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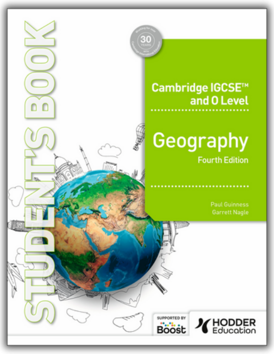

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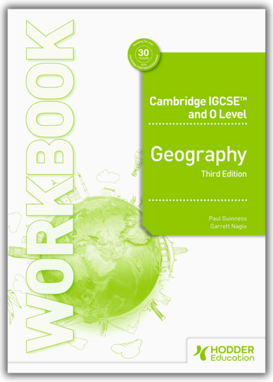

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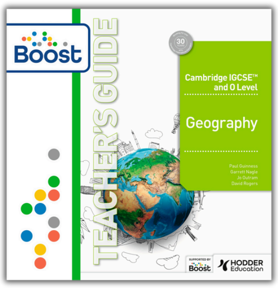

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Contents

1 Changing river environments

Key questions

- ★ What are the main hydrological characteristics and processes which operate in rivers and drainage basins?
- ★ How are river landforms associated with the processes of erosion, transportation and deposition?
- ★ In what ways do rivers present opportunities and hazards to people living near them?
- ★ What are the strategies and techniques used to manage river flooding?
- ★ What are the strategies and techniques used to manage pollution levels in rivers?

1.1 The main hydrological characteristics and processes which operate in rivers and drainage basins

Characteristics of rivers and drainage basins

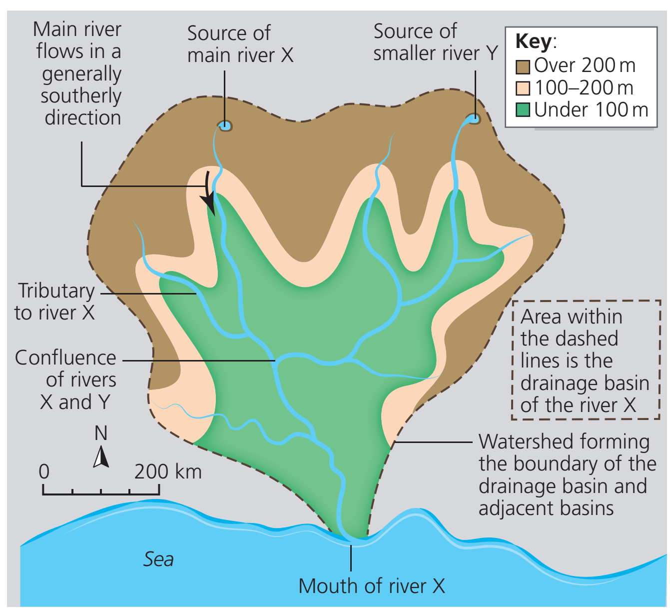
A **drainage basin** (or catchment area) is the area drained by a river and its tributaries. Some drainage basins are very small, at less than 10 km². However, the world's largest drainage basins are huge – the Mississippi River and its tributaries drain over one-third of the USA (Table 1.1).

Table 1.1 The drainage basins of some of the world's major rivers

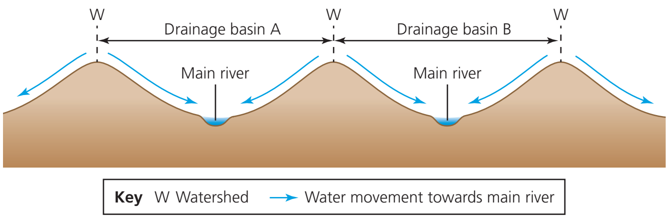
River	Continent	Length (km)	Area of drainage basin (km²)	Average discharge (m²/sec)
Amazon	South America	6,387	6,144,727	219,000
Nile	Africa	6,690	3,254,555	5,100
Mississippi/ Missouri	North America	6,270	3,202,230	16,200
Yangtze	Asia	6,211	1,800,000	31,900

Drainage basins have a number of distinct features (Figure 1.1):

- » 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.



▲ **Figure 1.1** Features of a drainage basin



▲ **Figure 1.2** Cross-section showing drainage basins and watersheds

A watershed (Figure 1.2) is a ridge of high land that forms the boundary between one drainage basin and other adjacent basins.

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 1.3). 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 1.4). There are many such springs at the foot of the North Downs and South Downs, in South East England, UK.

▲ **Figure 1.3** Meltwater stream emanating from the Fox Glacier in the Southern Alps, New Zealand

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** (surface runoff).

▲ **Figure 1.4** Water issuing from a spring at the boundary of permeable and impermeable rock, Malham Cove, Yorkshire, UK

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 which is due to the structure of rocks in the drainage basin.

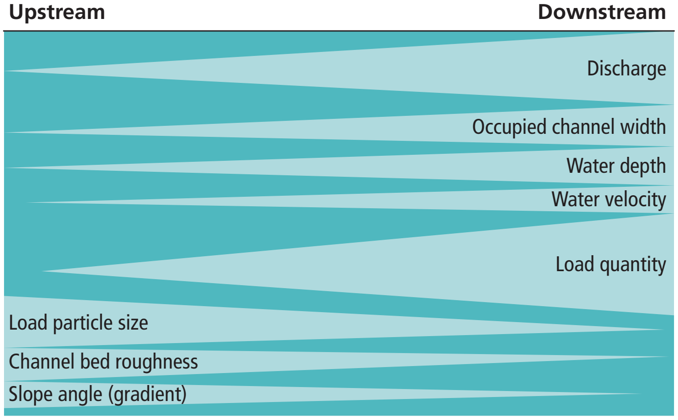
Mouth of a river

A river mouth occurs when a river empties into another body of water – a larger river, a lake, or a sea or ocean. The great majority of rivers drain into a sea or ocean, but some drain into lakes which may be far from a coastline. For example, the River Volga, the longest river in Europe (approx. 3,685 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 biggest delta in the world is the Ganges Delta in Bangladesh and India.

The long profile

The **long profile** of a river is a longitudinal section of the course of a river drawn along the river from source to mouth. It is expressed graphically as a curve, with the idealised form being a concave-upwards curve. Figure 1.5 shows how rivers change along their course from upstream to downstream:

- Discharge, width, depth, speed of flow/velocity, and load quantity all increase.
- Load particle size, channel bed roughness and the river's gradient all decrease.



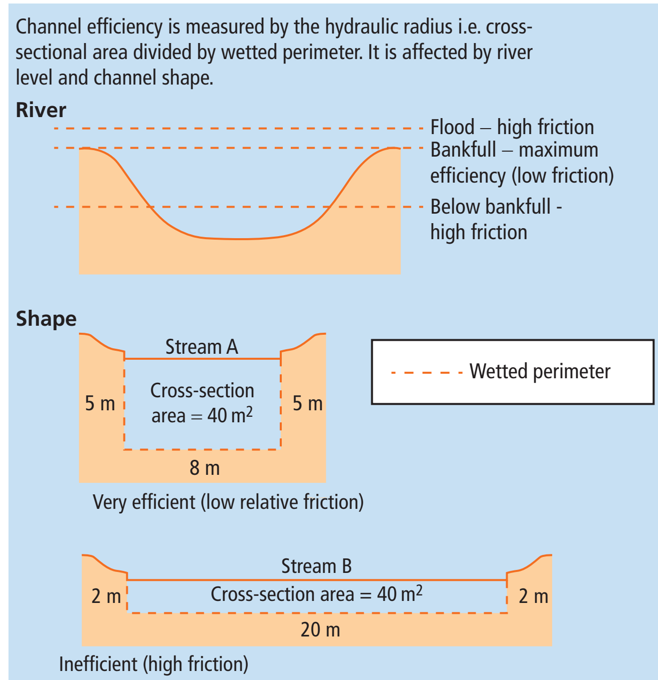
▲ **Figure 1.5** Changes in a river downstream

Channel shape

The efficiency of a stream's shape is measured by its **hydraulic radius** — that is, the cross-sectional area divided by **wetted perimeter** (Figure 1.6). The wetted perimeter is the total length of the bed and bank sides in contact with the water in the channel. The higher the ratio the more efficient the stream and the smaller the frictional loss. The ideal form is semi-circular.

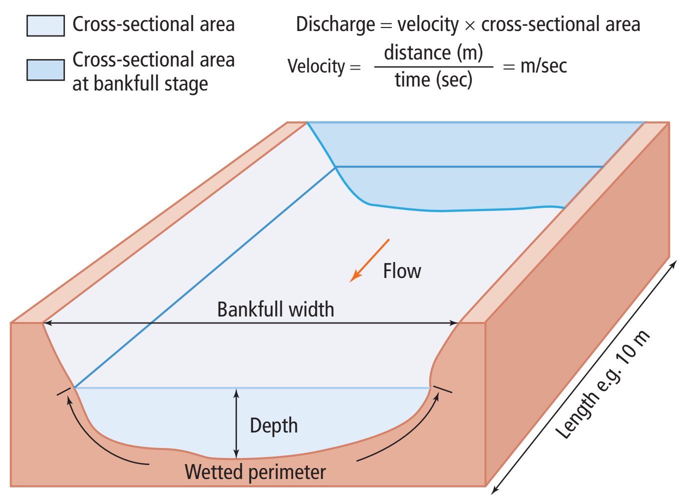
Figure 1.6 shows two channels with the same cross-section area, but with different shapes and hydraulic radii:

- Stream A: With a larger hydraulic radius it has a smaller amount of water in contact with the wetted perimeter. This results in less friction, reduced energy loss, and therefore greater velocity.
- Stream B: With a smaller hydraulic radius it has a larger amount of water in contact with the wetted perimeter. This results in greater friction, more energy loss and reduced velocity.
- Stream A is more efficient than stream B.



Wetted perimeters	Hydraulic radius
Stream A: 5 + 5 + 8 = 18 m Stream B: 2 + 2 + 20 = 24 m	Stream A: 40/18 = 2.22 m Stream B: 40/24 = 1.66 m

▲ **Figure 1.6** Wetted perimeter and cross-sectional area



▲ **Figure 1.7** Discharge

There is a close relationship between **velocity** and **discharge** and the characteristics of the channel in which the water is flowing. These include depth, width, and channel roughness.

- River velocity is the speed at which water is flowing in metres per second (m/s).

- Discharge (Figure 1.7) is the volume of water that passes through a section of the river per unit of time, expressed in cubic metres per second (m^3/s). The discharge of a river is calculated by multiplying the river's cross-sectional area by its velocity.

Channel roughness

Channel roughness describes how rough (uneven) the bed of a river is. Channel roughness causes friction, which slows down the velocity of the river water. Friction is caused by irregularities in the riverbed such as boulders, pebbles, potholes, vegetation, and contact between the water and the river bed and banks.

If a river bed was equally smooth from its source to its mouth, it would be reasonable to expect that the velocity of rivers would be greater near the source because of the steeper gradients associated with upland source regions. However, the reverse is true due to the very high degree of channel roughness in upland areas compared to the relatively smooth channels beds usually found in the lowland sections of rivers.

Discharge normally increases downstream, as does width, depth and velocity. By contrast, channel roughness decreases. The increase in channel width downstream is normally greater than that in channel depth. Large rivers, with a higher w/d ratio, are more efficient than smaller rivers with a lower w/d ratio, because less energy is spent in overcoming friction. Thus, the carrying capacity increases and a lower gradient is required to transport the load. Although river gradients decrease downstream the load carried is smaller, and therefore easier to transport.

Activities

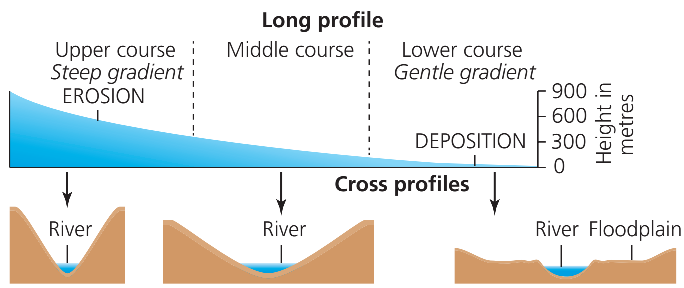
1. Describe three different sources of rivers.
2. What is the long profile of a river?
3. Explain the terms (a) wetted perimeter (b) hydraulic radius.
4. What is channel roughness and how does it affect the efficiency of a river?

The Bradshaw model

The **Bradshaw model** is a geographical model which suggests how a river's characteristics change from the source to the mouth of a river. Figure 1.8 shows the generalised ways in which the long and cross profiles of a river change as the river's gradient decreases. The long profile is sub-divided into three sections:

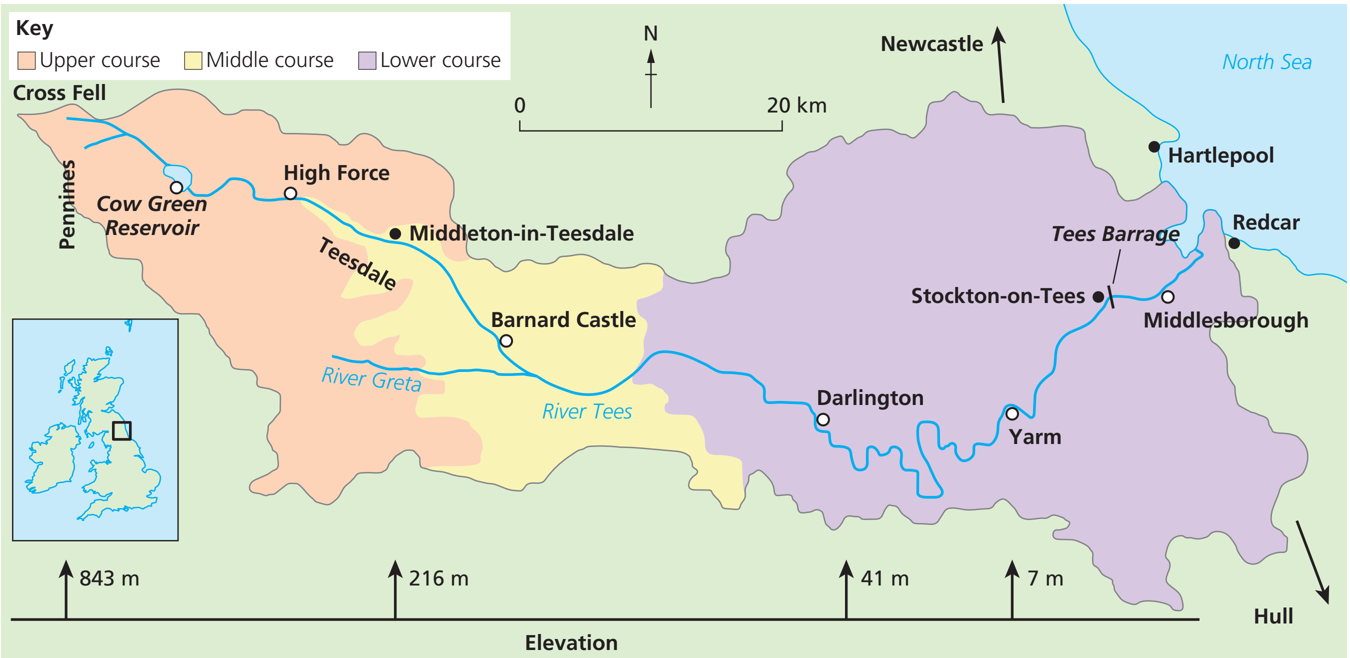
- Upper course
- Middle course
- Lower course

The characteristics of these three sections are distinctly different as are the physical processes operating in them. Look back at Figure 1.5 to remind yourself of how factors such as width, depth, velocity and discharge change from upstream to downstream.



▲ **Figure 1.8** Long and cross profiles of a river

The River Tees in North East England, UK, is a reasonable exemplification of the Bradshaw model. The Tees is one of the major rivers in North East England. It drains an area of about 1,800 square km. The source of the Tees is at Cross Fell, on the eastern side of the Pennine mountains (Figure 1.9). The river rises at a height of over 750 metres, flowing 160 km (channel length) eastwards to the mouth of the river in the North Sea. The Tees exhibits most of the classic processes and landforms of the upper, middle and lower courses of rivers.



▲ **Figure 1.9** Map of the River Tees from source to mouth

Upper course

This is mainly an area of moorland where the main land use is sheep farming. Annual precipitation can rise to over 2000mm per year on the highest land. Precipitation decreases significantly eastwards towards the North Sea. The river channel is shallow and narrow. The bed is uneven with sizeable angular boulders in places. There is much friction and the water flows more slowly here than further downstream where the channel is (a) wider (b) deeper (c) less uneven. High levels of friction upstream can cause considerable turbulence.

Vertical erosion has created a steep channel gradient and steep valley sides. These features, combined with impermeable rock, result in the river reacting quickly to rainfall. Impressive waterfalls are evident at Cauldron Snout and High Force along with clear examples of interlocking spurs. High Force (Figure 1.10) is the UK's largest waterfall at 21 metres high. A deep plunge pool has been eroded at the base of the waterfall. At High Force, a bed of hard rock (dolerite) overlies softer rock (sandstone and shale). Look at Figure 1.21, a few pages forward, to understand what happens when this occurs. As the waterfall has eroded upstream, it has left behind an impressive gorge downstream of High Force. Rapids are also in evidence in this section of the river.

▲ **Figure 1.10** High Force waterfall

Middle course

Below Middleton-in-Teesdale the valley widens out and the channel slope becomes more gentle. The fertile soils of the early stage flood plain provide for productive agriculture. Lateral erosion takes over from vertical erosion, forming distinctive meanders. Good examples can be seen near Barnard Castle. The Tees is joined by important tributaries including the rivers Lune, Balder and Greta. The result is a substantial increase in the volume of water in the river.

Lower course

Here the channel gradient is gentle with the river very close to sea level as it meanders across a fertile clay plain to its estuary between Hartlepool and Redcar, downstream of Middleborough. The Tees is now predominantly tidal in nature. Deposition is the dominant process, evidenced by mud flats at low tide. The river has now formed much larger meanders, for example near Yarm, across its wide flood plain. Oxbow lakes and levees are clearly evident. Just downstream of Yarm, the River Levin joins the Tees. The original winding river channel below Stockton has been straightened by artificial cuts to aid navigation. The mouth of the Tees is in the form of a large estuary with mudflats and sandbanks.

Activities

1 Study Figure 1.8.
  (a) Describe the changes in gradient and altitude from the upper course to the lower course.
  (b) How does the cross profile of a river change from source to mouth?
2 Describe the source and the mouth of River Tees.

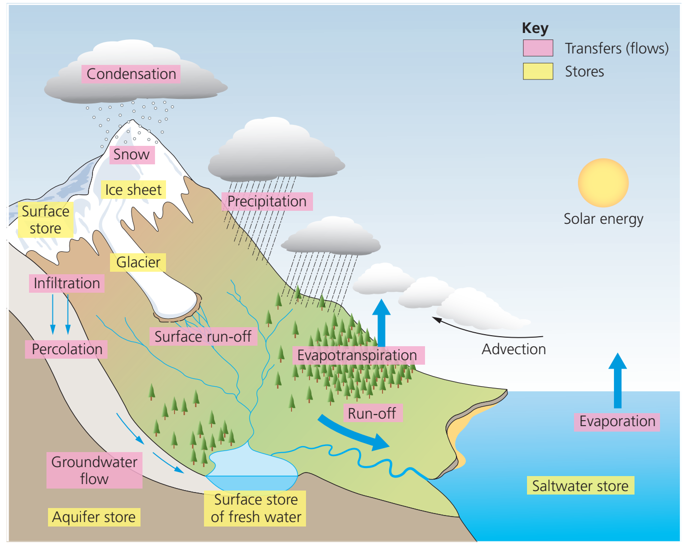
How the drainage basin operates within the water cycle

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

Figure 1.11 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.

Over 97% of the world's water is stored in oceans and seas. These water bodies make up about 70% of the surface of the Earth. This water is of course saline. Of the rest of the world's water (<3%) which is fresh, just over 2% is held as ice and snow with most of this in Antarctica and Greenland. This is followed by 0.6% as groundwater, and 0.1% in rivers, lakes, and surface reservoirs. Only 0.001% is held in the atmosphere at any one time. This amounts to only about 10 days' supply of average rainfall around the world. Without transfers in the hydrological cycle, the world would run short of fresh water very quickly.



▲ **Figure 1.11** Processes, stores and transfers in the hydrological cycle

- Antarctica covers an area of almost 14 million km^2 and contains 30 million km^3 of ice. This equates to around 61% of all fresh water on Earth. 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 km^2, which is about 70% of the surface of Greenland.
- About 30% of the Earth's fresh water is held as groundwater. At over 1.7 million km^3, the Great Artesian Basin in Australia underlies 22% of the country and is arguably the largest groundwater aquifer in the world.
- 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.

Transfers of water occur between stores by the following processes:

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

▲ **Figure 1.12** Ice melting (a transfer) at the edge of Antarctica, the world's largest mass of ice by far

Evaporation, condensation and precipitation

These are the three main processes in the hydrological cycle. Water exists in three states – liquid, solid and vapour – and the three states are constantly interchanging!

Evaporation is the process in which 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. Look how quickly water evaporates from a concrete or tarmac surface on a very hot day compared with 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 enough drinking water. Fortunately, large amounts of water evaporated from the seas and oceans are carried by air masses onto land where condensation and precipitation take place.

Condensation is the process by which 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. Thus, clouds are tiny water droplets suspended in air, while rain droplets (precipitation) are much larger. This larger size enables rain droplets to overcome rising currents in the air to reach the ground surface.

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

Processes which operate in a drainage basin

While the global hydrological system 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.

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**. This adds to **channel flow** which is the movement of water within the river channel.
- 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 said to be **saturated** (Figure 1.13). Because the soil is unable to take in any more water, the rain flows on the surface under the influence of gravity or remains on a flat surface in a waterlogged state. Flowing surface water is called **surface runoff** or overland flow.

▲ **Figure 1.13** A waterlogged field near the town of Navan, Republic of Ireland

If the soil is not saturated, rainwater will soak into it through the process of **infiltration**. It then 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 (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 which holds groundwater is known as an **aquifer**.

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 summer when trees and plants have a greater leaf coverage.

- Some rainwater will be stored on leaves and then evaporated 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 or plant stems (**stemflow**) to reach the ground.

Vegetation takes in moisture through its root system. It loses some of this into the air by **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.

Activities

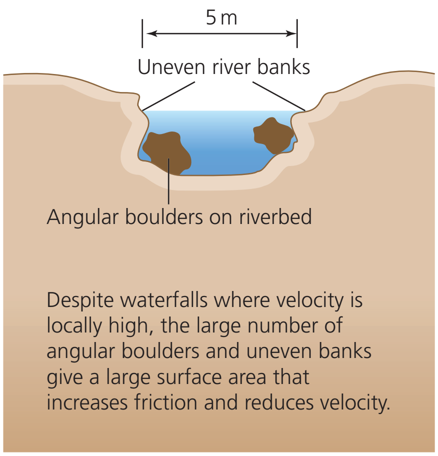
1. Study Figure 1.11.
   (a) List three stores and three transfers (flows) in the hydrological cycle.
   (b) Draw a labelled diagram to show the relationship between evaporation, condensation and precipitation.
2. Why is the global hydrological system a closed system, while the hydrological cycle of an individual drainage basin is an open system?
3. Explain the differences between (a) overland flow and groundwater flow (b) infiltration and percolation.
4. What is evapotranspiration?

Processes which operate within a river

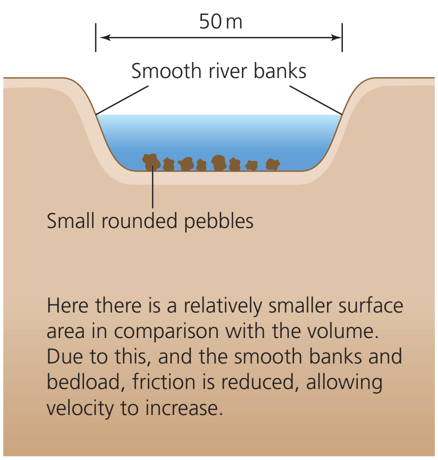
Energy is needed for transfers to occur. Around 95% of a river's energy is used to overcome **friction**. The remaining 5% or so is used to erode the river channel and transport this material downstream. The amount of energy in a river is determined by:

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

Figure 1.14 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 1.15 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.



An upland stream



A lowland river

▲ **Figure 1.14** Velocity and discharge in the upper and lower courses of a river

▲ **Figure 1.15** River in its upper course, British Columbia, Canada

Erosion

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

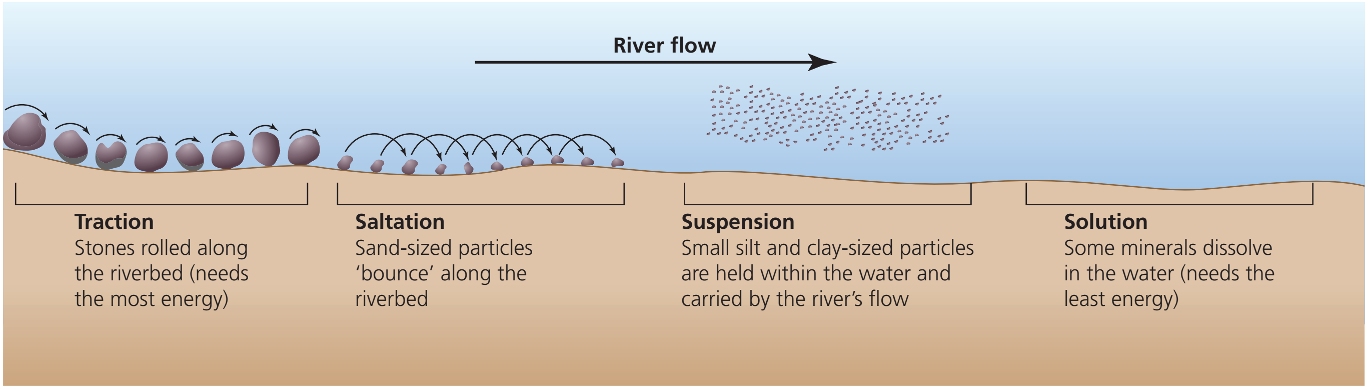
- **Hydraulic action**: the sheer force of river water removing loose material from the bed and banks of the river.
- **Abrasion/corrasion**: the wearing away of the riverbed and banks by the river's load hitting them repeatedly.
- **Attrition**: in swirling water, rocks and stones collide with each other and with the bed and banks. Over time the sharp edges become smooth and the rocks and stones become smaller in size (Figure 1.16).
- **Solution**: some rocks such as limestone which are soluble in slightly acidic water, dissolve slowly in river water.

▲ **Figure 1.16** Rocks in a dry section of riverbed, rounded and reduced in size by attrition – Kyrgyzstan, Central Asia

Along the course of a 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**.



▲ **Figure 1.17** The processes of transportation

Transportation

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

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

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

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 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 gives examples of the factors affecting the processes of erosion, transportation and deposition.

Table 1.2 Factors affecting processes: some examples

Factor	Erosion, transport and deposition
Climate	Heavy rainfall → higher discharge → increased action of river processes. Higher temperature → increased evaporation → lower discharge and reduced action of river processes.
Slope	Steep slopes result in fast-flowing rivers with strong erosive power. Gentle slopes encourage deposition.
Geology	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	Snowmelt and melting glaciers have a big impact on river regimes and processes
Aspect	South-facing slopes (in the northern hemisphere) have higher rates of evaporation and transpiration, which can affect discharge.

Activities

1. Define friction.
2. How much of a river's energy is used to overcome friction?
3. Describe and explain the differences between the two diagrams in Figure 1.14.
4. List the four processes of (a) erosion (b) transportation.
5. Under what conditions is deposition likely to occur?

Detailed specific example: Restoring Shanghai's Suzhou Creek

Location, causes and consequences

Suzhou Creek (Figure 1.46) is a part of the Yangtze River drainage basin. Its source is Taihu Lake, from which it winds 125 km, of which almost 53 km flows through Shanghai, before its confluence with the larger Huangpu River. Shanghai is one of the world's largest cities. It is located at the mouth of the Yangtze River and bounded to the east by the East China Sea.

▲ **Figure 1.46** Suzhou Creek flowing through Shanghai

Beginning in the early 1900s, the waters of Suzhou Creek deteriorated, mainly due to increasing population and the expansion of industrial activities. Domestic sewage and industrial wastewater were discharged directly into the river, gradually polluting the water quality. By the late 1970s the entire river was heavily polluted. Suzhou's fish and shrimp populations became extinct in the 1980s. By this time, it had become the most polluted water body in Shanghai. There was a high level of visual pollution and frequent complaints about the foul odour released by the mix of pollutants. Algal blooms had become a common occurrence in early summer.

Table 1.5 The increasing population of Shanghai

Year	Population (millions)
2024	29.9
2010	20.3
1990	8.6
1970	6.1

An important transport route for centuries, Suzhou Creek had become overloaded with boats transporting a wide array of products. Apart from its transport function, the waterway also provided vital flood control and drainage functions for the area, and water for farmland irrigation and nearby factories. For a long period the river had deteriorated to:

- Raw industrial pollution
- Urban wastewater
- Spills and waste from boats
- Human waste.

The situation had become so bad that the river was nicknamed the "black and stink". Suzhou Creek now:

- failed to meet even China's lowest national water quality standards (Class V)
- had become a public health hazard due to the risks of spreading diseases such as cholera, typhoid and dysentery.

Low-income communities were most vulnerable to the hazards posed by the river as they lived, and their children played, near the creek.

Restoration in three phases

In an attempt to tackle this major water pollution problem, the Shanghai Municipal Government and the Asian Development Bank (ADB) entered a long-term partnership in 1996 to restore the creek. The Economic and Social Development Plan for Shanghai was adopted to begin the 12-year Suzhou Creek Rehabilitation Project. The first phase of the project was launched in 1998 and completed in 2003. It involved:

- The reduction of sewage discharge into the river by developing systems to divert sewage away from the creek.
- Construction of a pumping station to flush the creek and input oxygen into the dead water body.
- The installation of a water lock between the Huangpu River and Suzhou Creek.
- Construction of a wastewater treatment plant, with a capacity of 400,000 cubic meters a day.
- The installation of solid waste collection wharves.

The second phase followed on immediately from the first phase and was completed in 2005. Its objectives were to:

- Maintain and improve the current water quality (building on the improvements in the first phase).
- Construct embankments to develop large areas of green space along the riverbanks.

The third phase (2006–2008) continued the emphasis of improving riverside accessibility for surrounding residents. Public use of riverfront space, appropriate distribution of a riverfront greenbelt, and regulation of riverfront buildings were included in the Suzhou Creek Landscape Planning.

Activities

1. Why is Suzhou Creek regarded as an important waterway?
2. How did the river become so polluted?
3. Describe the three phases in the restoration of the river.
4. Suggest why so many organisations were involved in the restoration project.

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