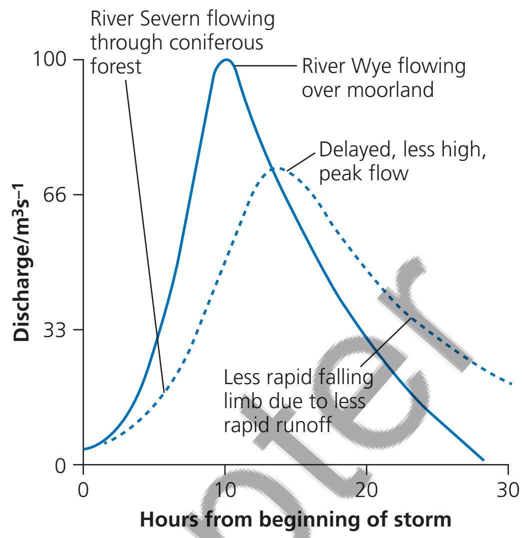
A **dam** regulates river flow for the purposes of flood control, navigation, irrigation, hydropower production and human water supply. The reservoirs of water held behind dams experience significant evaporation, particularly those in hot, dry climates.

Other factors influencing river regimes

- Drainage basin size and shape: small drainage basins respond most quickly to rainfall events.
- Slopes: steeper slopes create more overland flow.
- Drainage density: basins with a high drainage density respond very quickly to storms.



▲ **Figure 1.9** A storm hydrograph



▲ **Figure 1.10** Storm hydrographs for the rivers Severn and Wye

Storm hydrographs

A **storm hydrograph** (Figure 1.9) shows how the discharge of a river varies over a short time period, such as 24 hours, and usually refers to a single storm event (period of rainfall).

- Before a storm begins, water is supplied to the river mainly by groundwater flow (base flow).
- During a storm, some water infiltrates into the local soil while some flows over the surface as overland flow.
- Overland flow, in particular, reaches the river quickly, causing a rapid rise in the level of the river, as shown by the rising limb on Figure 1.9. The angle of the rising limb shows how quickly discharge increases in a river.
- The peak flow is the maximum discharge of the river as a result of the storm.
- The time lag is the time between the peak rainfall at the height of the storm and the maximum discharge.
- The discharge starts to fall as shown by the recessional limb. The recessional limb shows the speed with which the discharge declines after the peak.

Figure 1.10 shows the impact of land use on the storm hydrographs of two rivers in the same region of the UK. Although the sources of both rivers are close together, the land use in the two river basins varies significantly. The River Wye flows over moors and grassland, while the River Severn flows through an area of coniferous forest. The geology, soils, topography and precipitation are similar in both river basins.

The effect of urban development on hydrographs is to increase peak flow and decrease time lag. This is because urban environments are designed to drain away surface water as quickly as possible.

ACTIVITY

Describe and explain the differences between the two storm hydrographs shown in Figure 1.10.

ACTIVITY

Suggest ways in which urban environments are designed to drain away surface water as quickly as possible.

REMEMBER

Rivers with similar climate, geology and landscape tend to have similar flow regimes. After this, local factors such as soil type, soil depth and vegetation cover influence the natural flow regime.

CHECK YOUR UNDERSTANDING

1. List the transfers (flows) of water shown in Figure 1.2.
2. Explain the differences between infiltration and percolation.
3. Define advection.
4. Describe the landscape shown in Figure 1.5.
5. Compare the sources of the rivers shown in Figure 1.6 and Figure 1.7.
6. Draw simple labelled diagrams to show the difference between an area with a high drainage density and an area with a low drainage density.
7. State **two** ways in which vegetation can affect the interception of precipitation.°
8. State **two** reasons for water abstraction.
9. What is a storm hydrograph?

1.2 Physical processes and river landforms

Key objectives

You should be able to:

- explain the fluvial processes involved in river valley and river channel formation, and the factors affecting these processes
- appreciate how channel shape, valley profile, gradient, velocity, discharge and sediment size and shape change along the course of a river
- understand how river landscapes change over the course of a river.

CASE STUDY

Changes in channel shape, valley profile, gradient, velocity, discharge, and sediment size and shape along the course of a named river.

Fluvial processes and river channel formation

Rivers play a major part in forming the landscape in drainage basins through the processes of **erosion**, **transportation** and **deposition** (see pages 11–12). Two other important landscape processes also operate in drainage basins – **weathering** and **mass movement**.

Weathering

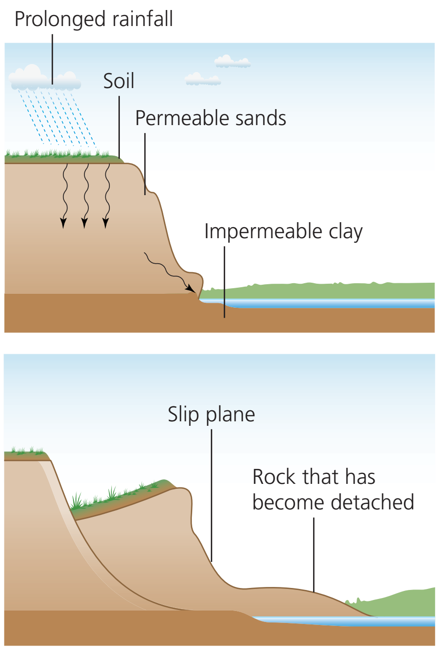
Weathering is the breakdown of rock *in situ* (not involving movement). The main elements of weather, precipitation and rainfall, play a major role in weathering. For example:

- **physical weathering** by freeze-thaw action (also known as frost shattering) (Figure 1.11). Freeze-thaw occurs when water in joints and cracks in rock freezes at temperatures below 0 °C. The frozen water expands by about 10% compared to its previous state, exerting considerable pressure on the rock around it. Freeze-thaw is most effective where moisture is plentiful and there are frequent fluctuations above and below freezing point.
- **chemical weathering** of rocks by rainwater, which is slightly acidic (Figure 1.12). Unlike physical weathering, chemical weathering is most effective below the surface since percolating water has gained organic acids from the soil and vegetation it has passed through. Acidic water helps to break down rocks such as limestone and granite.
- **biological weathering** (Figure 1.13) caused by organisms – plants, animals, fungi and microorganisms, such as bacteria. Biological weathering, particularly due to the root systems of plants and trees gradually breaking rock apart, is active in drainage basins.

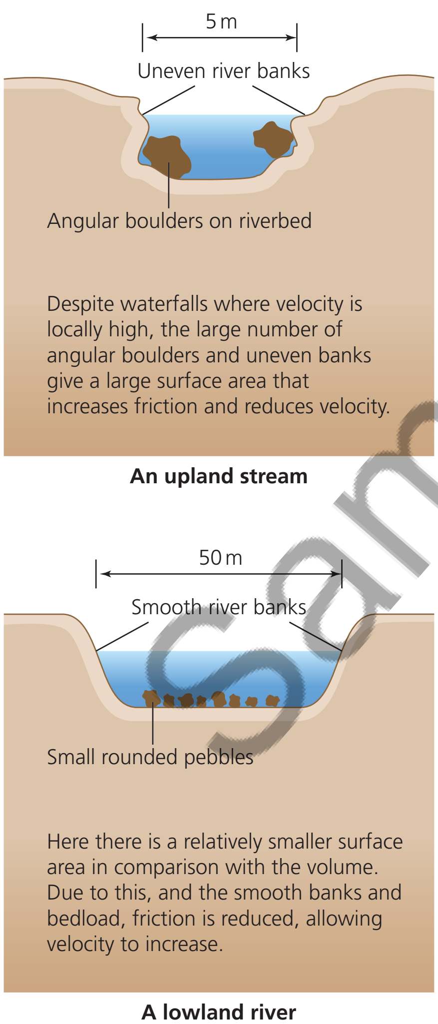
▲ **Figure 1.11** A scree slope formed by mass movement in Yorkshire, UK. The loose rock is the result of physical weathering higher up the valley side

▲ **Figure 1.12** This limestone pavement in Yorkshire, UK has been created largely by chemical weathering. As the joints (cracks) in the surface rock become larger, more precipitation percolates through the rock. Such landscapes generally lack surface drainage

▲ **Figure 1.13** Biological weathering in British Columbia, Canada. The break up of rock contributes to the loose material on the surface available to mass movement, which may eventually contribute to a river's load



▲ **Figure 1.14** Slumping



▲ **Figure 1.15** Velocity and discharge in the upper and lower courses of a river

Mass movement

Mass movement is the large-scale movement of weathered material downhill under the influence of gravity. Mass movement processes occur continuously on slopes, albeit very slowly in the majority of cases. It carries weathered material into rivers, which contributes additional material to a river's load and thereby:

- increases erosion in the upper course
- adds to deposition in the middle and lower courses.

The two main types of mass movement in drainage basins are:

- **Soil creep:** A slow, small-scale movement of individual soil particles downslope, that occurs mostly in winter. The rate is 1–3 mm per year in temperate areas and up to 10 mm per year in tropical rainforest. Soil creep frequently happens on slopes with an angle of more than 5 degrees.
- **Slumping:** This occurs when a significant section of rock moves a short distance down a slope in a rotational movement. This often occurs when softer materials, such as clay, overlie more resistant impermeable materials. The softer material becomes saturated with rainwater and as a result slides downwards along a concave surface.

Energy and processes

Energy is needed for transfers to occur. Around 95% of a river's energy is used to overcome **friction**. The remaining 5% or so is used to erode the river channel and transport this material downstream.

The amount of energy in a river is determined by:

- the amount of water in the river
- the speed at which the water is flowing.

Most friction occurs where the water is in contact with the bed and the banks. Rocks and boulders on the bed increase the amount of friction.

Figure 1.15 shows that in the upper course of a river, near the source, a river's channel is shallow and narrow, and the riverbed is often strewn with boulders and very uneven. There is a lot of friction so the water flows more slowly here than further downstream in the middle course and lower course where the channel is wider, deeper and less uneven.

Figure 1.16 shows a river in its upper course – notice the steep gradient, the boulders in the river and the amount of 'white water'. The latter is a good indication of a high level of friction.

Erosion

There are four processes of erosion that take place in a river:

- **Hydraulic action**: the sheer force of river water removing loose material from the bed and banks of the river.
- **Abrasion/corrasion**: the wearing away of the riverbed and banks by the river's load hitting them repeatedly.
- **Attrition**: in swirling water, rocks and stones collide with each other and with the bed and banks. Over time the sharp edges of the rocks and stones become smooth, and the rocks and stones become smaller in size.
- **Solution**: some rocks, such as limestone which is soluble in slightly acidic water, dissolve slowly in river water.

▲ **Figure 1.16** The white water in the upper course of this river in British Columbia, Canada indicates a high level of friction

MAKING LINKS

When you study section 2.1 you will see that similar processes of erosion operate on coastlines due to wave action.

ACTIVITY

Draw a labelled diagram showing the processes of transportation.

Along the course of the river there are two main types of erosion that take place:

- **Vertical erosion** (downward): This takes place in the upper course of the river near the source where the river cuts down into its bed, deepening the valley.
- **Lateral erosion** (sideward): This takes place in the middle and lower courses and widens the valley.

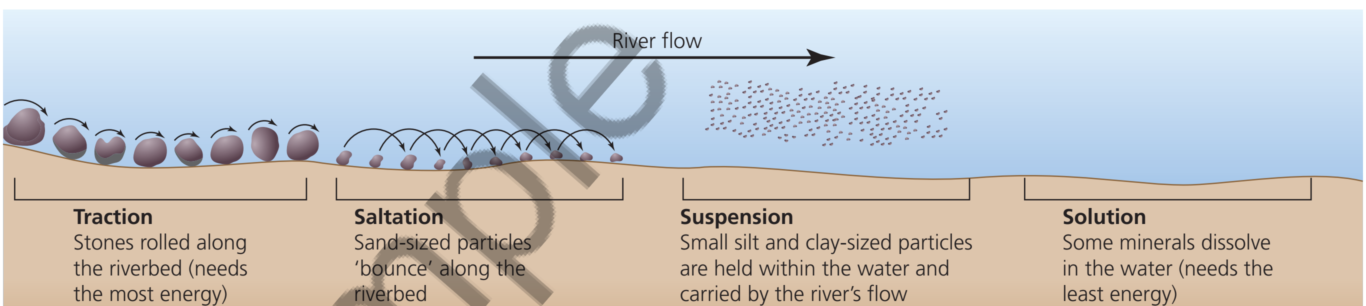
Most erosion occurs when discharge is high and rivers are in **flood**.

Transportation

There are four processes by which a river can transport its **load** (Figure 1.17):

- **Suspension**: the smallest particles (silts and clays) are carried in suspension by the moving water.
- **Solution**: in areas of calcareous rock (limestones), material is carried in solution as the dissolved load.
- **Traction**: large pebbles are rolled and shunted along the bed.
- **Saltation**: larger particles (sands, gravels, very small stones) are transported in a series of 'hops' or bounces.

The parts of the load that are moved by traction when the discharge of the river is low may be transported by saltation when the discharge is high.



▲ **Figure 1.17** The processes of transportation

Deposition

Deposition takes place when a river does not have enough energy to carry its load. This can happen when:

- the gradient decreases
- discharge falls during a dry period
- the current slows down on the inside of a meander
- the river enters a lake or the sea.

When a river loses energy, the large, heavy material known as the **bedload** is deposited first. Lighter material is carried further downstream. The gravel, sand and silt which is deposited is called **alluvium**. This is spread over the floodplain. The load transported by solution is carried out to sea with much of the clay, the lightest suspended particles.

Table 1.2 Factors affecting processes: some examples

Factor	Weathering and mass movement	Erosion, transport and deposition
Climate	Chemical and biological weathering are most active in hot, wet climates. Cold, dry climates accelerate physical weathering. Heavy rainfall can saturate material. The weight of the saturated material may cause it to slump. Moisture and temperature change aid soil creep.	Heavy rainfall → higher discharge → increased action of river processes. Higher temperature → increased evaporation → lower discharge and reduced action of river processes.
Slope	Strong relationship between angle of slope and mass movement (increasing shear-stress). The steeper the angle of the slope, the more likely mass movement is to occur (e.g. soil creep occurs on slopes of more than 5 degrees).	Steep slopes result in fast-flowing rivers with strong erosive power. Gentle slopes encourage deposition.
Geology	Massive rocks (such as granite) that have fewer joints tend to be more resistant to weathering than smaller ones. Limestone is particularly prone to chemical weathering by the process of solution.	Rivers erode valleys made of soft rock at a rapid rate. Very porous (chalk) and permeable (carboniferous limestone) rocks may lack surface river flow for all or part of the year.
Altitude	Physical weathering by freeze-thaw is very active at high altitudes over long periods of time.	Snowmelt and melting glaciers have a big impact on river regimes and processes
Aspect	Colder, north-facing slopes (in the northern hemisphere) have a higher rate of physical weathering than south-facing slopes.	South-facing slopes (in the northern hemisphere) have higher rates of evaporation and transpiration, which can affect discharge.

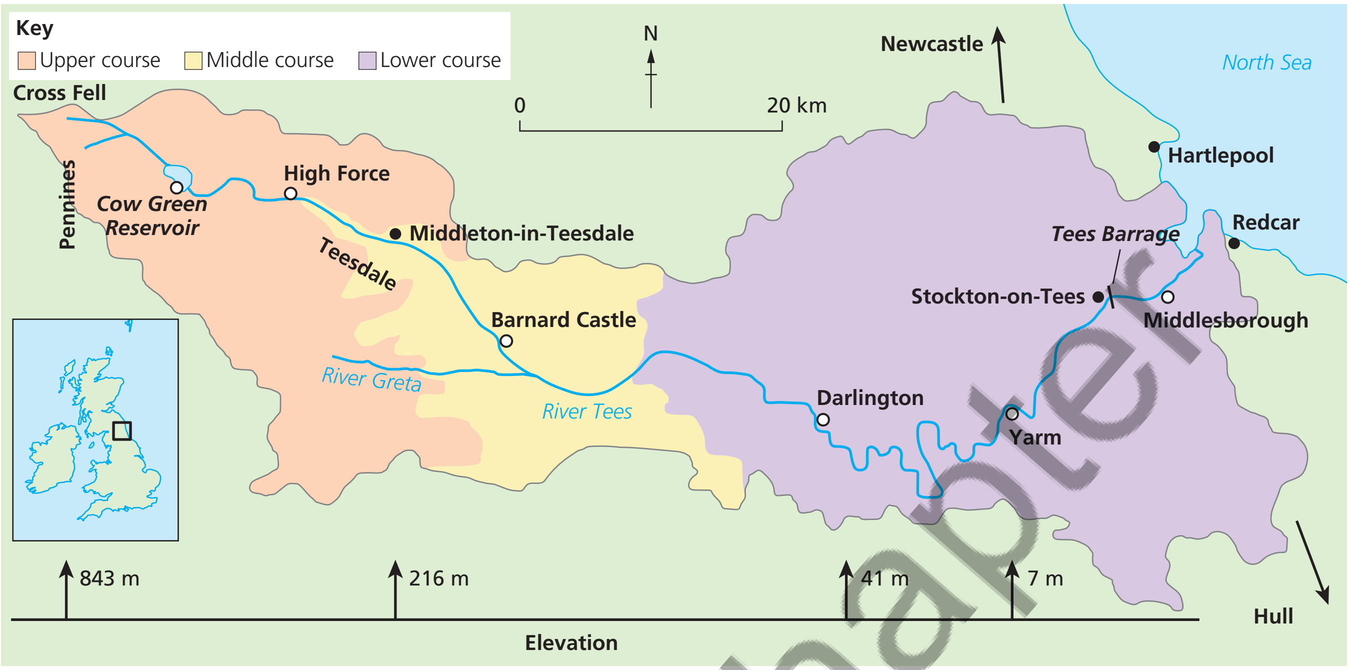
REMEMBER

Without weathering and mass movement, the load carried by rivers would be greatly reduced and would only come from the direct action of river water on the riverbed and banks.

Case study: Channel shape, valley profile, velocity and discharge along the course of the River Tees

The River Tees is a major river in North East England, UK. It drains an area of about 1800 km^2. Its source is at Cross Fell, on the eastern side of the Pennine mountains (Figure 1.18). The river rises at a height of over 750 m, and flows about 160 km (channel length) eastwards to reach the mouth of the river on the North Sea coast near Middlesbrough. The Tees exhibits most of the classic processes and landforms associated with the upper, middle and lower courses of a river. Figure 1.19 shows how the long and cross profiles of the Tees change from the source to the mouth as the river's gradient decreases. For example, the river's:

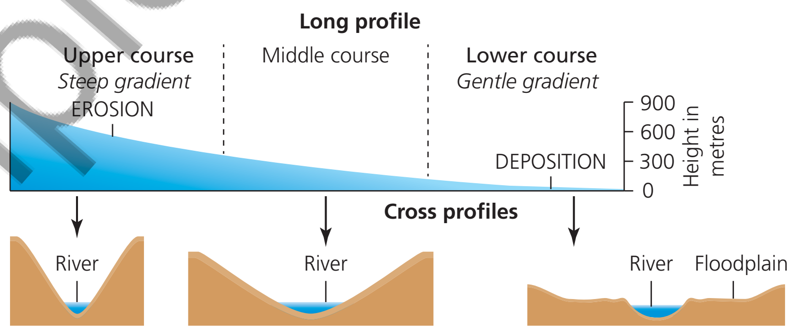
- depth, width, **volume**, **velocity** and discharge increases
- sediment size decreases and sediment shape becomes more rounded.



▲ **Figure 1.18** Map of the River Tees from source to mouth

Upper course

The upper course is an area of mainly moorland used for sheep farming with high levels of annual precipitation (over 2000 mm per year) on the highest land. Precipitation decreases significantly eastwards towards the North Sea.



▲ **Figure 1.19** Long and cross profiles of the River Tees

In its upper course, the river channel is shallow and narrow, and the riverbed is uneven with sizeable angular boulders in places. As there are high levels of friction the water flows more slowly here than further downstream, where the channel is wider, deeper and less uneven, and there can be considerable turbulence.

Vertical erosion has created a steep channel gradient and carved steep valley sides. These features, combined with impermeable rock, result in the river responding quickly to rainfall. Impressive waterfalls (see page 15) are evident at High Force along with clear examples of interlocking spurs (see page 16).

▲ **Figure 1.20** High Force waterfall

Spectacular changes along the long profile of a river often occur along geological boundaries. High Force (Figure 1.20) is the UK's largest waterfall at 21 m high. At High Force, a bed of hard rock (dolerite) overlies softer rock (sandstone and shale). The river has eroded the softer sandstone and shale more quickly creating an overhang of the more resistant dolerite and a plunge pool at the base of the waterfall. Figure 1.24 on page 17 explains the formation of a waterfall. Over time, as the process has continued and the overhang has collapsed, the waterfall has eroded upstream, leaving behind an impressive gorge downstream of High Force. Rapids are also in evidence in this section of the river.

There are many examples of human intervention along the course of the Tees. A series of reservoirs were built in the upper reaches of the River Tees to satisfy the high demand for water in the urban areas further downstream. Most prominent is the Cow Green reservoir, which is located on the River Tees itself. The reservoir was built in 1970 to provide water for the expansion of industrial premises on Teeside.

Middle course

Below the town of Middleton-in-Teesdale the valley widens out and the channel's gradient becomes more gentle. The fertile soils of the early-stage floodplains provide productive agricultural land. Lateral erosion takes over from vertical erosion, forming distinctive meanders, such as those near Barnard Castle. The Abbey rapids are located just downstream of Barnard Castle. The Tees is joined by tributaries. The result is a substantial increase in the volume of water in the river.

Lower course

With the river very close to sea level the channel gradient is gentle as it meanders across a fertile clay floodplain to its estuary between Hartlepool and Redcar. The Tees is now predominantly tidal in nature. Deposition is the dominant process, evidenced by mudflats at low tide. The river has now formed much larger meanders, for example, near Yarm, across its wide floodplain. It has also formed ox-bow lakes and levees (formed when the river has flooded). Flood prevention schemes are in evidence in Yarm and other urban areas along the course of the Tees. In 1995 the Tees Barrage was built at Stockton-on-Tees. This was to prevent flooding at high tide and during storm events. The original winding river channel below Stockton has been straightened out by artificial cuts to aid navigation. For example, a large meander (the Mandale Loop) was cut off, shorteening the river by 4 km. The mouth of the Tees takes the form of a large estuary with mudflats and sandbanks, which are an important ecosystem.

ACTIVITY

Using Figure 1.19, describe the long and cross profiles of the River Tees.

REMEMBER

When a case study/example naturally divides into sections as this one does – upper, middle and lower course – ensure that you have a good knowledge of all sections so that you can give a balanced response to questions about the case study/example.

Changes in river landscapes over the course of a river

Geological variations over the course of a river can have a significant impact on its long profile. Long profiles often have 'irregularities' such as waterfalls and lakes. An exercise comparing the course of a river on a 1: 50,000

Ordnance Survey map with a geology map of the same area can often yield useful information.

- Rivers flowing over hard rock erode at a slower rate as the bedrock is more resistant.
- The landscapes of hard, resistant rock are more likely to have steep valley sides. In contrast, areas of less resistant rocks tend to have more gently sloping valley sides.
- Rivers generally follow the path of least resistance on their journey from highland to lowland. In areas with both hard and soft rocks, river channels are more likely to form along the lines of less resistant rocks.
- Geology influences the type of erosional landforms that develop along the course of a river. For example, waterfalls and gorges are often found along the boundaries between hard and soft rocks, and lakes may form where a zone of soft rock has been eroded to a greater depth (by fluvial or glacial action) than the course of a river immediately upstream and downstream.

Upland landforms

The characteristic river landforms in upland areas (Figures 1.20 to 1.23) are a steep V-shaped valley, a steep gradient, interlocking spurs, potholes, waterfalls, rapids and gorges. In the upper course, much of the river's energy is needed to overcome friction. The rest is used to transport the load.

V-shaped valleys

Rivers in upland areas contain large boulders that can erode the riverbed rapidly when the river is in flood. This results in the river cutting downwards into its bed by vertical erosion to form steep V-shaped valleys. Soil and loose rock on the valley sides are washed down the steep slopes by overland flow into the river, adding to the river's load.

Interlocking spurs

Rivers begin to meander in the upper course. Erosion is concentrated on the outside banks of these small meanders. This eventually produces **interlocking spurs** that alternate on each side of the river. Figure 1.22 shows that interlocking spurs are ridges of high land that project towards the river at right angles and decrease in height towards the river. Interlocking spurs are eroded further down a river's course when lateral erosion takes over from vertical erosion as the dominant process in the river.

Potholes

Where the riverbed is very uneven, pebbles carried by fast, swirling water can become trapped temporarily by obstacles in the riverbed. The swirling currents cause the pebbles to rotate in a circular movement, eroding (by abrasion) circular depressions, known as **potholes,** in the riverbed (Figure 1.23).

Waterfalls and rapids

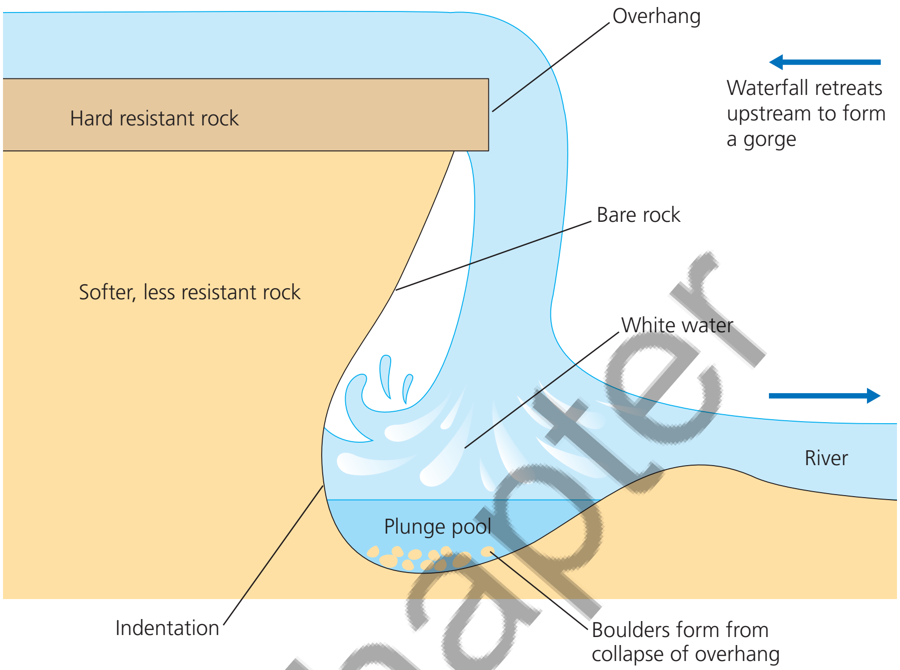
Waterfalls are the most spectacular feature of the upper course of a river, but can also be found in the middle course. They occur when:

- there is a sudden change in the river's course due to differences in rock hardness along the valley (Figure 1.24)
- a fault line has created an escarpment over which the river flows
- glaciation has left a tributary valley hanging high above the main valley.
- a steep drop at the edge of a plateau has been formed by uplift of the land.

▲ **Figure 1.21** Rivers begin to meander in their upper course. In this photo, the river flows from left to right down a steep gradient in this snow-covered mountain landscape in Switzerland

▲ **Figure 1.22** The interlocking spurs of the Waitaki River in New Zealand. The river drains eastwards into the South Pacific Ocean

▲ **Figure 1.23** Potholes on the River Wharfe, Yorkshire Dales, UK



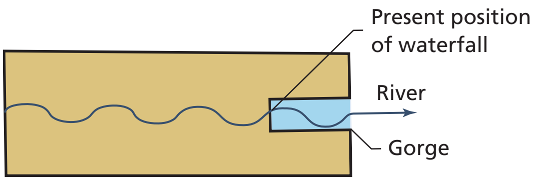
▲ **Figure 1.24** Formation of a waterfall

▲ **Figure 1.26** Victoria Falls across the (Zambia/Zimbabwe border), southern Africa

Figure 1.24 shows the formation of a waterfall when a river flows from a band of hard, resistant rock onto a band of softer, less-resistant rock. Waterfalls can form when the hard rock is horizontal, vertical or dipping upstream.

1. The underlying softer rock erodes faster, causing the hard rock to overhang.
2. The overhang continues to be undercut by corrasion and hydraulic action.
3. The overhang steadily becomes larger until it reaches a critical point where it is no longer supported and collapses.
4. The rocks that crash down into the plunge pool are swirled around by the currents, creating a plunge pool. This increases erosion, making the plunge pool deeper. The rocks in the plunge pool are eroded mainly by attrition.

This process, beginning with a layer of hard rock collapsing, repeats over time. As a result, the waterfall retreats upstream, carving out a steep-sided **gorge** (Figure 1.25).



▲ **Figure 1.25** Formation of a gorge by recession as shown from above

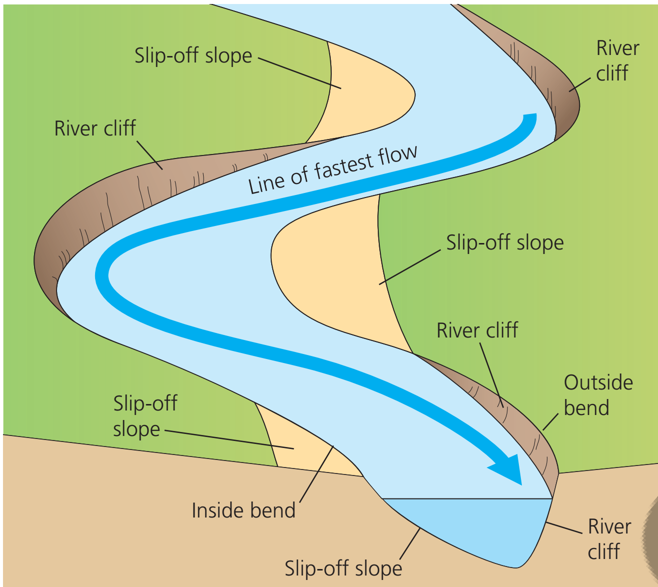
The tallest waterfall in the world is the Angel Falls (979 m) located in the rainforest of Canaima National Park, Venezuela.

Where alternating bands of hard and soft rock cross the course of a river, it creates an uneven riverbed and a zone of turbulent water known as rapids. Rapids can also form when a layer of hard rock dips gently downstream.

Lowland landforms

As more tributaries join the main river downstream, the volume of water increases. In lowland areas, throughflow and groundwater flow, if the rock is permeable, also add water to the river.

Meanders and meander migration



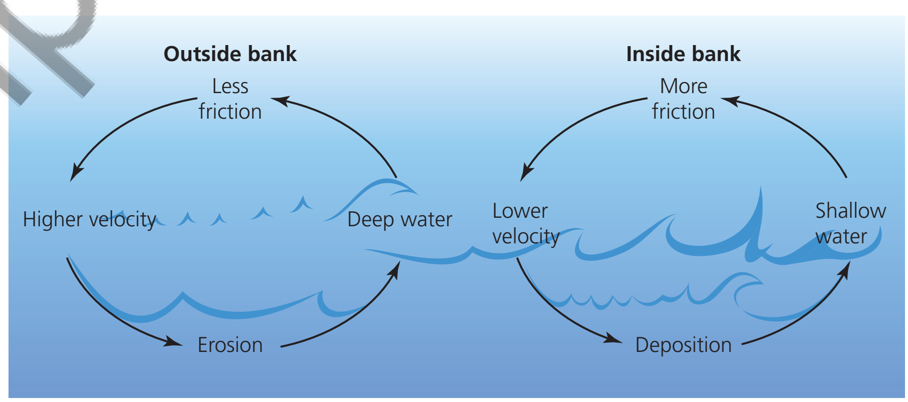
▲ **Figure 1.27** Cross-section of a meander

In lowland areas, **lateral erosion** takes over from vertical erosion as the most important process and, as a result, meanders (wide bends in the river's course) develop (Figure 1.27). Meanders become larger as a result of lateral erosion.

Figure 1.27 shows the main processes in the development of a meander.

1. The current is fastest and most powerful on the outside bank of the meander (Figure 1.28), particularly on the downstream section. Erosion is relatively rapid. The outside bank is **undercut** (particularly on the downstream section). Eventually the outside bank collapses and retreats, causing the meander to spread further across the valley.
2. If the meander has already reached the side of the valley, erosion on the outside bend may create a very steep slope or **river cliff**.
3. The current on the inside of the meander is much slower (Figure 1.28). As the river slows it deposits some of its load. This deposition builds up to form a gently sloping **slip-off slope** (Figure 1.29).
4. Therefore, the water on the inside of the meander is shallow and deep on the outside.

▲ **Figure 1.29** Meander and slip-off slope on the Marsyangdi River in the Annapurna Himalayan Range, Nepal



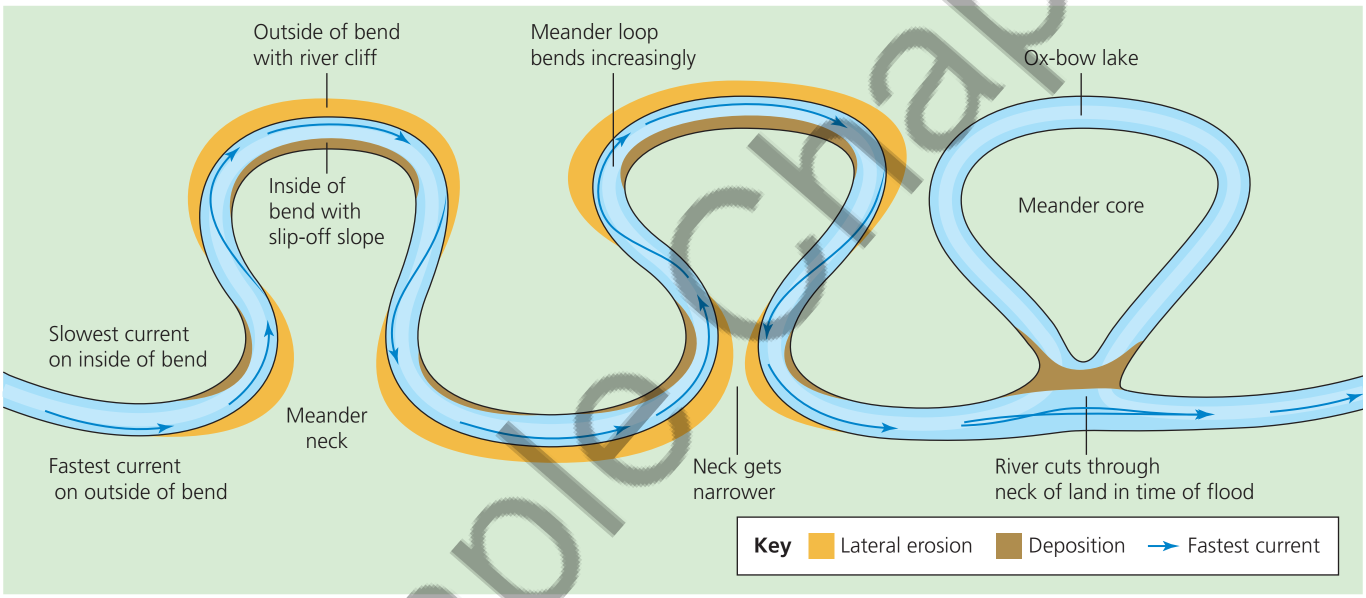
▲ **Figure 1.29** Processes operating on the inside and outside banks of a meander

Due to the power of lateral erosion, meanders slowly change their shape and position. As they erode sideways, they widen the valley. However, they also move or migrate downstream and erode the interlocking spurs to give a much more open valley compared with the upper course (Figure 1.29).

Ox-bow lakes

As a river flows towards its mouth, the meanders become more pronounced and the valley becomes wider and flatter.

- As erosion continues to cut into the outside bends of a meander, a **meander neck** may become narrower (stage 2 in Figure 1.30).
- Eventually, when the river is in flood, it may cut right across the meander neck to shorten its course (stage 3).
- For a while, water flows along both the old meander route and along the new straight course.
- However, as the current slows down at the entry and exit points of the meander, deposition occurs.
- Over a period of time, the meander is cut off from the new straight course to leave an **ox-bow lake**.



▲ **Figure 1.30** Formation of an ox-bow lake

REMEMBER

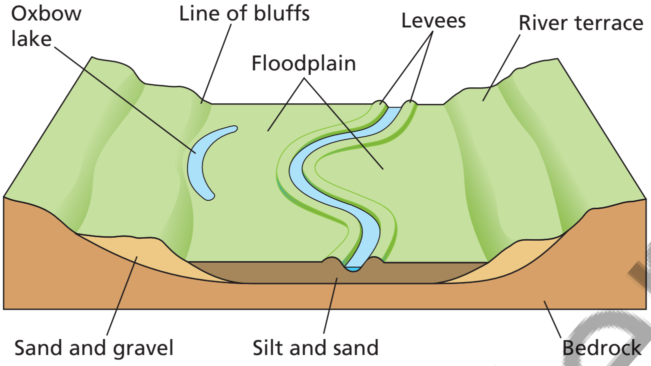
When drawing a diagram of an ox-bow lake, make sure you label where the erosion and deposition are occurring.

Floodplains and levees

A **floodplain** is a wide area of almost flat land on both sides of a river (Figure 1.32). As explained previously, it is formed by the movement of meanders.

When discharge is high, the river is able to transport a large amount of material in suspension. At times of exceptionally high discharge, the river overflows its banks and floods the low-lying land around it. The increase in friction as the river surges across the floodplain reduces its velocity and causes the material carried in suspension to be deposited on the floodplain as **alluvium**. Alluvium is deposits of clay, silt and sand left by floodwater, which usually produce very fertile soils. The heaviest or coarsest sediment is dropped nearest to the river and forms natural embankments called **levees** alongside the river (Figure 1.31). The lightest sediment is carried towards the valley sides. Each time a flood occurs, a new layer of alluvium is formed. Over years, this gradually builds up the height of the floodplain.

▲ **Figure 1.32** Floodplain of the River Tuul, Mongolia



▲ **Figure 1.31** Cross-section of a river floodplain

If sea level falls and the river starts to cut down into its bed to adjust to the new lower coastline, the old floodplain is left perched above the new river channel at a higher level as a **river terrace**.

Braiding

Braiding is when a river splits into two or more channels. The channels are separated by islands of sediment. This occurs when:

- a river carries a very large load, particularly sand and gravels, in relation to its velocity
- discharge changes rapidly from season to season.

The river deposits so much sediment that the channel becomes choked and the river is forced to split up to find its way through the deposited material. The banks formed from sand and gravels are unstable. As a result, the channel becomes very wide in relation to its depth. The channels and the islands of sediment within them are constantly changing.

CHECK YOUR UNDERSTANDING

10 Explain the process of freeze-thaw action.
11 What are the **two** main types of mass movement in drainage basins?
12 Describe **two** processes of river erosion.
13 With reference to Figure 1.18, describe how the elevation of the River Tees changes from its upper course to its lower course.
14 Suggest why so much of the River Tees is in its lower course compared to its upper and middle courses.
15 Describe the landforms and processes operating in the upper course of the River Tees.
16 What are interlocking spurs?
17 Explain how ox-bow lakes are formed.
18 What is alluvium?

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