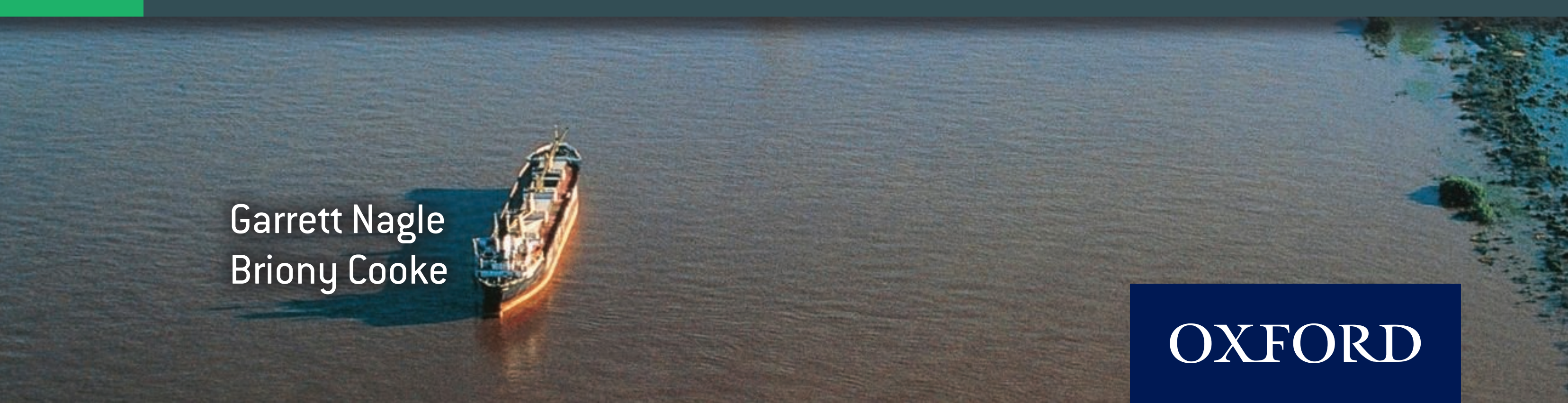
OXFORD IB DIPLOMA PROGRAMME

IN COOPERATION WITH ib

2ND EDITION

GEOGRAPHY

COURSE COMPANION



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Contents

Additional case studies are available wherever you see this icon:

OPTION A
FRESHWATER – DRAINAGE BASINS

Key terms

Drainage basin	The area drained by a river and its tributaries.
Freshwater	Freshwater includes rivers, lakes, wetlands, groundwater, glaciers and ice caps.
Hydrological cycle	A conceptual model that describes the storage and movement of water between the biosphere, atmosphere, lithosphere and the hydrosphere.
Watershed	Also known as the drainage divide, this is the imaginary line defining the boundary of a river or stream drainage basin separating it from the adjacent basin(s).
Discharge	The volume of water passing a given point over a set time.
Physical water scarcity	Lack of available water where water resource development is approaching or has exceeded unsustainable levels; it relates availability to demand and implies that arid areas are not necessarily water scarce.
Economic water scarcity	Lack of water where water is available locally, but not accessible for human, institutional or financial capital reasons.
Storm hydrograph	A graph showing how a river changes over a short period, such as a day or a couple of days.
Flood	A discharge great enough to cause a body of water to overflow its channel and submerge surrounding land.

This optional theme encompasses the physical geography of freshwater in a systems framework, including core elements of hydrology (and the factors and processes that give rise to bankfull discharge and flooding) and fluvial geomorphology (including river process and landform study).

It also covers the study of water on the land as a scarce resource requiring careful management, including freshwater bodies such as lakes and aquifers. This includes the ways in which humans respond to the challenges of managing the quantity and quality of freshwater, as well as the consequences (whether intended or unintended, positive or negative) of management within drainage basins.

The importance of integrated planning is emphasised, in addition to the geopolitical consequences of growing pressures on internationally shared water resources.

Through study of this optional theme, students will develop their understanding of processes, places, power and geographical possibilities. They will also gain understanding of other concepts including systems (the hydrological cycle), flood mitigation (attempts to tackle flooding) and water security.

Key questions

1. How do physical **processes** influence drainage basin systems and landforms?
2. How do physical and human factors both increase (exacerbate) and reduce (mitigate) flood risk for different **places**?
3. What are the varying **powers** of different stakeholders in relation to water management issues?
4. What are the future **possibilities** for management intervention in drainage basins?

1 Drainage basin hydrology and geomorphology

Conceptual understanding

Key question

How do physical **processes** influence drainage basin systems and landforms?

Key content

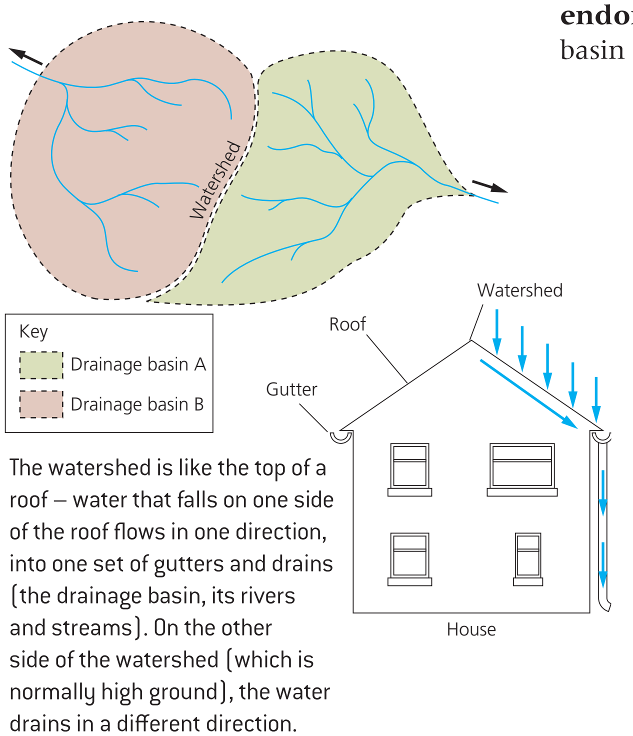
- The drainage basin as an open system, with inputs (precipitation of varying type and intensity), outputs (evaporation and transpiration), flows (infiltration, throughflow, overland flow and base flow) and stores (including vegetation, soil, aquifers and the cryosphere).
- River discharge and its relationship to stream flow (velocity) and channel shape/hydraulic radius.
- River processes of erosion, transportation and deposition, and spatial and temporal factors that influence their operation, including channel characteristics and seasonality.
- The formation of typical river landforms including waterfalls, floodplains, meanders, levees and deltas.

The drainage basin as an open system

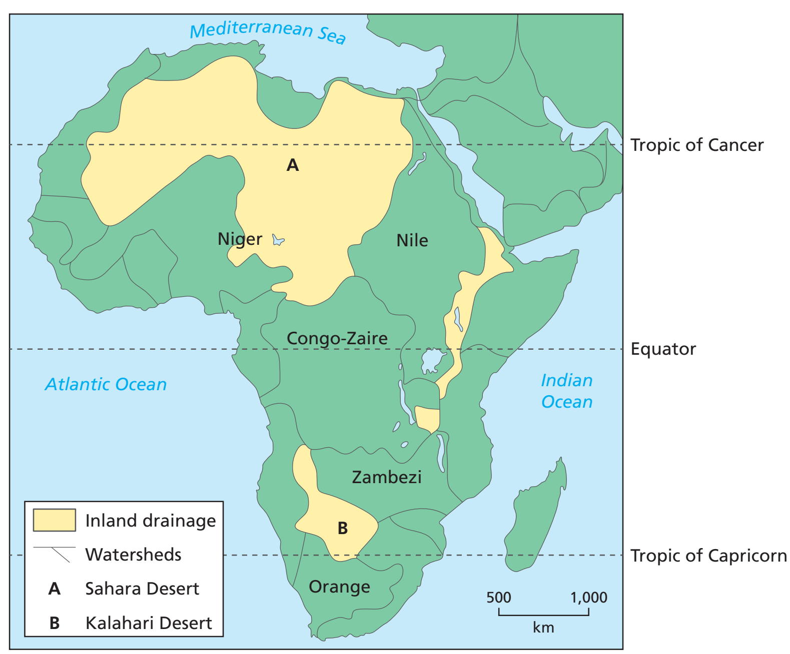
A **drainage basin** is an area within which water supplied by precipitation is transferred to the ocean, a lake or larger stream. It includes all of the area that is drained by a river and its tributaries. Drainage basins are divided by watersheds (also known as drainage divides) – imaginary lines separating adjacent basins (Figure A.1). The watershed is rather like the top of a sloping roof, dividing water into one gutter or another.

Some drainage basins are extremely large. Figure A.2 shows the major drainage basins for Africa. In contrast, very small drainage basins occur in small streams near the source of a river. Figure A.3 shows some drainage basins and watersheds for streams in the Arthur's Pass region of New Zealand.

Some rivers drain into the sea – the Nile is a good example. Others do not reach the sea but drain into an inland depression for example. These drainage basins are called **endorheic** or **closed drainage basins**. The Okavango drainage basin on Figure A.2 is an example of an endorheic basin.



▲ **Figure A.1:** Drainage basins and watershed



▲ **Figure A.2:** Major drainage basins in Africa

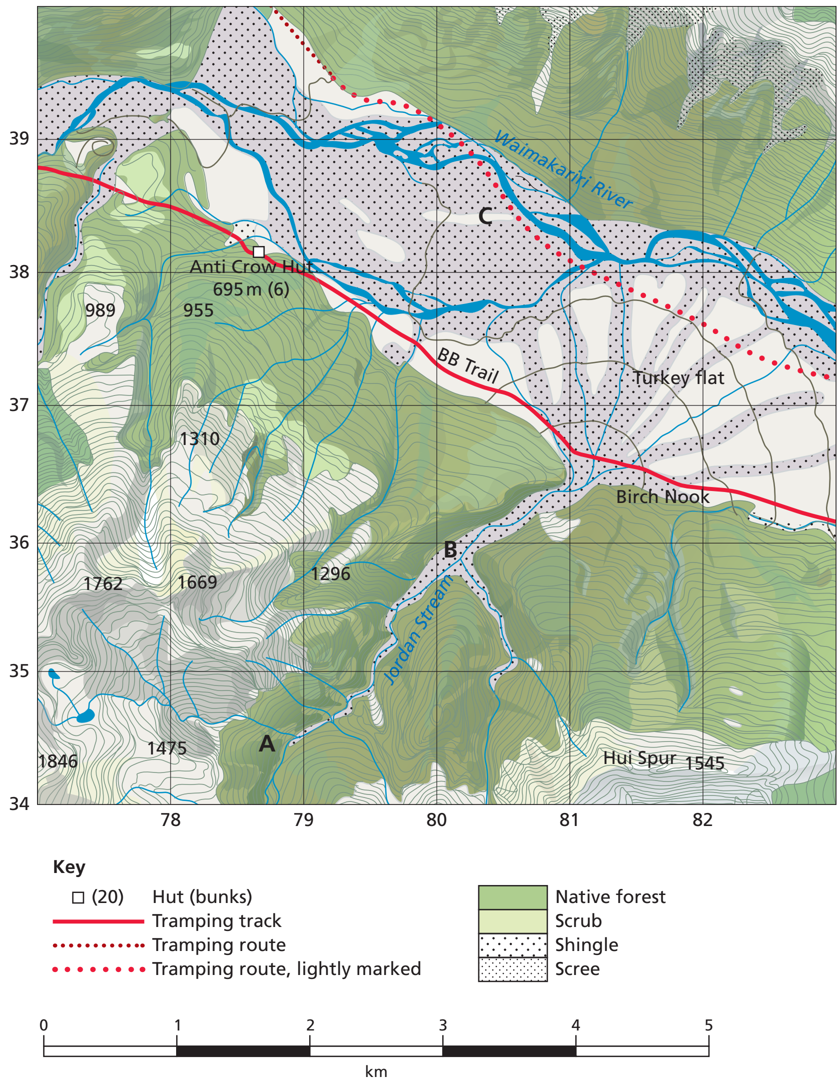


Figure A.3: A small drainage basin: Arthur's Pass, New Zealand

Activity 1

Compare the drainage basins of the rivers at A, B and C in Figure A.3.

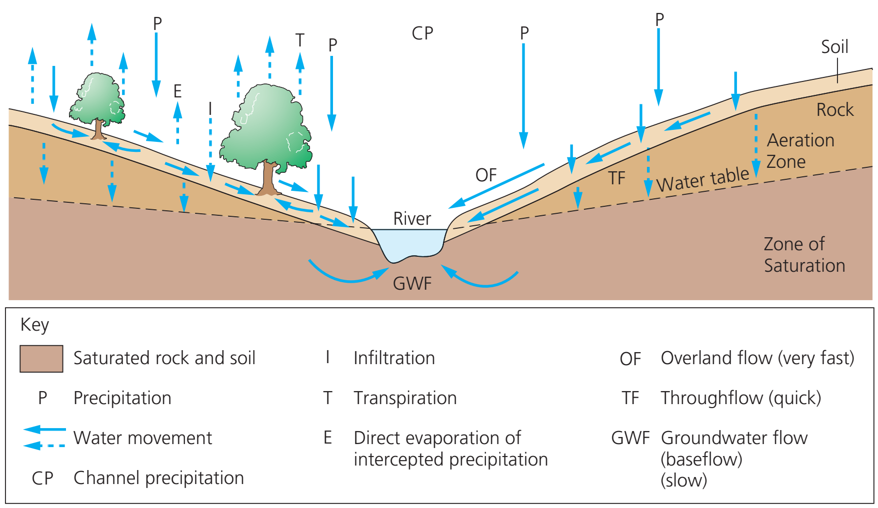
Activity 2

1. Identify three stores and three processes in the drainage basin system.
2. Explain why drainage basins are considered to be open systems.

The drainage basin as an open system, including the major flows and stores

The **hydrological cycle** refers to the cycle of water between the biosphere, atmosphere, lithosphere and hydrosphere. At a local scale – the drainage basin (Figure A.4) – the cycle has a single input, precipitation (PPT), and two major losses (outputs), evapotranspiration (EVT) and run-off. A third output, leakage, may also occur from the deeper subsurface to other basins. The drainage basin system is an **open system** as it allows the movement of energy and matter across its boundaries (Figure A.5). Water can be stored at a number of stages or levels within the cycle. These stores include vegetation, surface, soil moisture, groundwater and water channels. These stores are linked by a number of flows.

Figure A.4: Drainage basin hydrology



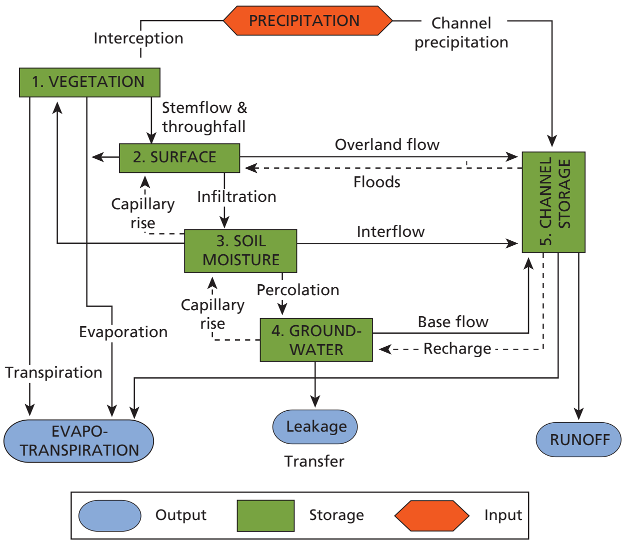


Figure A.5: Drainage basin hydrology – a systems approach

Photo A.1: Soil erosion leads to soil compaction and increased overland flow

Inputs

Precipitation

The main input into the drainage basin is **precipitation**. Precipitation includes all forms of rainfall, snow, frost, hail and dew. It is the conversion and transfer of moisture in the atmosphere to the land. The main characteristics of precipitation that affect local hydrology are:

- the total amount of precipitation
- intensity
- type (snow, rain and so on)
- geographic distribution and
- variability.

Other inputs could include irrigation water, water transfer schemes and the use of desalinated water.

Outputs

Evaporation

Evaporation is the process by which a liquid or a solid is changed into a gas. It is the conversion of solid and liquid precipitation (snow, ice and water) to water vapour in the atmosphere. It is most important from oceans and seas. Evaporation increases under warm, dry conditions and decreases under cold, calm conditions. Evaporation losses will be greater in arid and semi-arid climates than they will be in polar regions.

Factors affecting evaporation include meteorological influences such as temperature, humidity and wind speed. Of these, temperature is the most important factor. Other factors include the amount of water available, vegetation cover and colour of the surface (albedo or reflectivity of the surface).

Evapotranspiration

Transpiration is the process by which water vapour escapes from living plants, mainly the leaves, and enters the atmosphere. The combined effects of evaporation and transpiration are normally referred to as evapotranspiration (EVT). EVT represents the most important aspect of water loss, accounting for the loss of nearly 100 per cent of the annual precipitation in arid areas and 75 per cent in humid areas. Only over ice and snow fields, bare rock slopes, desert areas, water surfaces and bare soil will purely evaporative losses occur.

Potential evapotranspiration (P.EVT)

The distinction between actual EVT and potential evapotranspiration (P.EVT) lies in the concept of **moisture availability**. Potential evapotranspiration is the water loss that would occur if there was an unlimited supply of water in the soil for use by the vegetation. For example, the actual evapotranspiration rate in Egypt is less than 250 mm, because there is less than 250 mm of rain annually. However, given the high temperatures experienced in Egypt, if the rainfall was as high as, say, 2,000 mm, there would be sufficient heat to evaporate that water. Hence the potential evapotranspiration rate there is 2,000 mm. The factors affecting evapotranspiration include all of those that affect evaporation. In addition, some plants have adapted to help them reduce moisture loss, such as cacti.

Flows

Infiltration

Infiltration is the process by which water soaks into or is absorbed by the soil. The **infiltration capacity** is the maximum rate at which rain can be absorbed by a soil in a given condition.

Infiltration capacity decreases with time during a period of rainfall, until a more or less constant value is reached. Infiltration rates of 0–4 mm^{-1}/hour^{-1} are common on clay soils whereas 3–12 mm/hour are common on sand soils. Vegetation also increases infiltration. This is because it intercepts some rainfall and slows down the speed at which it arrives at the surface. For example, on bare soils where rain-splash impact occurs, infiltration rates may reach 10 mm/hour. On similar soils covered by vegetation, rates of 50–100 mm/hour have been recorded. Infiltrated water is chemically rich as it picks up minerals and organic acids from vegetation and soil. Plant roots provide fine channels for percolation (percolines).

Infiltration is inversely related to overland run-off and is influenced by a variety of factors such as duration of rainfall, antecedent soil moisture (pre-existing levels of soil moisture), soil porosity, vegetation cover, raindrop size and slope angle.

Overland flow

Overland flow (surface run-off) is water that flows over the land's surface. It occurs in two main ways:

- when precipitation exceeds the infiltration rate
- when the soil is saturated (all the pore spaces are filled with water).

In areas of high precipitation intensity and low infiltration capacity, overland run-off is common. This is seen clearly in semi-arid areas and in cultivated fields. By contrast, where precipitation intensity is low and infiltration is high, most overland flow occurs close to streams and river channels.

Throughflow refers to water flowing through the soil in natural pipes and **percolines** (lines of concentrated water flow between soil horizons).

Base flow refers to the part of a river's **discharge** that is provided by groundwater seeping into the bed of a river. It is a relatively constant flow although it increases slightly following a wet period.

Stores

Vegetation

Interception refers to water that is caught and stored by vegetation. There are three main components:

- **interception** – water that is retained by plant surfaces and which is later evaporated away or absorbed by the plant
- **throughfall** – water that either falls through gaps in the vegetation or which drops from leaves, twigs or stems
- **stemflow** – water that trickles along twigs and branches and finally down the main trunk.

Interception loss varies with different types of vegetation. Interception is less from grasses than from deciduous woodland owing to the smaller surface area of the grass shoots. From agricultural crops, and from cereals in particular, interception increases with crop density. Coniferous trees intercept more than deciduous trees in winter, but this is reversed in summer.

Soil

Soil moisture refers to the subsurface water in the soil. **Field capacity** refers to the amount of water held in the soil after excess water drains away, that is, saturation or near saturation. **Wilting point** refers to the range of moisture content in which permanent wilting of plants occurs. The wilting point defines the approximate limits to plant growth.

Aquifers

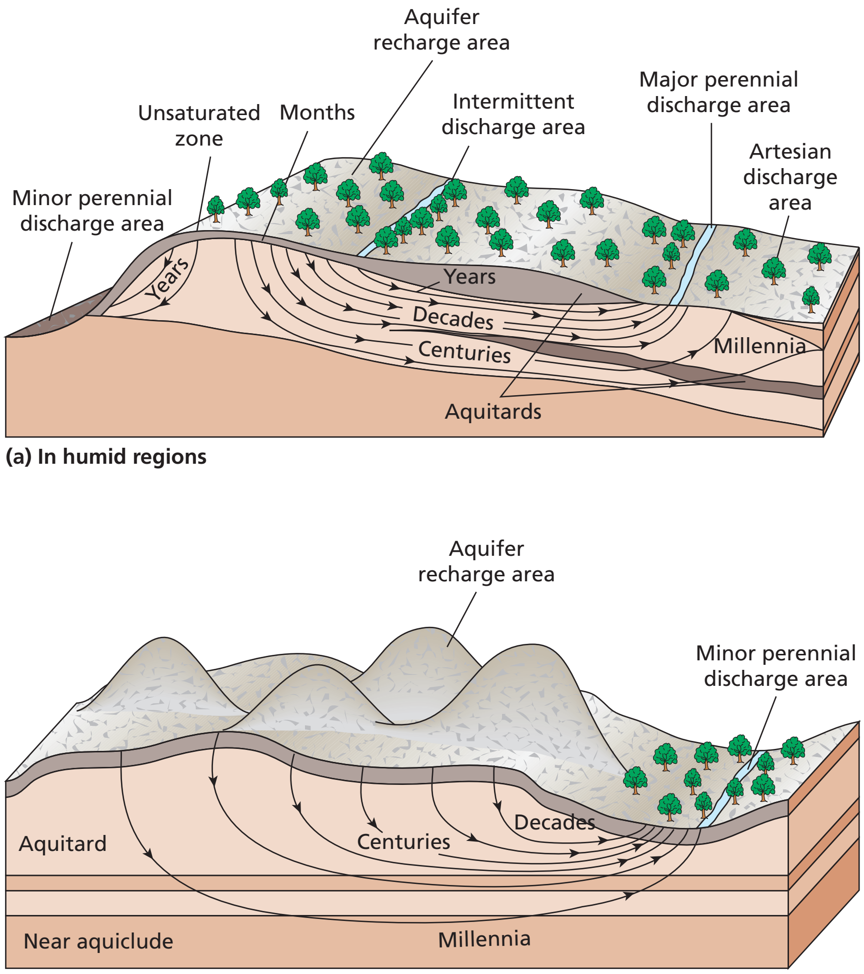
Groundwater refers to subsurface water. Water moves slowly downwards from the soil into the bedrock – this is known as percolation. Depending on the permeability of the rock this may be very slow, or in some rocks, such as carboniferous limestone and chalk, it may be quite fast, locally. The permanently saturated zone within solid rocks and sediments is known as the phreatic zone. The upper layer of this is known as the **water table**. The water table varies seasonally. It is higher in winter following increased levels of precipitation. The zone that is seasonally wetted and seasonally dries out is known as the aeration zone. Most groundwater is found within a few hundred metres of the surface, but it has been found at depths of up to 4 km beneath the surface.

Groundwater is very important. It accounts for 96.5 per cent of all **freshwater** on the Earth. However, while some soil moisture may be recycled by evaporation into atmospheric moisture within a matter of days or weeks, groundwater may not be recycled for as long as 20,000 years. **Recharge** refers to the refilling of water in pores where the water has dried up or been extracted by human activity. Hence, in some places, where recharge is not taking place, groundwater is considered a non-renewable resource.

Aquifers (rocks that contain significant quantities of water) provide a great reservoir of water. Aquifers are permeable rocks such as sandstone and limestone. The water in aquifers moves very slowly and acts as a natural regulator in the hydrological cycle by absorbing rainfall that would otherwise reach streams rapidly. In addition, aquifers maintain stream flow during long dry periods. Where water flow reaches the surface (as shown by the discharge areas in Figure A.6) springs may be found. These may be substantial enough to become the source of a stream or river.

Groundwater recharge occurs as a result of:

- infiltration of part of the total precipitation at the ground surface
- seepage through the banks and bed of surface water bodies such as ditches, rivers, lakes and oceans
- groundwater leakage and inflow from adjacent rocks and aquifers
- artificial recharge from irrigation, reservoirs and so on.



▲ **Figure A.6:** Groundwater sources

Cryosphere

The **cryosphere** is the snow and ice environment. Up to 66 per cent of the world's freshwater is in the form of snow and ice. (Over 97 per cent of the world's water is salt water, so there is a limited supply of freshwater available to humans.) High latitude regions and high altitude areas may have important stores of snow and ice. Some of this may melt seasonally to produce major changes in the basin hydrological cycle.

River discharge

River **discharge** is the volume of water passing a given point over a set time (Figure A.7). Discharge is found by multiplying the cross-sectional area of a river or stream by the mean velocity of the water. Steeper slopes should lead to higher velocities because of the influence of gravity. Velocity also increases as a stream moves from pools of low gradient to rapids. Discharge is normally expressed in cubic metres per second, or m^3/sec (cumecs).

Discharge (Q) normally increases downstream, as does width, depth and velocity. By contrast, channel roughness decreases (Figure A.8). The increase in channel width downstream is normally greater than that of channel depth. Large rivers with a higher width to depth (w:d)

ATL **Research and communication skills**

1. Research and quantify the main flows and stores for any named drainage basin.
2. Explain how you acquire this information in the field.
3. Prepare a map showing physical background and the variables that affect flows and stores in your chosen basin.
4. Explain how human activities impact upon the basin.

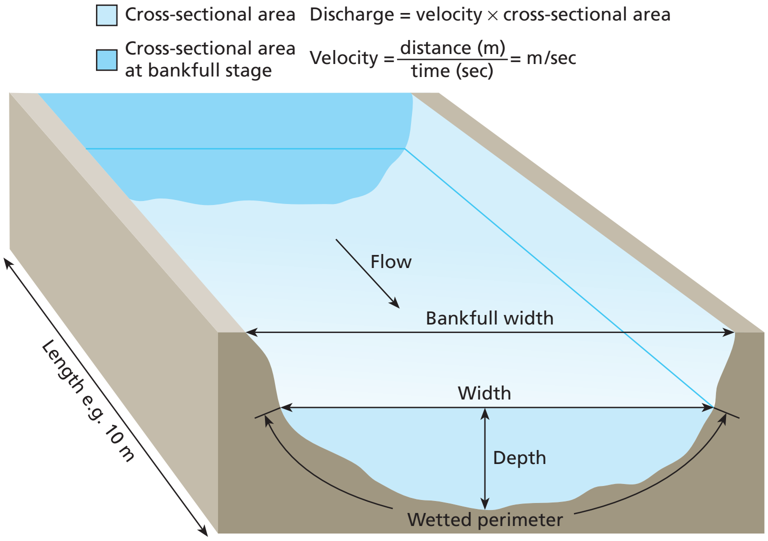


Figure A.7: Discharge in a river

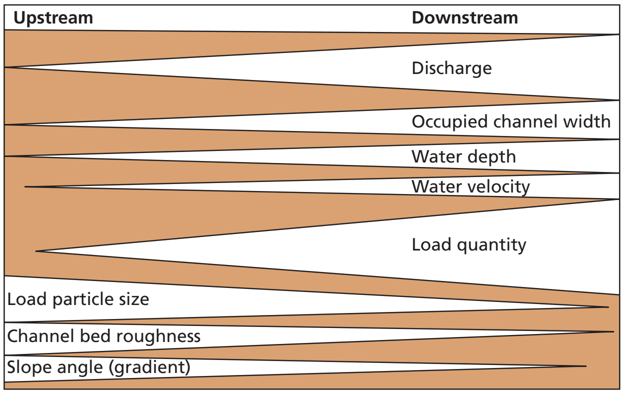


Figure A.8: The Bradshaw model of channel variables

ratio are more efficient than smaller rivers with a lower w:d ratio since 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.

Stream flow

Water flow in rivers

Hydraulics is the study of water flow in a channel. Water flow is subject to two main forces: **gravity**, which causes downstream flow, and **frictional resistance** with the bed and bank, which opposes the flow downstream. In addition, the **volume of water** within a channel and the **shape of the channel** affect the amount of energy a stream has to do its work.

Water flow is not steady or uniform. It is **turbulent**, chaotic and eddying. Turbulence provides the upward motion in the flow which allows the lifting and support of fine particles. The conditions necessary for turbulent flow to occur are:

- complex channel shapes such as meandering channels and alternating pools and riffles
- high velocities
- cavitation in which pockets of air explode under high pressure.

By contrast, laminar flow is the movement of water in a series of sheets (or laminae). It is common in groundwater and in glaciers, but not in rivers, although it can occur in the bed in the lower course of a river. The best conditions for laminar flow are:

- shallow channels
- smooth, straight channels
- low velocities.

If laminar flow alone occurred in rivers, all of the sediment would remain on the bed.

When water velocities are low, turbulence is reduced and not readily visible to the eye (except at the banks). As water levels rise, mean velocity increases, the hydraulic radius increases, and the stream appears more turbulent. Turbulence is therefore a product of channel roughness and velocity.

Velocity

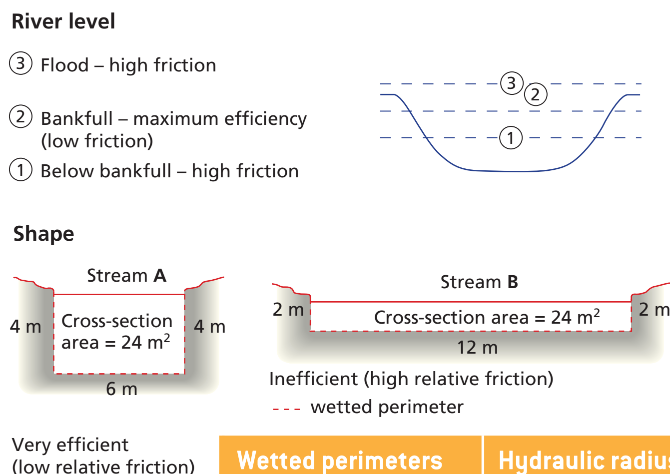
The effect of friction is to create an uneven distribution of velocity in a stream. Water closest to the bed and bank travels slowest, while water nearest the centre travels fastest. The highest velocity is thus mid-stream about a third of the way down (at the surface it is affected by surface resistance). The shape of the channel also affects velocity. In asymmetric channels maximum velocity is nearer the deep bank and slightly under the surface. This has important implications for erosion and deposition.

Velocity varies with a number of factors: volume of water; roughness of bed; gradient of stream; width, depth and shape of channel.

Channel shape

The efficiency of a stream's shape is measured by its **hydraulic radius**, the cross-sectional area divided by the wetted perimeter (Figure A.9). The higher the ratio, the more efficient the stream is and the smaller the frictional loss is. The ideal form is semicircular.

There is a close relationship between velocity, discharge and the characteristics of the channel in which the water is flowing. These include depth, width, channel roughness and hydraulic geometry. The width:depth ratio is a good measure of comparison. The shape of the channel is also determined by the material forming the channel and river forces. Solid rock allows only slow changes, whereas alluvium allows rapid changes. Silt and clay produce steep, deep, narrow valleys (the fine material being cohesive and stable), whereas sand and gravel promote wide, shallow channels.



Wetted perimeters	Hydraulic radius
Stream **A**:	Stream **A**:
4 + 4 + 6 = 14 m	$\frac{24}{14}$ = 1.71 m
Stream **B**:	Stream **B**:
2 + 2 + 12 = 16 m	$\frac{24}{16}$ = 1.5 m

▲ **Figure A.9:** Hydraulic radii

Channel roughness

Channel roughness causes friction, which slows down the velocity of the water. Friction is caused by irregularities in the river bed, boulders, trees and vegetation, and contact between the water and the bed and bank. Manning's n is a formula that describes the relationship between channel roughness and velocity:

$$v = \frac{R^{2/3}S^{1/2}}{n}$$

where v = velocity, R = hydraulic radius, S = slope and n = roughness. The higher value of n, the rougher the bed, as shown in Table A.1.

▼ **Table A.1:** Channel roughness and velocity

Bed profile	Sand and gravel	Coarse gravel	Boulders
Uniform	0.02	0.03	0.05
Undulating	0.05	0.06	0.07
Irregular	0.08	0.09	0.10

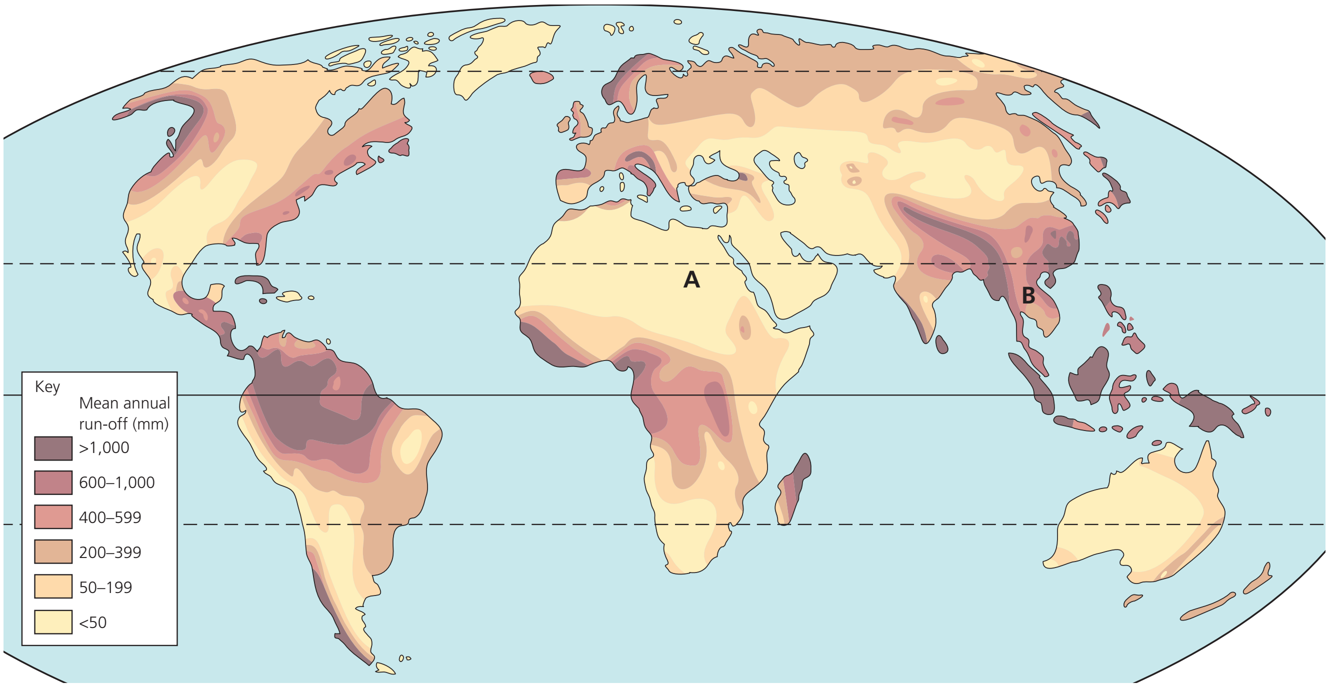


Figure A.10: Global variations in mean annual run-off/basin area

Activity 3

Study Figure A.10 which shows global variations in the mean annual run-off.

1. What is meant by the depth-equivalent discharge?
2. Describe the patterns shown in Figure A.10.
3. Using an atlas, suggest reasons for:
   a. the value at location A, and
   b. the value at location B.

Mean annual discharge

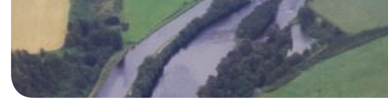
A useful statistic is the mean annual discharge divided by the drainage basin area. This gives a depth-equivalent discharge (that is, how much water runs off the surface for each area). The values range from over 1,000 mm for the Amazon river to 31 mm for the Colorado river. In terms of absolute discharge, the Amazon is highest at 230,000 m^3/sec. (Some 700 m upstream from its mouth it is 2.5 km wide and 60 m deep!) Second is the Zaire river at 40,000 m^3/sec, while the Mississippi is just 18,000 m^3/sec. Even in **flood**, the discharge of the Mississippi has only once reached 57,000 m^3/sec.

Processes of erosion, transportation and deposition

Erosion

Corrasion or **abrasion** is the wearing away of the bed and bank by the load carried by a river. Technically corrasion is the process and abrasion is the result, but the terms are used interchangeably. Corrasion is the mechanical impact produced by the debris eroding the bed and banks of the stream. In most rivers it is the principal means of erosion. The effectiveness of abrasion depends on the concentration, hardness and energy of the impacting particles and the resistance of the bedrock. Abrasion increases as velocity increases (kinetic energy is proportional to the square of velocity).

Attrition is the wearing away of the load carried by a river. It creates smaller, rounder particles.



Hydraulic action is the force of air and water on the sides of rivers and in cracks. It includes the direct force of flowing water and the force of air exploding. As fluids accelerate, pressure drops and may cause air bubbles to form. Cavitation occurs as bubbles implode and eject tiny jets of water with velocities of up to 130 m/sec. These can damage solid rock. Cavitation is an important process in rapids and waterfalls, and is generally accompanied by abrasion.

Corrosion or **solution** is the removal of chemical ions, especially calcium. The key factors controlling the rate of corrosion are bedrock, solute concentration of the stream water, discharge and velocity. Maximum rates of corrosion occur where fast-flowing streams pass over soluble rocks such as chalk and limestone.

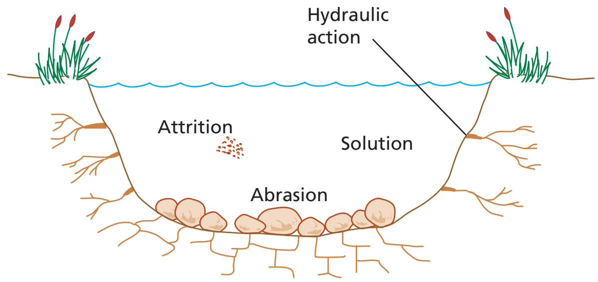


Figure A.11: Types of erosion

There are a number of factors affecting rates of erosion including:

- **Load** – the heavier and sharper the load, the greater the potential for erosion
- **Velocity** – the greater the velocity, the greater the potential for erosion (Figure A.13)
- **Gradient** – increased gradient increases the rate of erosion
- **Geology** – soft, unconsolidated rocks such as sand and gravel are easily eroded
- **pH** – rates of solution are increased when the water is more acidic
- **Human impact** – deforestation, dams and bridges interfere with the natural flow of a river and frequently end up increasing the rate of erosion.

Erosion by the river will provide loose material. This eroded material (plus other weathered material that has moved downslope from the upper valley sides) is carried by the river as its load.

Transport

The load is transported downstream in a number of ways (Figure A.12).

- The smallest particles (silts and clays) are carried in suspension as the suspended load.
- Larger particles (sands, gravels, very small stones) are transported in a series of "hops" as the saltated load.
- Pebbles are shunted along the bed as the bed or tracted load.
- In areas of calcareous rock, material is carried in solution as the dissolved load.
- Floatation is the process by which materials, such as leaves and occasionally bodies, are carried on the surface of ariver.

The load of a river varies with discharge and velocity. The capacity of a stream refers to the largest amount of debris that a stream can carry, while the competence refers to the diameter of the largest

> **Common mistake**
>
> ✗ Some students believe that clay is easy to erode because it is so small.
>
> ✓ Clay is difficult to erode because it is so small that it tends to be very cohesive (it sticks together).

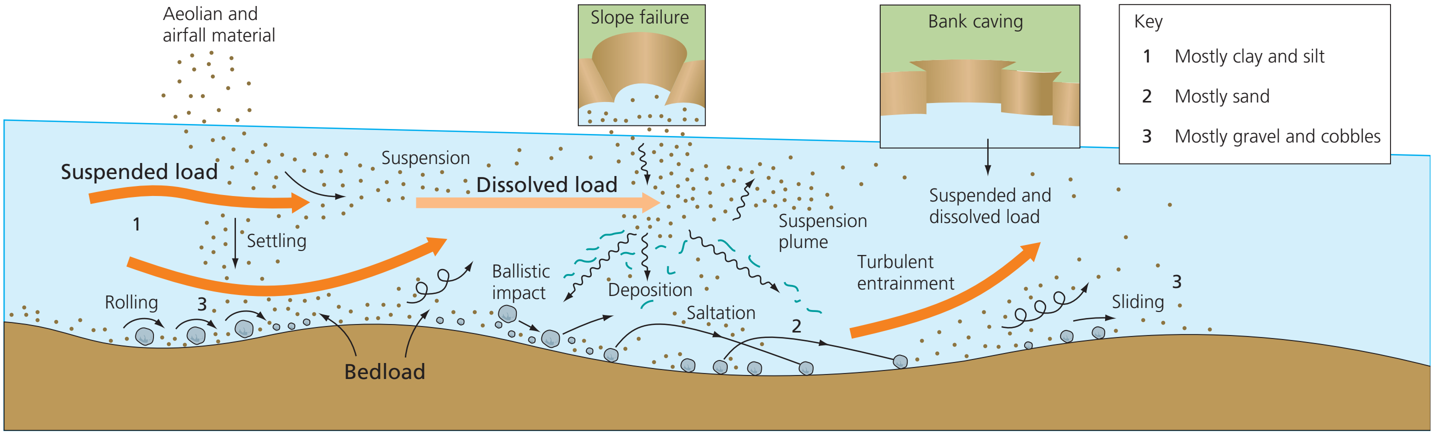


Figure A.12: Types of transport

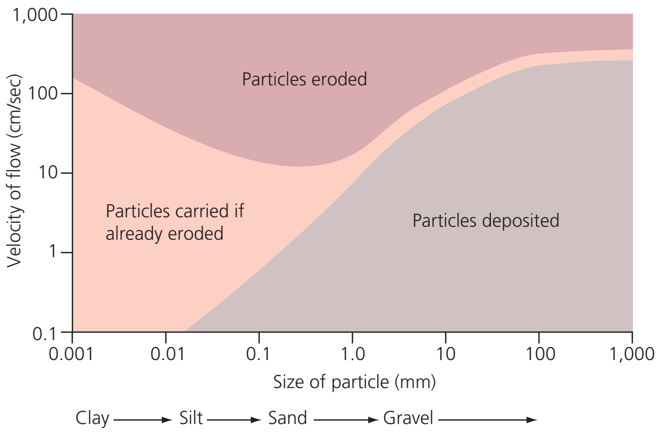


Figure A.13: Hjulström curves

particle that can be carried. The critical erosion velocity is the lowest velocity at which grains of a given size can be moved. The relationship between these variables is shown by means of a Hjulström curve (Figure A.13). For example, sand can be moved more easily than silt or clay as fine-grained particles tend to be more cohesive. High velocities are required to move gravel and cobbles because of their large size. The critical velocities tend to be an area rather than a straight line on the graph.

There are three important features of Hjulström curves.

- The smallest and largest particles require high velocities to lift them. For example, particles between 0.1 mm and 1 mm require velocities of around 100 mm/sec to be entrained, compared with values of over 500 mm/sec to lift clay (0.01 m) and gravel (over 2 mm). Clay resists entrainment due to its cohesion, gravel due to its weight.
- Higher velocities are required for entrainment than for transport.
- When velocity falls below a certain level (settling or fall velocity) those particles are deposited.

Activity 4

Study Figure A.13 which shows the Hjulström curve.

1. Describe the work of the river when sediment size is 1 mm.
2. Comment on the relationship between velocity, sediment size and river process when the river is moving at 0.5 m/sec^{-1}.

Deposition

There are a number of causes of deposition such as:

- a shallowing of gradient which decreases velocity and energy
- a decrease in the volume of water in the channel
- an increase in the friction between water and channel.

River processes vary seasonally. Some rivers have a clear wet season, when the velocity is greater, depth increases and width may increase. Monsoonal rivers erode and

Photo A.2: Erosion and deposition is highly seasonal at Myrdalsjohkull in Iceland carry more sediment in the wet season. Some rivers, such as the river that flows from the Solheimjokull glacier in Iceland, have a very high flow in spring following the spring snow melt. Once the discharge drops, it deposits its load, forming and reshaping a braided channel. Erosion and deposition may vary due to human activity – the building of large dams increases deposition behind the dam but encourages erosion downstream as the river no longer has a load to carry.

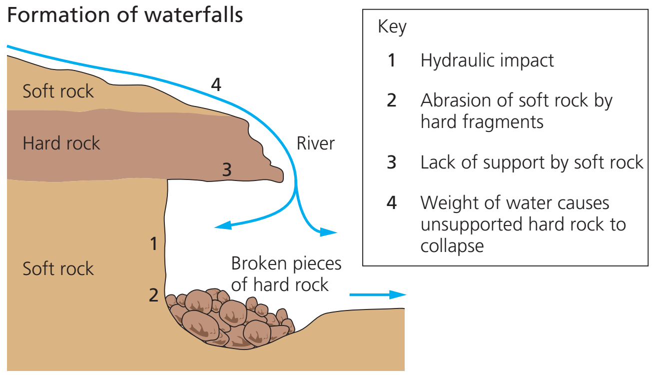
> **ATL Communication skills**
>
> Prepare a two-minute presentation on the Hjulström curve.

The formation of typical river landforms

Waterfalls

Waterfalls frequently occur on horizontally bedded rocks. The soft rock is undercut by hydraulic action and abrasion (Figure A.14). The weight of the water and the lack of support cause the waterfall to collapse and retreat. Over thousands of years the waterfall may retreat enough to form a gorge or recession, such as at Niagara Falls. Gorges can also be formed by the collapse of a cave.

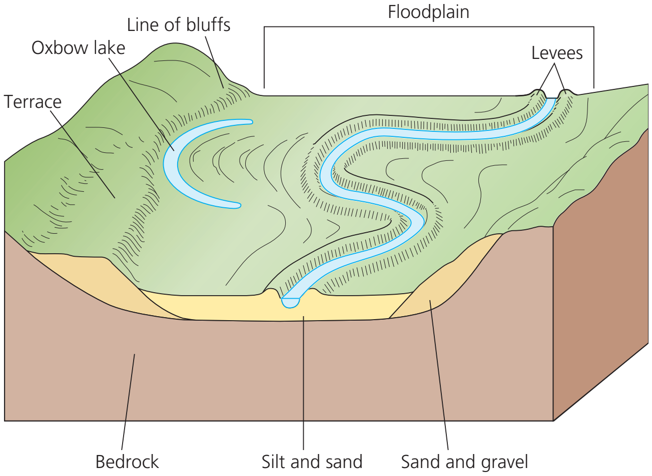
▲ **Photo A.3:** The Axara Falls at Thingvellir, Iceland



▲ **Figure A.14:** Formation of waterfalls

Flood plains

The main features of deposition are flood plains, meanders, levees, oxbow lakes and deltas. Flood plains are areas of low relief formed by deposition when a river floods (Figure A.15). The alluvium is generally a mixture of sand and gravel, eroded on the outside of the meander and built up by channel deposition as a series of bars. Flood plains vary greatly in size, and low-magnitude high-frequency floods cover only a small part of the flood plain.



▲ **Figure A.15:** Flood plains

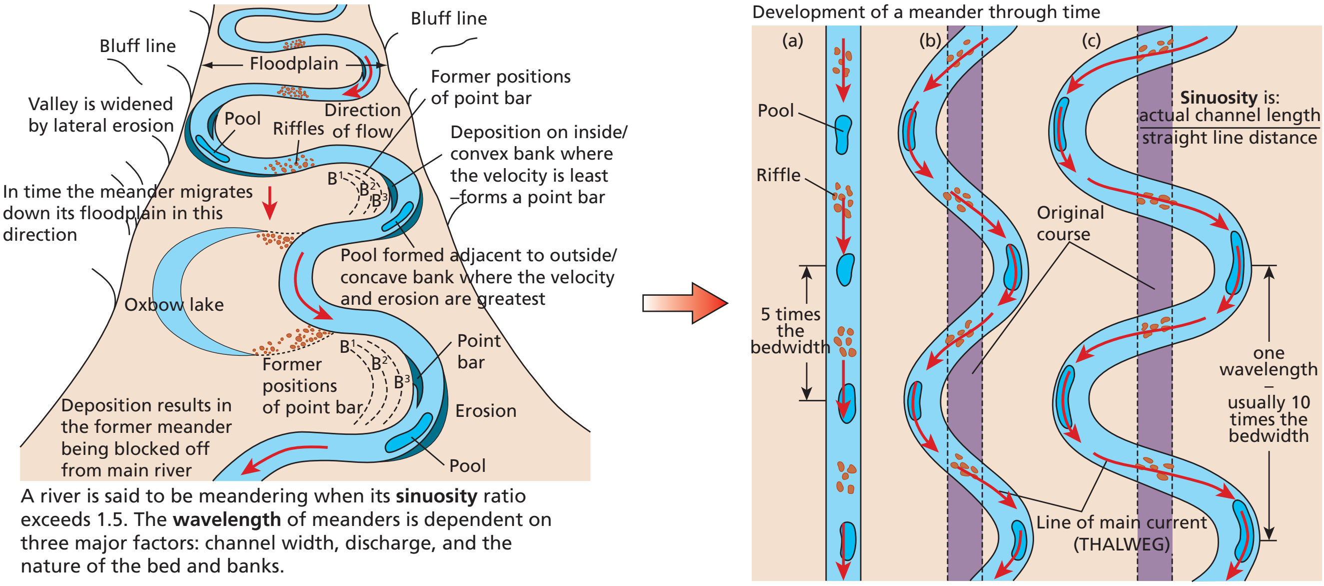
Meanders

Meandering is the normal behaviour of fluids and gases in motion. Meanders can occur on a variety of materials, from ice to solid rock. Meander development occurs in conditions where channel slope, discharge and load combine to create a situation where meandering is the only way that the stream can spread its energy over the entire length of the channel.

▼ **Photo A.4:** The Port Meadow flood plain in Oxford, UK

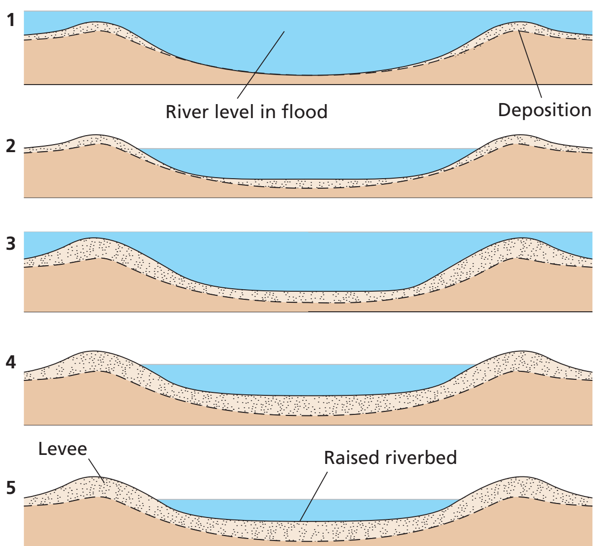
Levees

One of the most prominent deposits are levees (Figure A.17). These are formed by the deposition of coarse material near the channel, while the finer deposits are carried out



A river is said to be meandering when its **sinuosity** ratio exceeds 1.5. The **wavelength** of meanders is dependent on three major factors: channel width, discharge, and the nature of the bed and banks.

▲ **Figure A.16:** Formation of meanders



1 When the river floods, it bursts its banks. It deposits its coarsest load (gravel and sand) closer to the bank and the finer load (silt and clay) further away.

2, 3, 4. This continues over a long time, for centuries.

5 The river has built up raised banks called levees, consisting of coarse material, and a floodplain of fine material.

▲ **Figure A.17:** Formation of levees

into the flood plain. Levees are raised banks at the edge of a river. They are formed by repeated flooding of the river. When the river floods its speed is reduced. This is because it is slowed down by the vegetation on the flood plain. As its speed is reduced it has to deposit some of its load. It drops the coarser, heavier material first and the finer, lighter material last. This means that over centuries the levees build up from coarse material, such as sand and gravel, while the flood plain consists of fine silt and clay. The levees on the Yangtze river are up to 20 m higher than the flood plain.

Deltas

When a stream flows into a standing body of water it may form a delta (Figure A.18). For deltas to be formed a river needs to carry a large volume of sediment. Deposition is increased if the water is salty, as this causes salt particles to group together (a process termed **flocculation**) and become heavier, so they are deposited. Vegetation also increases the rate of deposition by slowing down the water, a process known as **bioconstruction**.

Deposition occurs because of the rapid drop in stream velocity. There is a regular succession of deposits. The finest deposits are removed furthest (the bottom-set beds), medium-grade deposits are deposited as steep-angled wedges (fore-set beds), and the coarsest material is deposited at the top (top-set beds). There are a wide variety of deltas depending upon whether marine, tidal or fluvial processes dominate. Similarly, there are a wide variety of shapes, including the curving shoreline of the **arcuate** type (for example the Nile) and the projecting **bird's foot type** (for example the Mississippi).

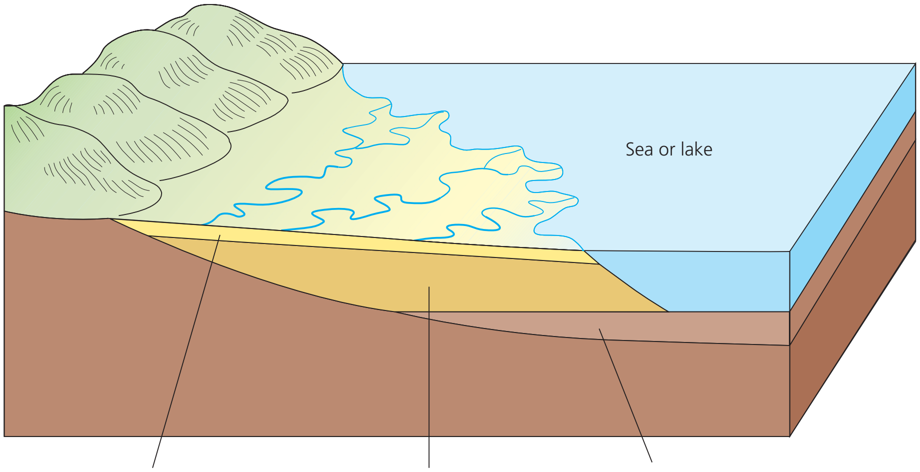


Figure A.18: Formation of deltas

Concepts in context

In this section, we have seen how many **processes** operate in drainage basins. These include precipitation, infiltration, overland flow, evapotranspiration and interception. There are also processes of erosion, transport and deposition. The actual process that occurs depends on climate geology, relief and, increasingly, human activities.

The processes that operate in drainage basins use much energy. Some processes, such as erosion, transport or evaporation require a lot of energy. Others, such as deposition, require less energy. In the upper sections where gradients are steep, gravity may have a greater influence on rivers than in lower sections.

Check your understanding

1. Define the term "drainage basin" and "endorheic".
2. Explain why the hydrological cycle can be considered to be an open system.
3. Describe how a systems approach of the drainage basin hydrological cycles (Figure A.5) differs from that of a graphical representation (A.4).
4. What is the evidence of erosion in: (a) an upland river and (b) a lowland river?
5. Describe how the load of a river varies between upstream and downstream.
6. Define the following hydrological characteristics: (a) interception, (b) evaporation, (c) infiltration, (d) groundwater, (e) base flow.
7. Briefly explain the formation of waterfalls.
8. With the use of an annotated diagram explain the formation of levees.
9. Outline the main processes in the formation of deltas.
10. Describe the main characteristics of an aquifer.