

# 1

# Hydrology and fluvial geomorphology

In this chapter you will learn about:

- How the hydrological cycle operates in general terms and the more specific ways in which water moves through a drainage basin.
- How storm and annual hydrographs are influenced by the climate and by the characteristics of the drainage basin.
- How the processes of erosion, transportation, deposition and sedimentation shape the river channel and help to produce the landforms found along the river's course.
- How people use rivers and how people contribute to the causes and effects of floods. The prediction, prevention and amelioration of river floods.

## The drainage basin system

### The hydrological cycle

The **hydrological cycle** is an example of a model (or theory). Geographers use models to help them describe and explain reality. The real world is complex and is often difficult to understand so geographers use models to simplify it. Models are useful because they help us understand the important processes and cycles that occur on the Earth's surface. However, because they are simplifications, they don't always tell the full story and they should be used with care. The hydrological cycle is a useful and versatile model because it can be applied at a range of scales, so the model applies to any land area on Earth.

The hydrological cycle is the way that water moves from the sea, through the air, onto (and into) the land, and back into the sea. It is driven by the sun's heat and by gravity. It is often known simply as the water cycle.

At any one time, the Earth's water is distributed as follows:

- 97 per cent is in the sea
- 2.1 per cent is frozen as snow and ice (mostly Greenland and Antarctica)
- 0.8 per cent is fresh water in rivers, lakes and the ground
- 0.1 per cent is in the atmosphere.

People use **fresh water** and fresh water accounts for less than 1 per cent of all the water on the planet. It is this 0.9 per cent of the Earth's water that is involved in the hydrological cycle at any one time. This is why we need to fully understand the hydrological cycle in order to use the available fresh water as efficiently and effectively as possible.

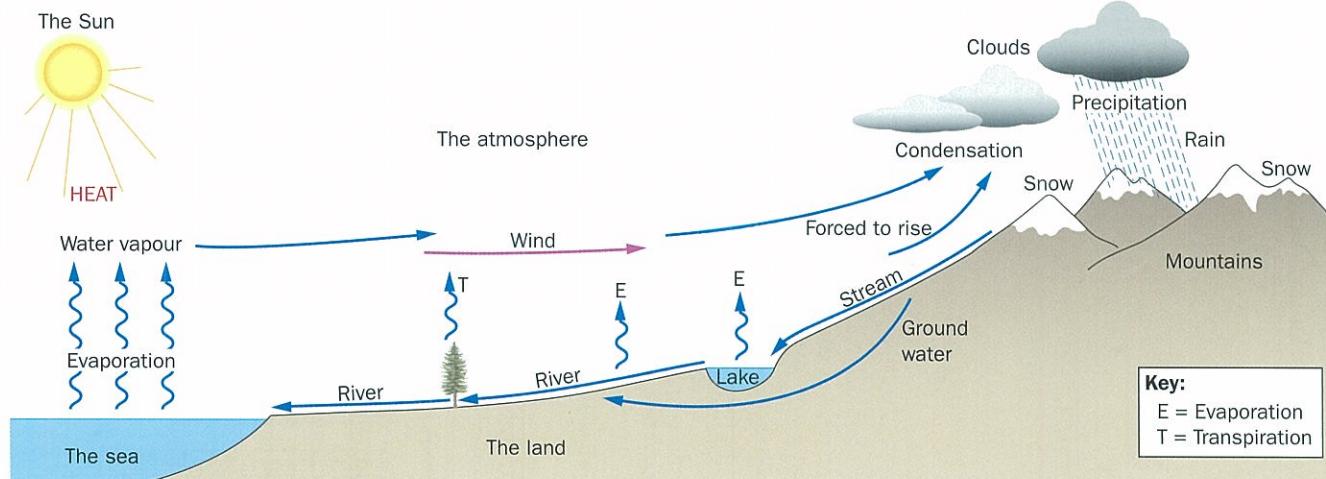


Fig. 1.1 The hydrological cycle

- 1.** Study Fig. 1.1 and then write a short paragraph to describe and explain the movement of water around the hydrological cycle. It should begin 'The sun shines down on the sea and...'.

## The drainage basin as a system

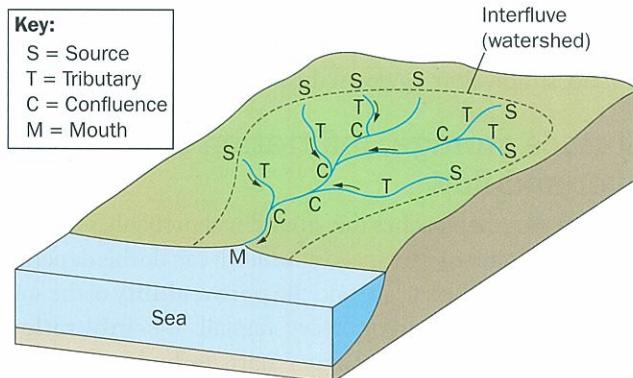
This is the part of the hydrological cycle which operates once rain has fallen onto a **drainage basin**. It is known as the drainage basin system because it has inputs, stores, flows and outputs. Geographers often use a *systems approach* in their studies. As with models, the systems approach allows geographers to simplify reality in order to understand it.

The drainage basin system is an open, dynamic system: *open* because water and energy flow into, through and out of the drainage basin; *dynamic* because the system responds to changes in its inputs: e.g. river **discharge** varies in response to changing inputs of precipitation.

We have to understand the drainage basin system in order to be able to understand how rivers behave, especially if we want to explain changes in river discharge and river flooding.

## The drainage basin

A drainage basin is the area of land drained by a river and its tributaries. A drainage basin supplies a river with its water.



**Fig. 1.2** A diagram of a typical drainage basin

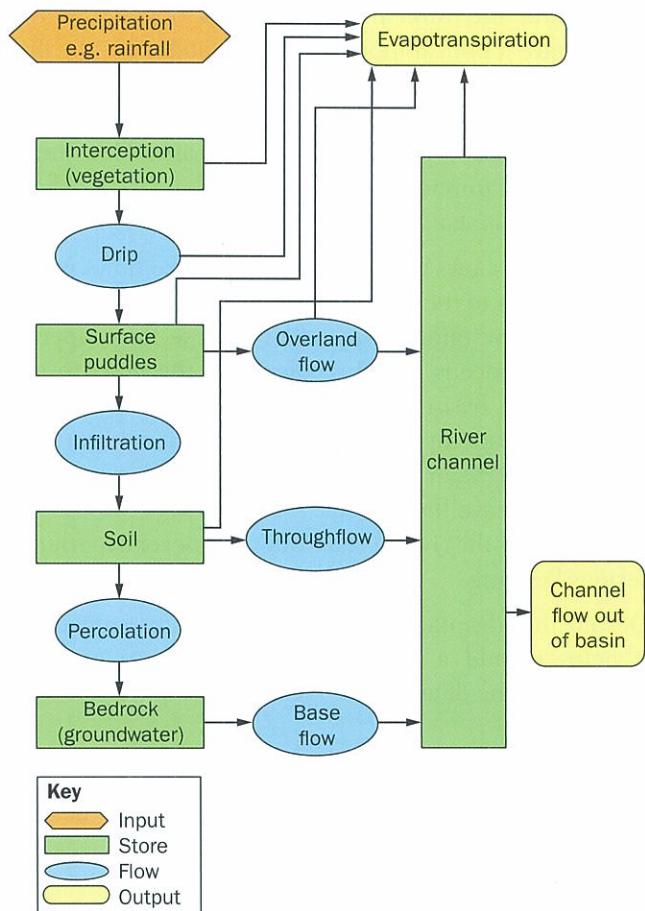
Geographers in different parts of the world often use different words for the same thing. This is the case here. In the UK, 'drainage basin' is the phrase used to describe the area of land drained by a river and its tributaries. Some UK geographers also use the phrase 'river catchment'. This phrase is also used in the USA, as is the word 'watershed'. Confusion arises here because in the UK the word 'watershed' is used for the boundary of a drainage basin, not for the drainage basin itself. It is probably best to avoid the word 'watershed' and stick to 'drainage basin' and 'interfluvium'.



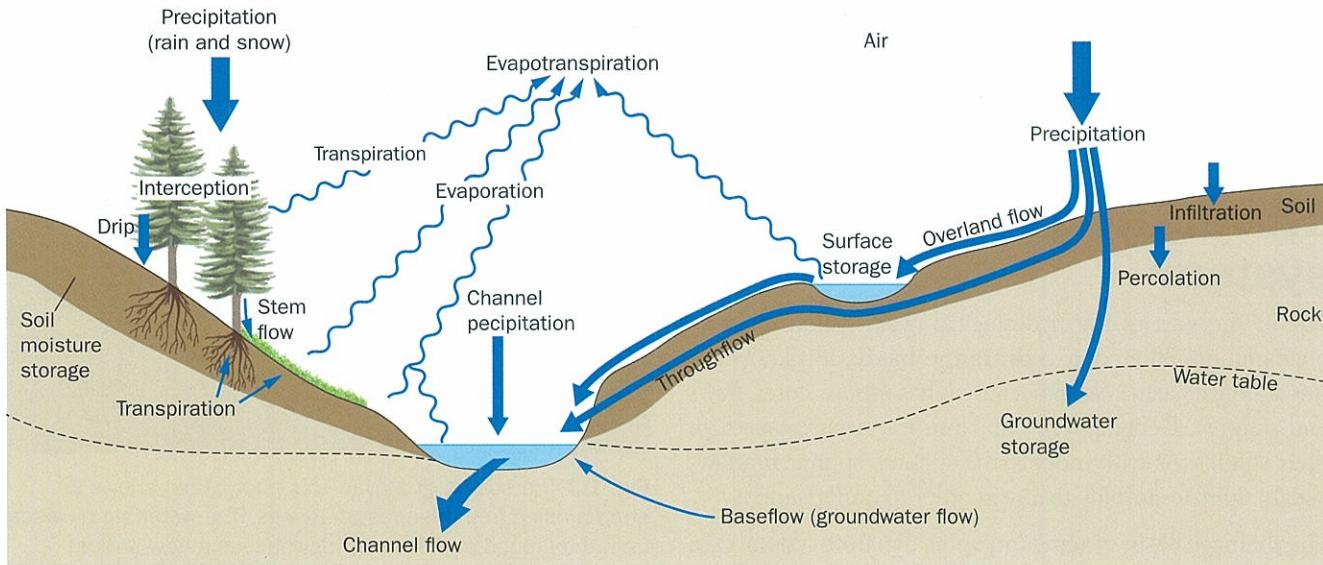
**Fig. 1.3** The source of a river. This photograph shows a stream rising from a series of springs. The water simply rises from the ground and flows off downhill as a new stream

- 2.** Write definitions of the following terms:

- Interfluvium
- Source
- Tributary
- Confluence
- Mouth.



**Fig. 1.4** The drainage basin system – a flow diagram



**Fig. 1.5** The drainage basin system – a pictographic representation. This shows a cross-section of a river valley. The stream is flowing ‘out of the page’, towards the reader

Fig. 1.4 shows the drainage basin system reduced to its basic components. This is a combination of a model with the systems approach.

The drainage basin system only has one input (precipitation) but has two outputs: **evapotranspiration** and **channel flow** (river discharge). This helps us understand the ways in which rivers operate. If two basins have identical inputs of precipitation, but the first basin has much more evapotranspiration than the second basin, the first basin will have much less water in the main river (discharge) than the second basin. This simple fact has huge implications for the way that rivers behave in different climate zones and from season to season.

Fig. 1.4 also shows that there are only three flows which provide water to the river: **overland flow**, **throughflow** and **baseflow** (groundwater flow). These flows operate at different speeds and the balance of the flows in any one drainage basin will determine how quickly a river responds to an input of rainfall. A basin with a high proportion of water reaching the river via overland flow will tend to have flash floods. A basin where most of the water reaches the river via baseflow may never experience serious flooding.

Despite the advantages of simplified diagrams, sometimes it helps to add a little more complexity in order to understand the details more clearly (see Fig. 1.5).

## The components of the drainage basin system

### Precipitation

Water falling from the sky. Rain is the most important form of precipitation.

### Interception

This is rain which is intercepted before it reaches the surface of the ground. It is usually intercepted by vegetation, especially by the leaves of trees. During a short summer shower it is possible to stay dry by standing under a tree because the tree’s leaves ‘intercept’ and ‘store’ the raindrops before they reach the ground.

### Throughfall (drip) and stemflow

In a prolonged rainstorm, the leaves become saturated and water will begin to drip to the ground. Stemflow is another important way in which water moves from the tree to the ground, simply flowing down the outside of the tree trunk.

### Surface storage, infiltration and overland flow

The first rain that reaches the ground will probably soak into the soil (infiltration). The speed at which it can do this depends on the nature of the surface and the **permeability** of the soil. During prolonged and/or heavy rainfall, the **infiltration capacity** is exceeded and water starts to build up on the surface. This is surface storage and produces puddles. On a slope, this surface water will flow downhill towards the river, producing overland flow (surface runoff). Overland flow is a relatively quick process. When the soil is saturated and rain continues to fall, the rainfall will then produce surface runoff. This runoff is called saturated overland flow.

Urban surfaces such as concrete are designed to be flat and impermeable. They rapidly produce Hortonian overland flow, which is shallow, laminar, and fast-moving. Hortonian overland flow is most commonly encountered on city streets, construction sites and dirt roads in the countryside. This process poses a significant problem in steep, recently ploughed rural areas, where the water

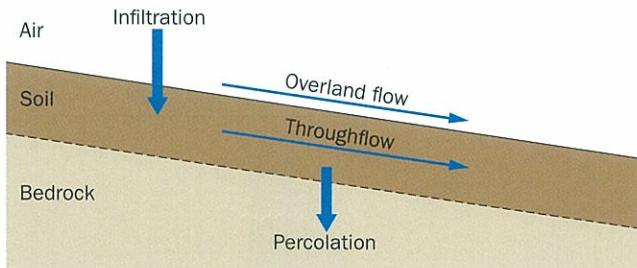
flowing over the surface can build up great speed and contribute to serious soil erosion.

## Soil storage, percolation, and throughflow

In the soil, water is held in pores, so soil often feels quite damp.

- Clay soil has very small pores and does not let water pass through it easily - it is an impermeable soil, but holds water well. Infiltration rates of 0-4 mm/hour are typical.
- Sandy soil has many large pores and allows water to pass through it easily. The pores are gaps between the sand grains and they make the sand **porous**. It is this **porosity** which makes the sandy soil permeable, but losing its water very quickly. Infiltration rates of 6-12 mm/hour are typical.

A permeable soil allows water to pass through it in two ways. Water that flows down into the bedrock is called **percolation**. Water that flows downhill through the soil, parallel to the surface, is called throughflow. Throughflow gets water to the river more slowly than overland flow, but faster than baseflow.



**Fig. 1.6** Water in the soil

## Groundwater and baseflow

Water that percolates into the bedrock is called **groundwater**. This water flows down through the rocks until it reaches the level of saturation or **water table**. Most groundwater eventually flows down through the rocks towards the nearest river. We call this baseflow or groundwater flow and it is normally a very slow process indeed. The water table moves up and down, depending on the amount of rainfall percolating downwards and the amount of baseflow flowing out of the rocks into the river. Where the water table reaches the surface other than at a river bed, groundwater reappears as a spring (see Fig. 1.3 on page 3). Where the rock structure is favourable, groundwater can remain in the rocks for a very long time. In the Sahara, there are underground stores of groundwater (**aquifers**) which fell as rain thousands of years ago.

Groundwater is an important source of fresh water. Wells can be dug and **boreholes** can be drilled down to the water table and the groundwater can be extracted. Because it has been filtered through the rocks, this water is normally very pure. Because of the continuous operation of the hydrological cycle, water is a renewable resource, but if groundwater is extracted faster than it is replaced, the water table will fall and the well will dry up. For example, the Saharan aquifers are being used

unsustainably and they will eventually dry up. This is because the rate of **recharge** (water moving from the surface into the rocks) is much slower than the rate of **abstraction**.

## Evapotranspiration

- Water evaporates from leaves, puddles and streams. The rate depends on the temperature of the water, the warmth and humidity of the air, and the speed of the wind.
- Plants draw water from the soil through their roots and allow it to evaporate into the air through their leaves. The water vapour exits the leaves through the stomata, pores which are found on the underside of the leaf. We call this **transpiration**.
- Together, we refer to this water loss from the basin as evapotranspiration. It is an important output of water from the basin and in an equatorial rainforest area it can amount to 80 per cent of the total output of water from the basin.

## Channel flow

Rainfall reaches the river via overland flow, throughflow and baseflow. Once it is in the river it flows downhill towards the sea as river discharge. This is another output from the drainage basin.

- 3.** (a) Copy and complete the following table using the words listed below:

Inputs	Flows	Stores	Outputs

Evapotranspiration	Infiltration	Soil
Vegetation	Baseflow	Drip (throughfall)
Overland flow	Bedrock	Ground water
Rainfall	Percolation	Stem flow
Throughflow	Puddles	

- (b) Name the output not listed in the table.

## The drainage basin system and human activity

People need water for many purposes including agriculture. Farmers need to have water in the soil in order to grow their crops. The amount of water in the soil depends on the balance between precipitation and **potential evapotranspiration**. **Actual evapotranspiration** is the amount of water that leaves the drainage basin in the form of water vapour going back to the atmosphere. Potential evapotranspiration is the amount of water that could go back to the atmosphere if an unlimited supply of soil moisture was available. For example,

in a desert area such as Egypt, rainfall is about 45 mm per year. The actual evapotranspiration is also 45 mm per year because that is all the water that is available. However, the climate of Egypt is so hot and dry that the potential evapotranspiration is over 2000 mm per year. The balance between the precipitation and potential evapotranspiration is known as the **water budget**.

The water budget (or water balance) is an ‘accounting’ of the inputs and outputs of water. It can be determined by calculating the inputs, outputs and storage changes of water in the drainage basin. The input of water is from precipitation and outputs are evapotranspiration and channel flow.

It is usually stated in the form of an equation:

$$S = P - Q - E$$

where  $S$  = soil storage

$P$  = precipitation

$Q$  = channel flow out of the basin

$E$  = evapotranspiration.

This water balance equation is used by hydrologists to plan and manage water supply within a drainage basin. It can be used to suggest possible water supply shortages for which special measures like hosepipe bans can be introduced to preserve water stocks. It has implications for irrigation, pollution control and flooding, too. The water balance changes from season to season.

## Case study: Malaga in southern Spain



Fig. 1.7 Location of Malaga

Malaga is on the Costa del Sol in southern Spain. The Costa del Sol is an important tourist area and there are many small farms producing fruit and vegetables for the tourist hotels and for export. Farmers need enough water in the soil for their crops to grow during the summer tourist season when the crops are in great demand. The annual rainfall is 526 mm but very little falls during the summer. The important question for farmers is how much of this water is available in the soil for their crops. Southern Spain has high summer temperatures and the potential evapotranspiration is high at the time when rainfall is low. The water budget graph shows this information.

The graph for Malaga shows the problems that local farmers face. Evaporation exceeds precipitation from April to October and the soil moisture is used up by the end of May. From June to October there is a soil moisture deficit and crops will not be able to grow unless irrigation water is available from reservoirs or deep wells.

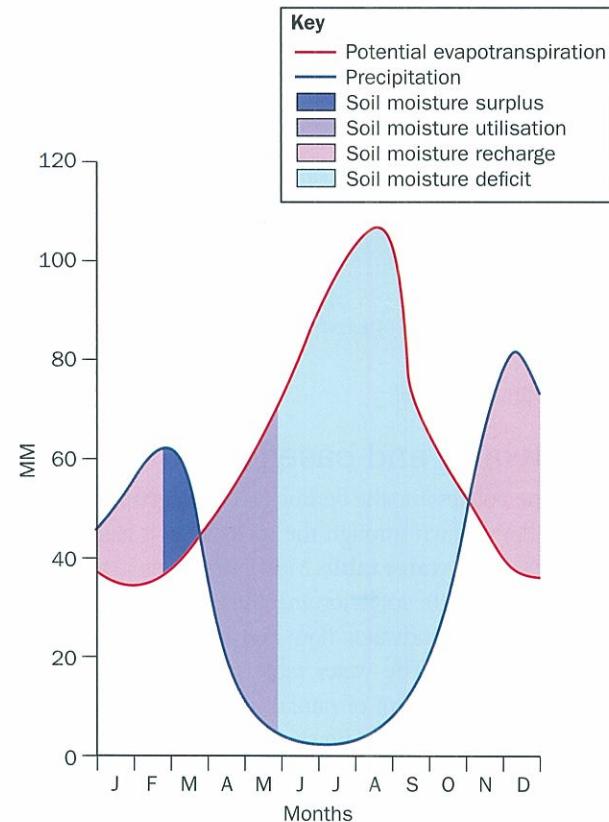


Fig. 1.8 Water budget graph for Malaga, Spain

Streams dry up at this time. Water supply for local people and tourists becomes a problem too – this is why there are so many reservoirs in the hills behind Malaga, storing winter rainfall for use in the summer. Soil moisture is recharged between November and March, but there is only a surplus for one month. Non-irrigated crops can only be grown during the winter months which are warm, as well as wet.

- 4.** Use Fig. 1.8 to compare potential evapotranspiration with precipitation in southern Spain. You should quote figures in your answer. Remember that when you are asked for a comparison you should not write two separate accounts.

**RESEARCH** Find out what the water budget graph looks like for a tropical rainforest area. Suggest how this water budget might influence the nature of the natural vegetation in the rainforest.

## Discharge relationships within drainage basins

### River discharge

The amount of water flowing down a river at any one time is called the discharge of the river. Discharge is measured in cubic meters of water per second (cumecs). Most large rivers have several gauging stations along their length, where a continuous record is kept of the river's discharge at that point.

The discharge of a river changes over time, depending on the amount of precipitation, the amount of evapotranspiration and the nature of the drainage basin itself. Drainage basins are open, dynamic systems and changes of discharge over time illustrate the *dynamic* nature of drainage basins.

- Key fact 1: Any factor that increases evapotranspiration will reduce river discharge because water is going back to the atmosphere rather than into the river.
- Key fact 2: Any factor that increases overland flow at the expense of throughflow and baseflow or groundwater flow will increase river discharge because overland flow gets water to the river much more quickly than the other two flows.

### The factors affecting river discharge

#### Climatic factors

The climate has a major impact on the operation of the drainage basin system. River discharge responds to changes in the input of precipitation and to changes in the outputs of evaporation and transpiration.

#### Precipitation

Precipitation is the major factor affecting river discharge because it is the only input into the system. Large amounts of rainfall will cause river levels to rise while a period of

dry weather will lead to falling river levels. The type and intensity of rainfall are also important. Heavy rainfall from a thunderstorm arrives at the surface quickly, exceeding the infiltration capacity of the soil and causing rapid surface runoff which increases discharge. Steady, drizzly rain arrives on the surface slowly and has more chance of infiltrating into the soil. This slows the rate at which water reaches the river, producing a smaller rise in discharge. Snowfall arrives on the surface as a solid and can't drain away. Sudden rapid melting can lead to a lot of overland flow (especially if the soil is frozen) and this increases the discharge. If the warm weather that melts the snow is accompanied by heavy rainfall, the discharge can be very high - the river, in effect, receives two inputs of precipitation at the same time.

#### Antecedent moisture

If the ground is already saturated from previous rainfall, a new input of rain will not be able to infiltrate into the soil, causing large amounts of overland flow and increasing discharge rapidly.

#### Temperature and evaporation

When temperatures drop below freezing point, the soil becomes frozen and impermeable. Rain which falls on frozen soil runs across the surface rapidly, increasing discharge quickly. Temperature also affects evaporation rates. When temperatures are high, evaporation is also high, resulting in less water reaching the river.

#### Transpiration and evapotranspiration

Forests in a river basin tend to reduce the discharge of the river. Increased interception and increased transpiration mean that evapotranspiration could be a more important output from the drainage basin than river discharge. In the Amazon basin in Brazil, 80 per cent of the rain that falls goes back to the atmosphere, reducing the discharge of the rivers. Vegetation also encourages infiltration and throughflow rather than overland flow. This reduces the speed at which rainfall reaches the river, reducing river levels.

#### Seasonality

In **temperate** areas of the world, such as Ireland, the season of the year has an important influence on river discharge. In Ireland, rainfall is spread fairly evenly throughout the year, but trees tend to be dormant in winter and have little effect on discharge at this time of year. The colder weather also reduces evaporation rates. This reduction in evapotranspiration is a major reason why Irish river levels are higher in winter. In tropical monsoon areas and in areas with a savanna climate, seasonality is also important. Rainfall occurs during the summer, increasing river discharge during this season. In areas with a Mediterranean climate, the opposite is true. Rainfall is mostly in the winter and streams tend to dry up during the summer.

# Drainage basin characteristics

The nature of the drainage basin affects the way water moves through it. Interception, infiltration and percolation all impact on the amounts of overland flow, throughflow and baseflow. These, in turn, determine the speed at which water moves through the drainage basin to the river. The rate at which water arrives at the river affects river discharge.

## Size and shape of the drainage basin

Basin size is important. Smaller drainage basins collect less rainfall than larger basins and the discharge of their rivers is smaller as a result. Smaller basins also respond more rapidly to inputs of rainfall. In 2004, heavy rain fell on the small drainage basin that includes Boscastle in the UK. The basin responded so rapidly that the flash floods gave people no warning and no time to prepare. Basin shape also affects flooding. Circular basins respond more promptly to rainfall inputs and have a higher discharge than long, narrow basins of a similar area.

## Drainage density

This is the total length of surface streams per square km. It is related to the infiltration rate. Basins with low infiltration have more overland flow and a higher **drainage density** than basins with high infiltration. As a result, drainage basins with a high drainage density respond more quickly to inputs of rainfall so they have rapid surface run-off and a rapidly rising, high discharge.

## Soil and rock type

A drainage basin with impermeable soil and bedrock will have a great deal of overland flow but less throughflow and baseflow. Because overland flow is a much faster process than the other two flows, this sort of basin will have higher discharge. A drainage basin with permeable (or porous) soil and bedrock will have much more infiltration and percolation, so throughflow and baseflow (groundwater flow) will be more important than overland flow. This will result in lower river discharge because throughflow and baseflow are much slower than overland flow. Baseflow from the large groundwater store in a basin with permeable rock will also keep the summer discharge relatively high, reducing seasonal variations in discharge.

Permeable rocks allow water to pass through them for different reasons. Granite and limestone contain tiny cracks, mostly vertical joints and horizontal bedding planes. Water can percolate down through these rocks along the cracks and we call these rocks *permeable* as a result. Chalk and Sandstone are made up of particles with pore spaces between the particles. Water can soak down through the pore spaces so these rocks are porous. Pervious limestone and porous sandstone are both permeable, in that they let water percolate down through them, but for different reasons.

## Slopes

A drainage basin with steep slopes will have more overland flow and higher river levels than a basin with more gentle slopes where there is more time for water to infiltrate.

## Vegetation type and land-use

Forests growing in a river basin tend to reduce the discharge of the river because forests increase interception, leading to greater evaporation. Forests also lead to increased transpiration, which also removes water from the basin before it can reach the river. Any land-use that creates impermeable surfaces or reduces vegetation cover tends to increase overland flow and river discharge. Pasture land allows rainfall to soak into the ground, but has less evapotranspiration than the forest it may have replaced, increasing river discharge. Floodplains tend to be fertile and are often used for arable farming which can involve the use of heavy machinery. These machines squash the soil, reducing infiltration, increasing overland flow and river discharge.

5. Explain how evapotranspiration influences river discharge.
6. Explain how overland flow, throughflow and baseflow affect river discharge.
7. 'Climatic factors are more important than drainage basin characteristics when explaining variations in river discharge'. To what extent do you agree with this statement?

## Hydrographs – graphing the changes in river discharge

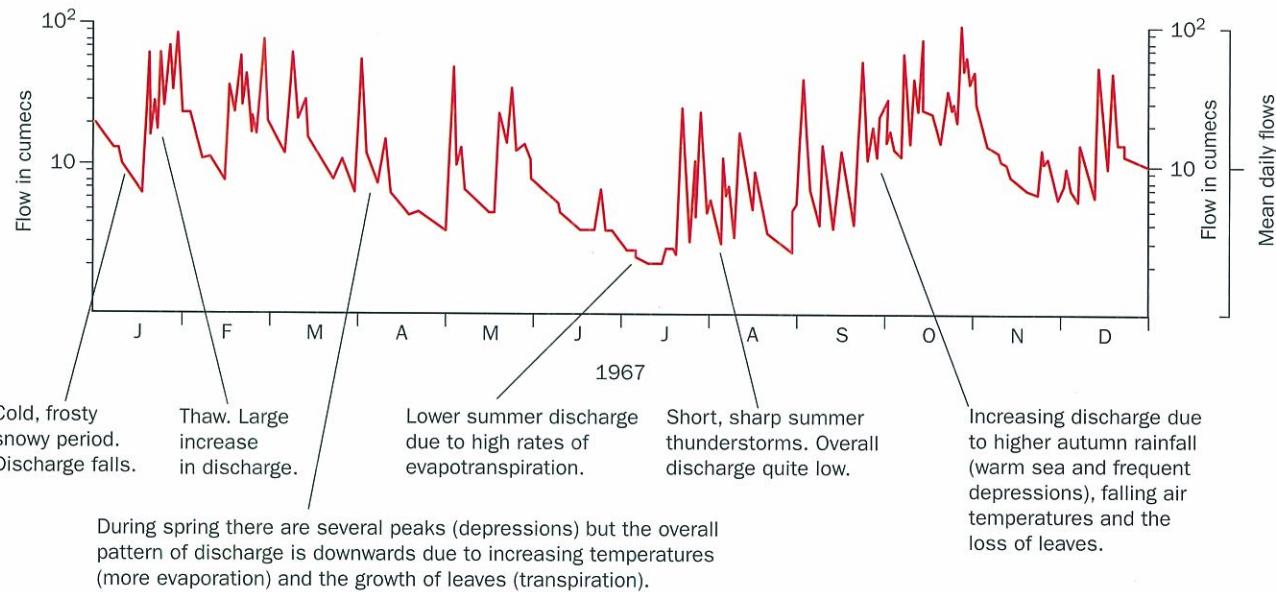
A graph showing how the river's discharge changes over time is called a **hydrograph**.

- A graph showing how a river's discharge changes over the course of one year is called an **annual hydrograph**.
- A graph showing how a river's discharge changes over a short period of time, responding to a single input of rainfall is called a **storm hydrograph**.

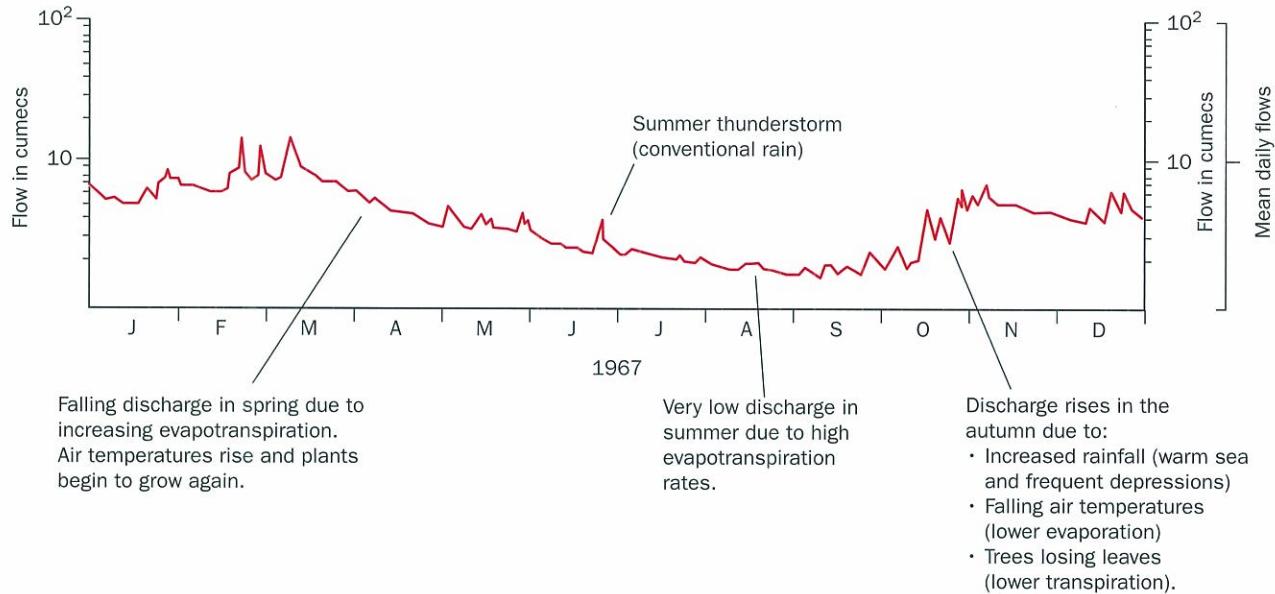
Each of these graphs can be used by hydrologists to help them understand the nature of a drainage basin and the factors that affect the discharge of its river. Water is a valuable resource so it is important to understand the river if its water is to be used sustainably. River flooding is an important hazard and if people are to manage flooding effectively, it is important to understand the way a river behaves and the factors that affect the changes in its discharge.

## Annual hydrographs

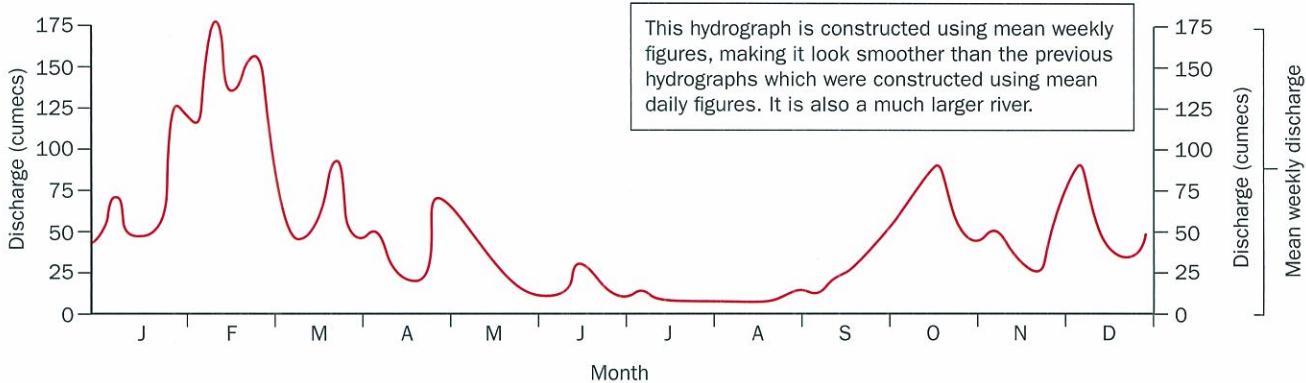
Annual hydrographs are useful when hydrologists study the responses of a river to its environment. The following examples are all taken from the British Isles.



**Fig. 1.9** River Dart annual hydrograph at Austin's Bridge, Devon, UK



**Fig. 1.10** River Avon annual hydrograph near Salisbury, Wiltshire, UK



**Fig. 1.11** River Severn annual hydrograph at Montford Bridge, Shropshire, UK

The River Dart is a short river that flows from Dartmoor in Devon. This is a very 'peaky' hydrograph, typical of rivers in western Britain. There is clearly a great deal of overland flow because the river responds quickly to the frequent inputs of rainfall. This river is likely to experience flash floods. The underlying reasons for the way that the River Dart behaves are as follows:

- high rainfall and frequent rainstorms, typical of hilly areas in western Britain
- impermeable soil and bedrock; Dartmoor is made of granite which encourages surface runoff at the expense of throughflow and baseflow
- a grass-covered drainage basin with very little forest to slow down and absorb rainwater.

The River Avon flows across Salisbury Plain, a chalk upland in southern Britain. This is a relatively smooth annual hydrograph with low and infrequent flood peaks. There is very little overland flow but a lot of baseflow. The river is responding to seasonal changes in rainfall and evaporation rates, rather than to individual rainstorms. Flooding is unlikely on this river. The underlying reasons for the way that the River Avon behaves are as follows:

- rainfall is relatively low in southern England
- permeable soil and bedrock; the bedrock is chalk, which is very porous and absorbs rainfall very easily. Throughflow and baseflow are much more important than overland flow because of the high infiltration rates. It might be supposed that this is a forested basin, but Salisbury Plain is actually mostly arable land or short grassland. It is the effect of the chalk bedrock which is the dominant factor affecting the discharge of this river.

## 8. Study Fig. 1.11.

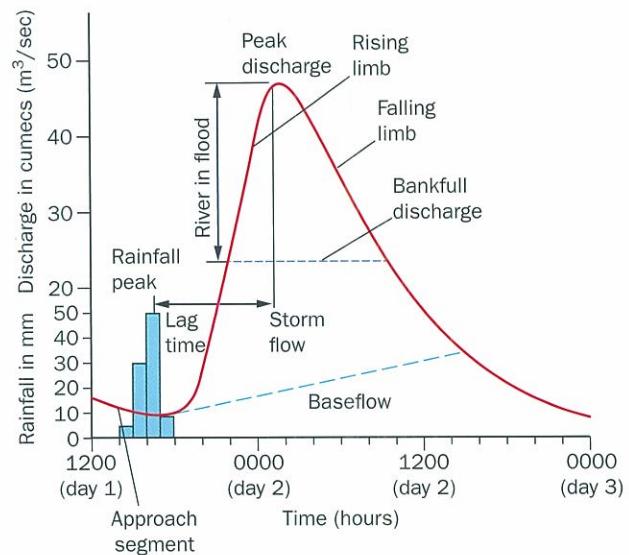
- Describe the changes that take place in the discharge of the River Severn between January and August.
- Suggest reasons for these changes. You should consider precipitation, temperature, rock type, land-use and other possible factors. (The River Severn rises in the mountains of central Wales. Snowfall is common in the winter months.)

## Storm hydrographs

How a drainage basin reacts to a large input of rainfall tells us about the nature of that drainage basin. We can then predict how it will react in future to similar rainstorms and make plans to cope with the perceived flood risk. The storm hydrograph is crucial here; it is the drainage basin's 'fingerprint'.

Definitions of some of the key words and phrases:

- **Discharge:** the amount of water in the river channel. It varies over time and it is the result of rainwater flowing



**Fig. 1.12** A typical storm hydrograph

into the channel via overland flow, throughflow and baseflow. In Fig. 1.12, the discharge responds to a large input of rainfall.

- **Cumecs:** cubic metres of water per second. The unit of measurement for river discharge.
- **Approach segment:** the discharge before the rainstorm.
- **Rising limb:** the discharge rises steeply after the storm, mostly due to overland flow.
- **Bankfull discharge:** when the river channel is completely full. If the river rises further there will be a flood.
- **Peak discharge:** the highest level that a river reaches during a flood.
- **Lag time:** the time between the maximum rainfall and the peak discharge. Drainage basins with a lot of overland flow have a short lag time.
- **Falling limb (or receding limb):** this is when river levels fall, after the peak discharge. It is less steep than the rising limb because throughflow is now reaching the river.
- **Stormflow:** stream discharge after a rainstorm, produced by a combination of overland flow and then throughflow. It is overland flow that makes the greatest contribution to the flood peak.
- **Baseflow (groundwater flow):** Stream discharge produced by water seeping from the bedrock. It is a very slow process.

## Influences on the shape of the storm hydrograph

The factors affecting the storm hydrograph are the same as the factors affecting river discharge. The speed at which the input of rainfall arrives in the river channel is the key influence. It is the balance of overland flow (relatively quick), throughflow (medium speed) and baseflow (relatively slow) that determines the shape and size of the storm hydrograph.

## Precipitation

Three aspects of precipitation influence the shape and size of the storm hydrograph:

- Prolonged rainfall leads to saturated ground and a lot of overland flow.
- Intense rainfall usually means that the infiltration capacity is exceeded, even in a permeable basin. This produces overland flow.
- Snowfall. Snow can't flow into the river because it is frozen. Snow often melts when a depression brings more precipitation in the form of rain. The warm air and the rain melt the snow, so two lots of precipitation reach the river together. The ground under the snow is often frozen and impermeable; therefore all the rainfall and the snowmelt run over the surface, producing a rapid and massive input of water into the river.

## Temperature

In summer it is warm so evaporation is high. In winter it is cold so evaporation is low and more precipitation goes into the river. Frozen ground leads to a lot of overland flow.

## Vegetation

Forests encourage interception, evapotranspiration and infiltration. Forested areas have smaller flood peaks.

## Seasonality

The three factors mentioned above show that similar inputs of rainfall can have different effects on the storm hydrograph at different times of the year.

## Soil and rock type

Permeable soil and rock reduce overland flow and enhance throughflow and baseflow. Impermeable soil and rock enhance surface runoff.

## Basin relief

Steep slopes and high relief in the drainage basin tend to get water to the river quickly and create high flood peaks.

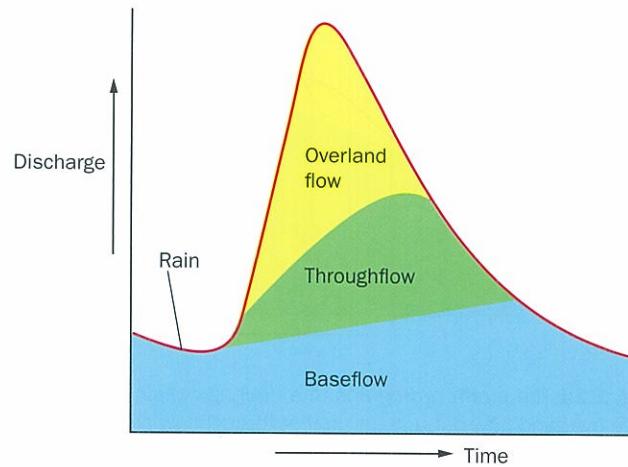
## Urbanisation

Tarmac and concrete increase overland flow, so water gets to the river faster. Gutters and drains speed up throughflow.

## Comparing storm hydrographs

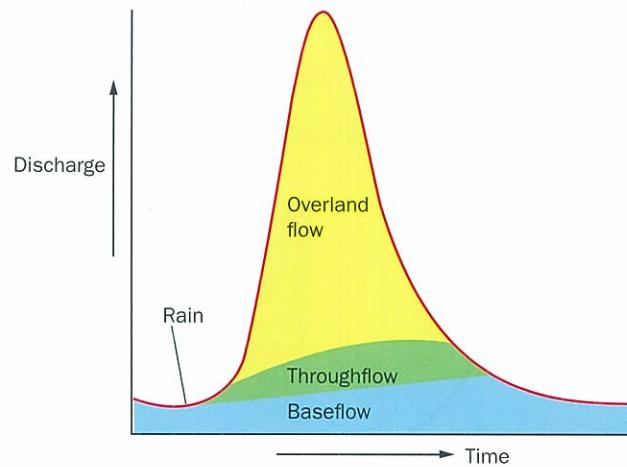
Different drainage basin factors produce differing storm hydrographs. We need to consider the contribution that overland flow, throughflow and baseflow make to the typical storm hydrograph.

- Rain falls on the drainage basin.
- The overland flow arrives first and builds up the flood peak.



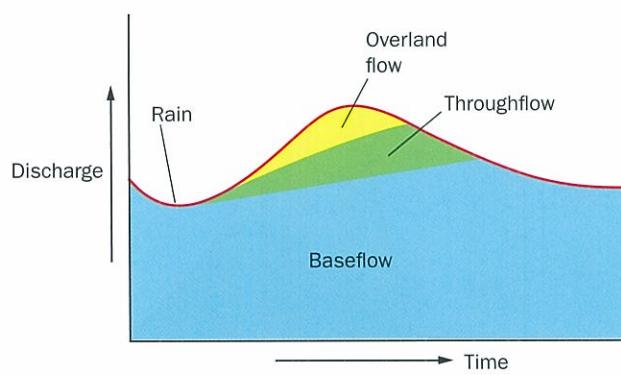
**Fig. 1.13** The makeup of a typical storm hydrograph

- After several hours or days (depending on the size of the drainage basin) the overland flow reduces and eventually stops. By this point, throughflow is contributing to the river's discharge and this stops the floodwaters going down as quickly as they rose. As a result, the falling limb is not as steep as the rising limb.
- Eventually, baseflow takes over. Baseflow takes much longer to reach the river than the other two flows, but because the groundwater store is vast, it keeps on supplying water to the river well after the rainfall has stopped. This is why most rivers don't dry up during a period of dry weather.



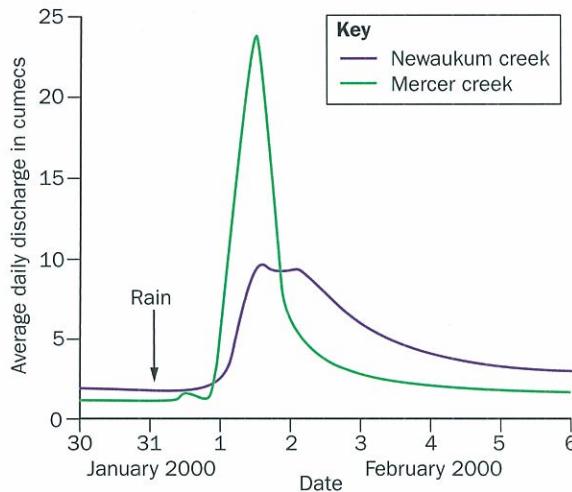
**Fig. 1.14** The storm hydrograph of a drainage basin with a lot of overland flow but not much throughflow and baseflow

Fig. 1.14 is typical of a deforested drainage basin or a drainage basin with impermeable soil and bedrock. It is also typical of an urbanised drainage basin. Notice that even in an impermeable or deforested drainage basin there is always some infiltration and percolation.



**Fig. 1.15** The storm hydrograph of a drainage basin with very little overland flow but a great deal of throughflow and baseflow

Fig. 1.15 is typical of a well-forested drainage basin or a drainage basin with permeable soil and bedrock. The lag time is long and peak discharge is low. Baseflow is controlling the discharge of this river.



**Fig. 1.16** The impact of urbanisation on the storm hydrograph

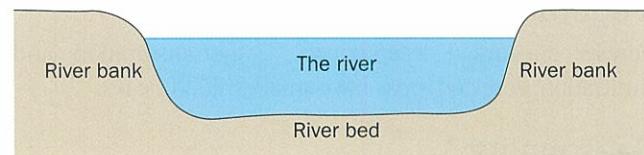
Fig. 1.16 shows the storm hydrographs for two, very similar and neighbouring drainage basins in western Washington, USA. Both drainage basins received equal inputs of rainfall from the same storm on 31 January 2000. Discharge in Mercer Creek, an urbanised drainage basin, increased more quickly and reached a higher peak than discharge in Newaukum Creek, a neighbouring rural drainage basin of equivalent size.

- 9.** Study Fig. 1.16. Suggest reasons for the differences in the two storm hydrographs.

## River channel processes and landforms

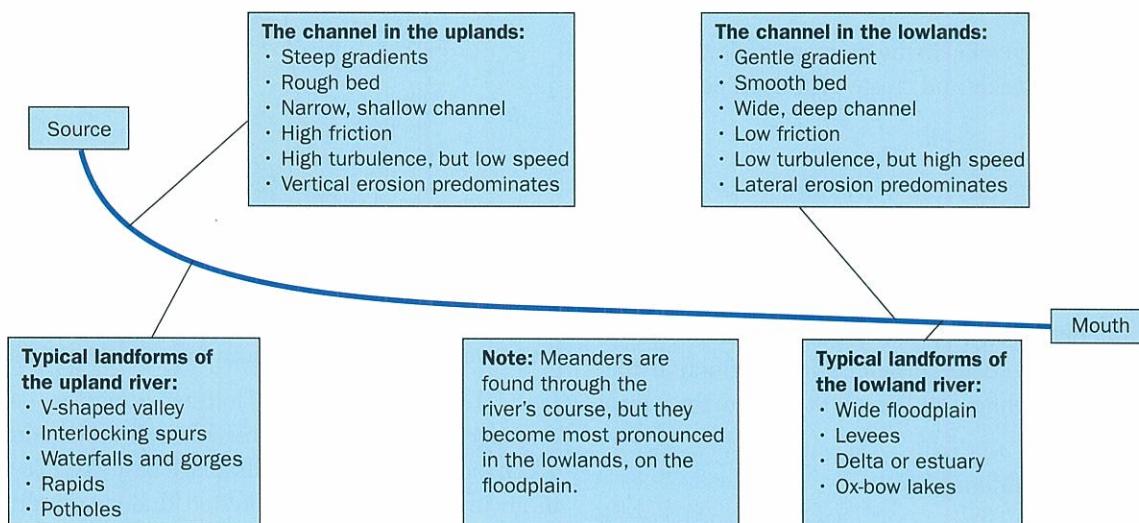
### Channel processes

The **river channel** is the 'trench' in which the river flows. It is defined by the river bed and the river banks.



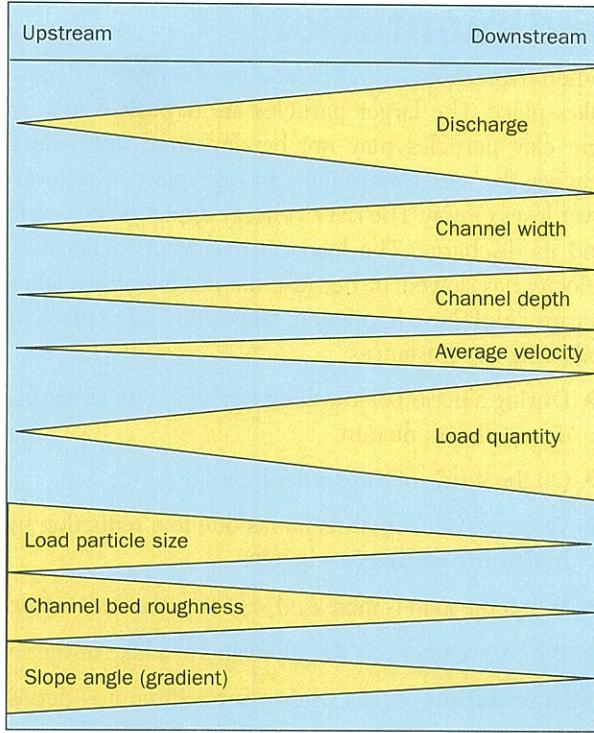
**Fig. 1.17** A cross-section of a river channel

Water flows downhill through the river channel. Because the flowing water has mass and velocity, it also has energy and it uses this energy to do work, changing the shape and nature of the river channel. Considerable changes to the river channel occur as the river flows from its source to its mouth. These



**Fig. 1.18** The long profile of a river channel

changes are illustrated by the **long profile** of a river channel. The long profile of a river channel is a line drawn from the source of the river (where it starts) to the mouth of the river (where it meets the sea). It shows how the gradient of the river channel changes as it flows downhill. The typical long profile is concave – steeper in the hills and gentler in the lowlands.



**Fig. 1.19** Bradshaw's model of downstream changes on a river

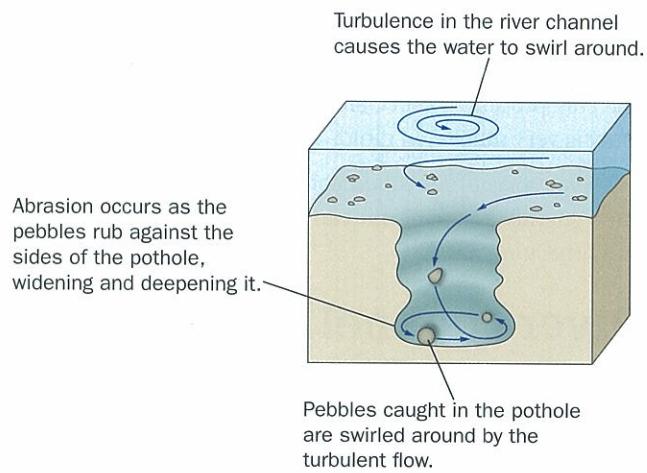
This diagram summarises many of the changes that take place in the river channel as you move downstream, from the source to the mouth. The river is an open, dynamic natural system and Bradshaw's model is important because it shows that the river can respond to changes in its inputs of discharge and **sediment** by changing any one of the variables shown.

- 10.** (a) What is 'discharge'? Describe and attempt to explain how it changes as the river flows downstream.
- (b) What is 'load quantity'? Describe and attempt to explain how it changes as the river flows downstream.
- (c) What is 'load particle size'? Describe and attempt to explain how it changes as the river flows downstream.

## River channel processes – erosion

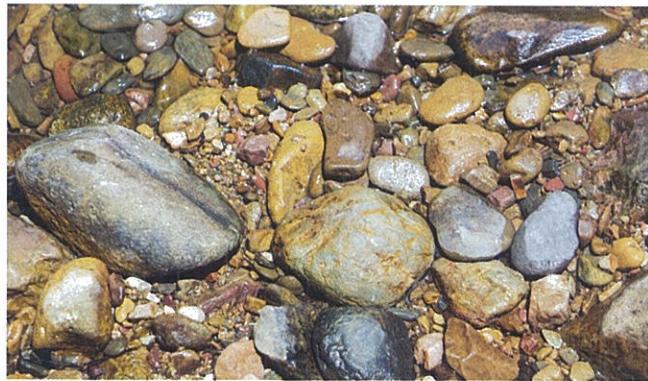
Erosion is the *wearing away* of the surface of the Earth. It is an active process, involving movement. Rivers erode their channels as they flow downhill towards the sea. Rivers have energy because the river water has mass and velocity and some of this energy is used to erode the river channel in four main ways.

**Abrasion** – sometimes called corrosion. A river uses its load of sediment to wear away its bed and banks. In the uplands, pebbles get caught in hollows in the river bed. As they swirl around, the process of abrasion produces a pothole.

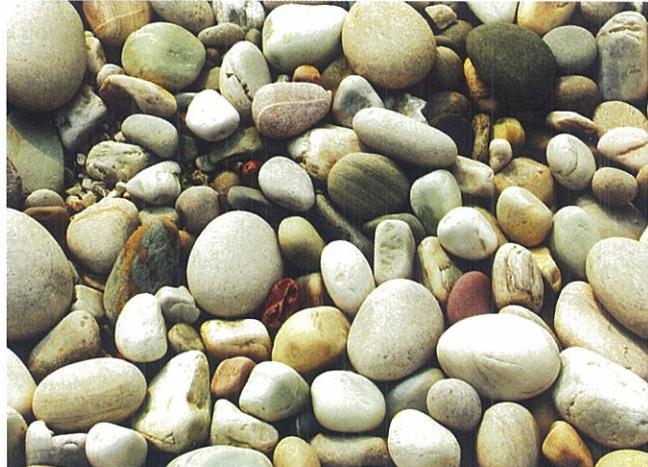


**Fig. 1.20** The effect of abrasion on a rocky river bed

**Attrition** – particles of sediment in the load of the river (especially the **bedload**) bump into each other and wear each other away. As a result, river sediment becomes smaller and more rounded as it is carried downstream.



Upstream, the bedload is mostly angular



Further downstream, attrition has made the bedload much rounder, smaller and smoother

**Fig. 1.21** The effect of attrition on a river's bedload

**Hydraulic action** – the direct force of the flowing river water can break material from the bed and banks. Even more powerful is the related process of **cavitation**, the force of exploding air. Powerful **eddies** in the flowing river water compress and decompress water in cracks in the river bank. This can lead to the formation of air bubbles in the water, which explode outwards, weakening the crack and leading to pieces breaking off. This process is especially important where the water is moving very quickly, in rapids and waterfalls.

**Solution** – sometimes called corrosion. Natural river water is often slightly acidic and it can dissolve rocks such as chalk and limestone.

## River channel processes – transportation

Rivers transport the load that is supplied to them in four main ways. The sediment is produced by river erosion and by other landscape processes such as weathering and mass movement on the valley sides.

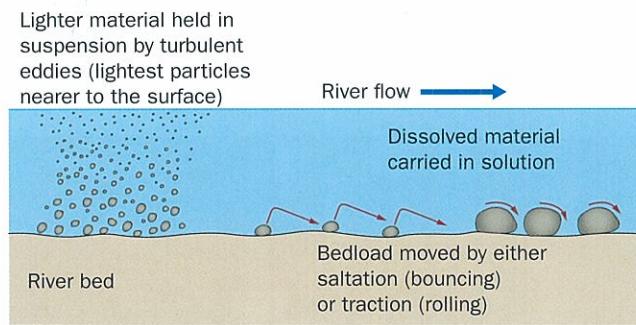


Fig. 1.22 How the river transports its load of sediment

**Traction** – the larger particles of the bedload are rolled along by the force of the flowing water. (The bedload is the load that spends all or some of its time on the river bed.)

**Saltation** – the smaller particles of bedload tend to hop along the bed of the river. A faster eddy picks them up and they move along in the body of the water until the current slows and they fall back to the river bed.

**Suspension** – this accounts for most of the load, especially in a lowland river. Lowland rivers nearly always look muddy and brown because of the large amounts of sand, silt and clay suspended in the water.

**Solution** – the dissolved load is derived from soluble rock such as limestone and chalk. Chalk streams are often clear because the dissolved load is not visible.

The load of the river varies as the energy of the river (discharge and velocity) changes. At times of high discharge, the river can carry a large amount of sediment – even small streams look muddy at times of flood. The load of a river is usually calculated at the **bankfull** stage, at the point when the river is flowing most efficiently, just before it spills out onto its floodplain. The

**capacity** of the river is the total amount of load that it is carrying. The **competence** of the river is the maximum size of particle that the river is capable of transporting at the bankfull stage.

## River channel processes – deposition and sedimentation

When rivers slow down they have less energy and deposition takes place. The larger particles are deposited first, while fine clay particles may not be deposited until the river reaches the sea. Deposition can take place whenever the river loses energy. The river's energy depends on its velocity and its discharge. The load can be dropped because the velocity has slowed, or because the discharge has fallen, or because both have happened. Deposition takes place in the following circumstances:

- During a period of low discharge when there has been a dry spell with no rain.
- On the inside of a meander bend.
- When a river bursts its banks due to a reduction in the **hydraulic radius** (see below).
- When the load is increased, e.g. after **deforestation**.
- When a river enters the still water of a lake or the sea.

**Sedimentation** occurs when river sediment is deposited from still water. This process is common on floodplains and on the sea bed. On the sea bed it is aided by the process of **flocculation**, the way that charged ions in sea water allow clay particles to coagulate together and settle out of suspension. The bottomset, foreset and topset beds in a **delta** (Fig. 1.36 on page 20) are produced by sedimentation. Material deposited as sediments may become sedimentary rock, linking river processes with the rock cycle.

## River channel processes – the Hjulström curves

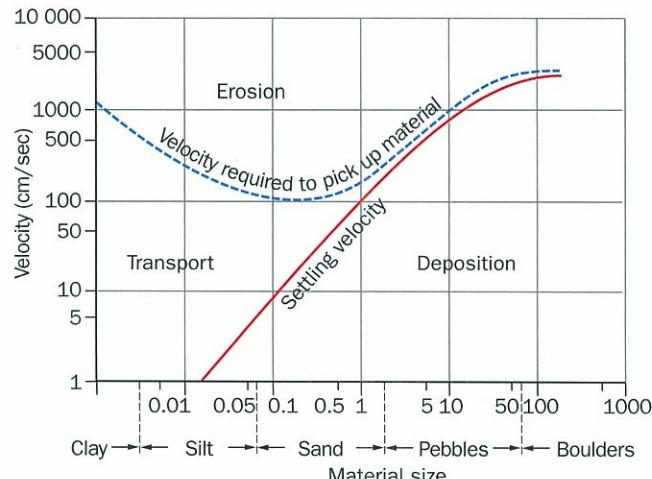


Fig. 1.23 The Hjulström curves

This diagram is a complex graph which uses logarithmic scales on both the horizontal and vertical axes. This is known as a **log/log graph**. This technique allows a wide range of data to be shown on a relatively small graph. The diagram shows the relationship between particle size and velocity. The top curve is sometimes known as the *critical erosion velocity curve* and shows the river velocity required to pick up sediment particles of different sizes. The lower curve is the *mean settling velocity curve* and shows the speed that the river has to slow to, before particles of different sizes will be dropped (deposited). The main points to note are:

- The velocity needed to keep particles moving is always lower than the velocity needed to start them moving. This means that if a swift eddy starts to move a particle, the river water will have to slow down significantly before the particle is dropped.
- Sand is the easiest material to erode. Sand can be picked up at lower velocities than either smaller or larger particles. Clay is cohesive (sticky) and pebbles are heavy – both need more energy to be eroded than sand particles do.
- Fine clays, once picked up, will stay in suspension even if the water stops moving. This is another reason why lowland rivers always look muddy.
- When a river slows down, the coarse material is dropped first, the finest last. This why **levées** form close to the river during a flood.

### 11. Study Fig. 1.23.

- How fast has the river to be moving before an average-sized pebble (10 mm) is picked up?
- At what velocity will a sand particle of 1 mm be dropped by the river?
- The velocity of water in the river channel increases after heavy rain. As the velocity reaches 1000 cm/sec, what is the status of: a tiny clay particle on the river bed, a sand grain and a boulder on the river bed?

## River flow – factors affecting the energy of a river

Rivers have *kinetic energy* because they have mass (discharge) and velocity.

Discharge is affected by precipitation and the characteristics of the drainage basin system. Discharge generally increases as a river flows downstream because more and more tributaries bring their water to the main river.

Velocity is affected by a range of factors but friction and gradient are the most important. Although we would expect rivers with a steep gradient to flow very quickly, research has shown that friction is more important than gradient. This is why rivers in

the lowlands with a gentle gradient, but a very smooth bed, flow faster than rivers in the uplands with a steep gradient, but a very rough bed. Upland rivers look as if they are flowing quickly but the extreme **turbulence** caused by the very rough river bed means that the downstream velocity is quite low. Friction is measured in two ways: bed roughness and hydraulic radius.

### Bed roughness

A rough channel produces more friction and provides more resistance to river flow than a smooth channel. Roughness is measured by Manning's N. There are different ways of calculating Manning's N, but the simplest formula is as follows:

$$N = \frac{R^{0.67} \times S^{0.5}}{V}$$

where:

N = Manning's N – the roughness coefficient

R = hydraulic radius (see below)

S = channel gradient (as a fraction)

V = mean velocity of flow

The gradient, hydraulic radius and the velocity can all be measured using fieldwork instruments, but the calculation of Manning's N is usually carried out using a computer. The higher the value of N, the rougher the bed. Small mountain streams typically have values of around 0.05, while lowland rivers have values closer to 0.015.

### Hydraulic radius

This is a measure of the *efficiency* of the river. It compares the friction caused by the bed and banks with the amount of discharge flowing down the river. In an efficient river, the water moves relatively easily, with minimum resistance to flow from friction. The formula for hydraulic radius is as follows:

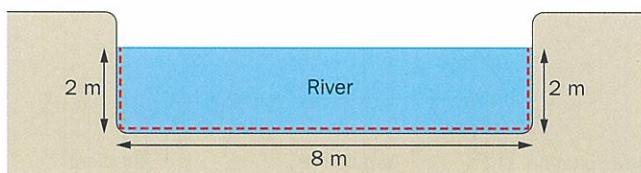
$$\text{Hydraulic radius} = \frac{\text{channel cross-sectional area (CSA)}}{\text{wetted perimeter (WP)}}$$

where:

CSA = channel depth × channel width

WP = length of the bed and banks in direct contact with the water in the river channel.

This is best shown in a diagram:



$$\text{cross-sectional area (CSA)} = 2 \text{ m} \times 8 \text{ m} = 16 \text{ m}^2$$

$$\text{wetted perimeter (WP)} = 2 \text{ m} + 8 \text{ m} + 2 \text{ m} = 12 \text{ m}$$

$$\text{hydraulic radius} = \text{CSA}/\text{WP} = \frac{16 \text{ m}^2}{12 \text{ m}} = 1.34 \text{ m}$$

**Fig. 1.24** How to calculate the hydraulic radius

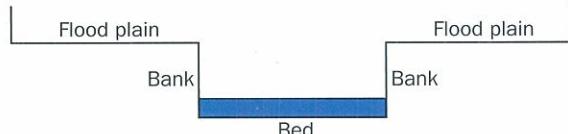
Hydraulic radius increases downstream. The hydraulic radius also changes as the discharge changes at any one point along a river.

**12.** Study Fig. 1.25. Calculate the hydraulic radius for:

- (a) low water
- (b) normal flow
- (c) the bankfull stage
- (d) the overbank flood.

When is the river at its most efficient? Explain your answer.

#### Low water



#### Normal flow



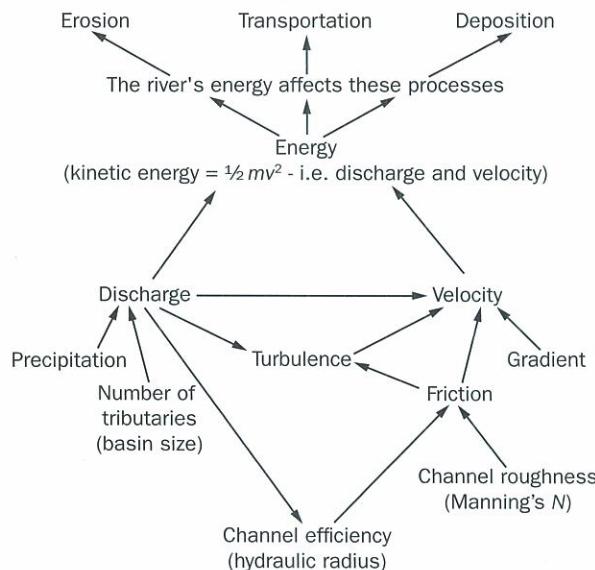
#### Bankfull



#### Overbank flood



**Fig. 1.25** Changing hydraulic radius



**Fig. 1.26** River channel processes – a summary diagram

**13.** Bradshaw's model (Fig. 1.19 on page 13) does not consider all the river variables. How would you expect the following factors to change as you move downstream:

- (a) channel efficiency (hydraulic radius)
- (b) friction
- (c) turbulence
- (d) channel cross-sectional area?

Figure 1.26 summarises the complex relationships between the various processes that operate within the river channel. Don't forget that the processes change with time, often depending on changes in the river's discharge.

## Patterns of flow

Water flows downhill in three main ways:

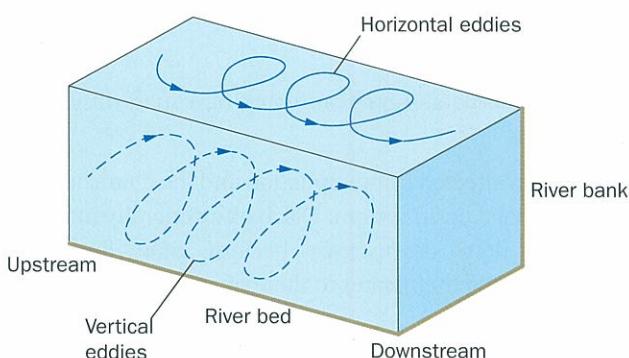
- laminar flow
- turbulent flow
- helicoidal flow.

### Laminar flow

Water flowing downwards over a smooth surface can flow in a simple sheet, with no eddies or meanders. This is known as laminar flow. Laminar flow can be observed on a smooth road surface or paved area during heavy rainfall, but it is very rare in nature because most surfaces exert enough friction for turbulence to disrupt the flowing sheet.

### Turbulent flow

Water flowing in a river channel is subject to friction, both with the river bed and the banks. This friction slows the water closest to the bed and banks and the water nearer the centre of the river overtakes the slow water. Because water is a liquid, this results in turbulence. Water at the sides of the river begins to eddy towards the banks and water close to the bed of the river begins to eddy downwards. Both types of eddy operate at the same time and this leads to chaotic, turbulent flow.



**Fig. 1.27** Turbulent flow

## Helicoidal flow

Water flowing down a plughole often starts to spiral as it flows downwards. This spiralling motion is typical of fluids moving at or close to the surface of a rotating planet. It is no surprise that water flowing down a river channel is subject to the same forces. The line of fastest flow (**thalweg**) follows a corkscrew or spiralling path as the river moves downstream. This is closely related to the development of meanders but even in a straight, artificial channel, helicoidal flow can be observed.

The spiralling movement of the thalweg is constrained by the river channel. Not only does the thalweg spiral from the surface to the river bed and back to the surface, but it also moves from one bank to another in a downstream direction. The vertical movement of the thalweg produces pools and riffles while the bank-to-bank motion concentrates erosion first on one bank and then on the other. This contributes greatly to the formation of regularly spaced meanders along the river's course (see Fig. 1.38 on page 21).

## Channel types

There are three main types of river channel:

- straight channels
- meandering channels
- braided channels.

The **sinuosity** of a river channel is a measure of how 'bendy' it is. It is calculated by dividing the length of the river channel by the length of the valley in which it flows. This can be done for a whole river but more usually it is done for sections of a river. A perfectly straight river will have a sinuosity of 1.0 but natural river channels are rarely perfectly straight. Any river with a sinuosity less than 1.5 is considered 'straight', while a river with a sinuosity of over 1.5 is considered to be 'meandering'.

## Straight river channels

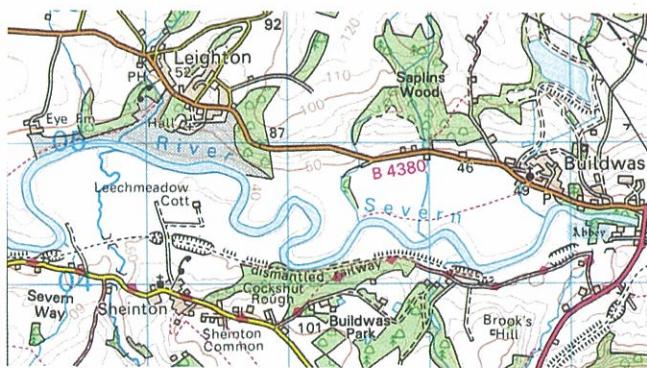
These are quite rare because helicoidal flow dominates in most rivers and makes them meander. Even on a straight river, the thalweg (line of maximum flow velocity) moves from side to side because of helicoidal flow.



**Fig. 1.28** A straight river channel. This is the river in Glen Tilt, Scotland, UK. The reason it is so straight is that it is guided by a straight fault (weakness) in the rocks

## Meandering river channels

Most rivers meander to some extent. Upland streams meander but the most pronounced meanders are found on floodplains where **lateral erosion** is facilitated by the soft nature of the river banks. Meanders are so common because spiralling is the normal behaviour of moving fluids on the surface of a rotating planet. Rivers are confined to their channels so the tendency to spiral downwards produces helicoidal flow. This is the main reason why rivers meander (see Fig. 1.29). Meanders are not produced by large obstacles in the river's course.



**Fig. 1.29** A meandering river channel. This map extract shows the River Severn near Ironbridge in Shropshire, UK

## Braided river channels

These are river channels that contain a large number of islands and bars made of sediment. They are found in areas where discharge varies a lot during the year and where a large amount of fairly coarse sediment is being carried by the river, for example glacial **outwash** streams and seasonal rivers in semi-arid areas. The braiding results from the deposition of sediment on the riverbed during a time of falling discharge. The river then splits as it flows around these deposits. A braided river channel can be extremely wide and constantly changing.



**Fig. 1.30** A braided river channel. This is a river on the Skeidararsandur glacial outwash plain in southern Iceland

## River landforms

Flowing water has energy which allows rivers to do work through the processes of erosion, transportation and deposition. These processes produce a whole range of distinctive *landforms* such as waterfalls, floodplains and

deltas. Together, these river landforms make up what we recognise as a river landscape.

## Landforms of the upper course

### Potholes



**Fig. 1.31** Potholes on a rocky river bed in South Africa

Potholes are formed by turbulence which swirls pebbles around in a depression on the river bed. The swirling pebbles enlarge the pothole by the process of abrasion. The process is explained in more detail in Fig. 1.20 on page 13. They are usually quite small features and they are evidence that vertical erosion predominates in upland rivers.

### Rapids



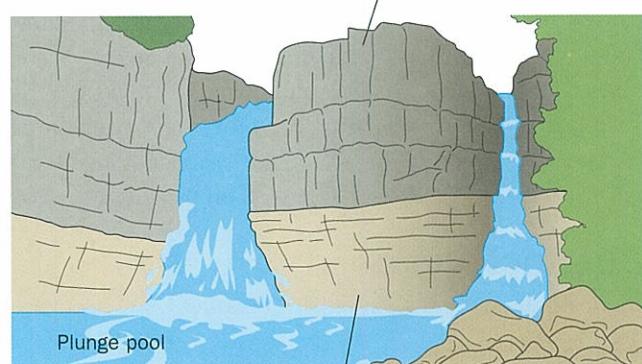
**Fig. 1.32** Rapids on the Orange River in South Africa

Rapids are common in the upper course of a river. They form at places where the gradient is steep and the river bed is rocky, resistant to erosion, and irregular. They are usually caused by a band, or bands, of hard rock in the river bed.

### Waterfalls and gorges

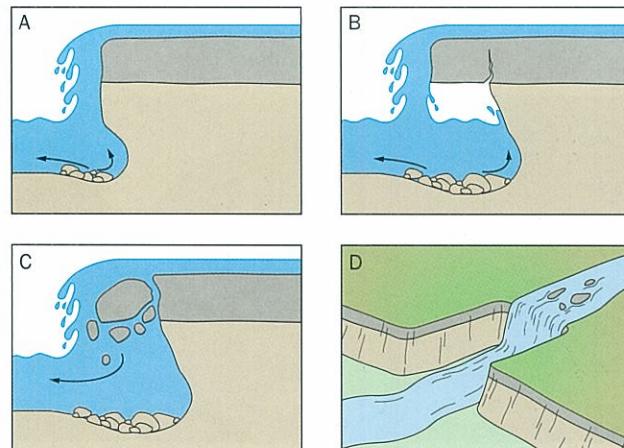
Waterfalls form where a horizontal layer of hard rock lies on top of a layer of softer rock in a river valley. The soft rock underneath is eroded more quickly by the river and gradually a **plunge pool** develops. The splashing water and eddy currents in the plunge pool undercut the hard rock layer above. This eventually creates an unsupported overhang of hard rock. The overhang then collapses into the plunge pool. If the processes of undercutting and collapse are repeated over a long period of time, the waterfall will retreat upstream – forming a deep, steep-sided valley called a **gorge**.

Horizontal bed of hard rock – the Whin Sill Dolerite.  
It is very difficult for the River Tees to erode this rock.



**Fig. 1.33** The High Force waterfall on the River Tees is one of the largest waterfalls in England

- 14.** (a) Make a copy of diagram A in Fig. 1.34. Add labels to the diagram to identify the main features. Write a short paragraph to explain what the diagram shows. Try to use subject specific vocabulary e.g. the names of the different types of erosion that are operating.
- (b) Repeat the exercise for the other three diagrams: B, C and D.



**Fig. 1.34** Four diagrams showing the development of a waterfall and a gorge over time

Gorges form best when the hard rock is especially resistant to weathering but succumbs to river erosion. As well as being formed by the retreat of a waterfall, gorges can form in other circumstances:

- In semi-arid areas, where there is a short wet season leading to vertical erosion of the river bed when the river is flowing, but no water for weathering at other times of the year.
- Where a mountain range has been formed across the path of a river, but the vertical erosion of the river has been able to keep up with the growth of the mountain range. The gorge of the Brahmaputra River where it flows from Tibet, through the Himalayas, is an excellent example. This is known as **antecedent drainage**.

## Landforms of the lower course

### Floodplains, levées and bluffs

A floodplain is the flat land next to the river which is liable to flood when the river rises after heavy rainfall. Floodplains are often badly drained, with marshes and **ox-bow lakes**. In their natural state they are unhealthy areas to live on because diseases are common. Sometimes the river actually flows above the level of the surrounding floodplain, but it is enclosed by natural embankments called levées.

Lateral erosion predominates on a floodplain. The river is close to sea level (**base level**) so it can't cut down much further. However, the floodplain is made of soft alluvium so lateral erosion is facilitated and the **meander belt** migrates constantly across the floodplain. Where a meander reaches the edge of the floodplain, it may erode back the low valley side, helping to maintain the low **bluffs** found at the side of most large floodplains.

The floodplain is made of alluvium (river silt) because it is formed by deposition of material from the river. There are

three main forms of deposition which contribute to the formation of the floodplain:

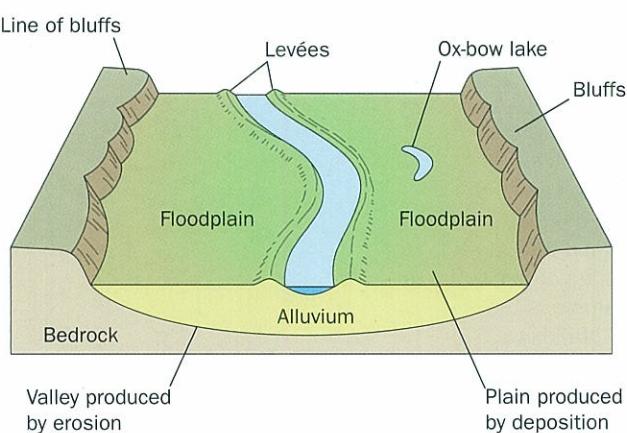
- The deposition of fine silt and mud (part of the suspended load) on the floodplain itself, during times of flood. As the floodwater spreads across the floodplain, the hydraulic radius decreases, friction becomes more important, the river slows, and deposition takes place. Most deposition takes place closest to the river. This means that areas further from the river receive thinner layers of sediment and don't grow upwards quite so fast. This leads to lower areas, further from the river channel, known as backswamps.
- The deposition of **point bars** in the slow water on the inside of meanders. These deposits spread across the floodplain as the meanders migrate.
- The deposition of sediment on the river bed at times of low water when the velocity of the river slows. This is why big rivers often raise themselves above the level of the floodplain.

Like the floodplain, levées are depositional features. When rivers reach bankfull stage and then burst their banks, the current slows and deposition takes place. The biggest particles are deposited first and when the river level falls after a flood, these coarse deposits form embankments at each side of the river. They are natural features but people often raise them and strengthen them to prevent flooding. Sometimes completely artificial embankments are built for the same purpose, and in the USA these embankments are also called levées.

## Landforms produced by sedimentation

### Deltas

These are depositional features which form when the river meets the sea or runs into a lake. When a river meets the still water of the sea or lake, the loss of velocity leads to a loss of energy and the river's load of sediment is deposited. Sea water contains charged ions of the salts dissolved in it and these charged ions lead to the flocculation of clay particles - tiny particles cluster together, becoming bigger and so are more able to settle to the bottom. Deposition of sediment blocks the river's main channel which splits into smaller channels called **distributaries**. Continued deposition over time means that the delta grows outwards into the sea, forming a flat, marshy extension of the land. There are often lakes and **lagoons** within the delta. Because deltas are formed of fertile alluvium they are attractive areas for human settlement. They are dangerous places to live, however, because they are susceptible to flooding, both by the river and by the sea. An example of a densely populated delta is the Ganges delta in India and Bangladesh.



**Fig. 1.35** Block diagram showing the main features of a floodplain

In lakes, this three-layer pattern is clear, but at the coast, erosion by waves and movement by tides makes the picture more complex.

(2) The foreset beds are composed of the coarser material that is rolled along the river bed by traction. The material is tipped seaward as the delta advances.

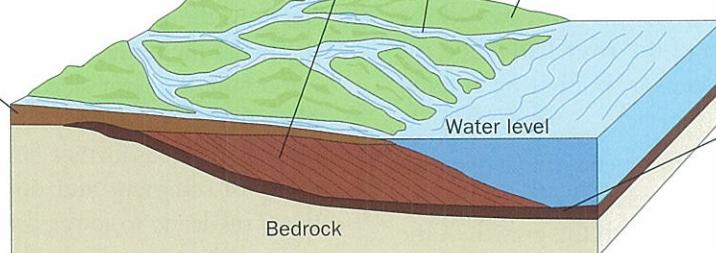
(3) The topset beds are deposited through the flooding of the distributaries and form a layer of rich alluvial soil over the delta.

Distributaries Delta

Water level

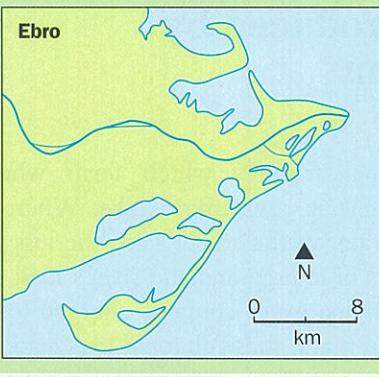
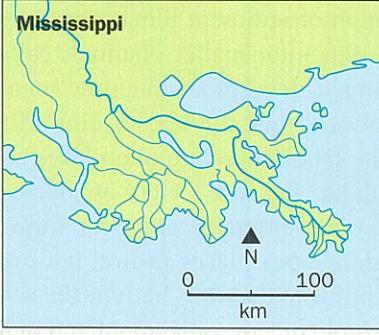
Bedrock

(1) The bottomset beds stretch furthest out to sea and are laid down first as material carried in suspension sinks to the sea floor.



**Fig. 1.36** The formation of a delta. The structure produced by the deposition of bottomset, foreset and topset beds

There are many types of delta but there are three classic types.

Map of delta	Description
The Niger delta	<p><b>Arcuate deltas</b> are fan-shaped and they form when the <b>tidal range</b> is quite low and there is a strong movement of sediment in one direction along the coast, e.g. by longshore drift or an offshore current. This keeps the seaward edge of the delta smooth in shape. A good example is the Niger delta in West Africa.</p> 
The Ebro delta	<p><b>Cuspatate deltas</b> are shaped like an arrowhead or a worn tooth. There is a low tidal range and two offshore currents shape this sort of delta, operating in opposite directions at different times of the year. A good example is the Ebro delta to the south of Barcelona in Spain.</p> 
The Mississippi delta	<p><b>Bird's foot deltas</b> are formed where the tidal range is low and where the river currents are strong. There is no clear offshore current to shape the delta so each distributary builds the land out into the sea, acting like a series of thin conveyor belts. The best example is the Mississippi delta in the Gulf of Mexico.</p> 

**Fig. 1.37** Types of delta

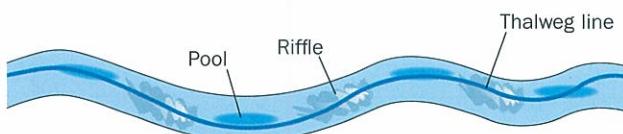
## Meanders and ox-bow lakes – river landforms produced both by erosion and deposition

Meanders are the most typical of all river landforms. They can be found at any point along a river's course and their associated landforms are relatively easily explained. However, the reasons why meanders form in the first place are complex and difficult to understand.

It used to be thought that meanders were caused by an obstacle along the course of the river, causing it to deflect from a straight course. Once initiated, the different rates of erosion and deposition in the inside and outside of meander bends ensured that meanders remained and developed. However this idea was thrown into doubt in the mid-20<sup>th</sup> century when it was noticed that there were certain regularities and relationships that applied to meanders wherever they were found. The most obvious was that whatever the size of the river, the wavelength of its meanders was roughly 8–10 times the width of the river. This sort of regular mathematical relationship implied that meandering was a fundamental part of a river's nature and that a universal principle was involved in their formation. This led geomorphologists to look at the way in which water flowed in rivers and to look for other regular relationships in the form of river channels.

### Pools and riffles

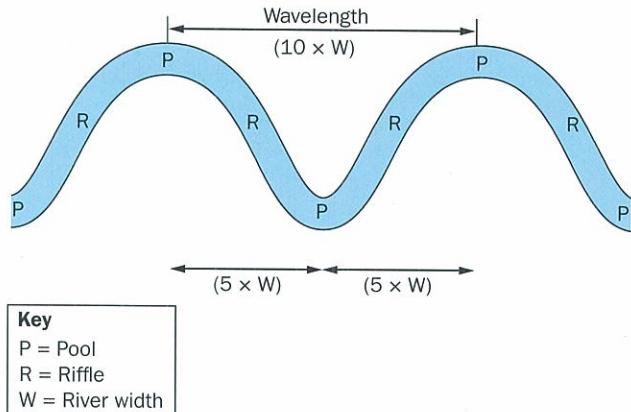
Straight rivers develop deeper sections where erosion predominates (pools) and shallower sections where sediment has been deposited (riffles). The process that causes this is complex and not fully understood but the regular spacing of pools and riffles (the distance from pool to pool is 4–5 times the width of the river) suggests it is related to helicoidal flow. Close study of the thalweg showed that the thalweg did indeed move in a corkscrew fashion (helicoidal) and that the rising and falling of the zone of maximum velocity within the river channel corresponded to the position of pools and riffles.



**Fig. 1.38** Pools and riffles on a relatively straight river channel

### Meanders

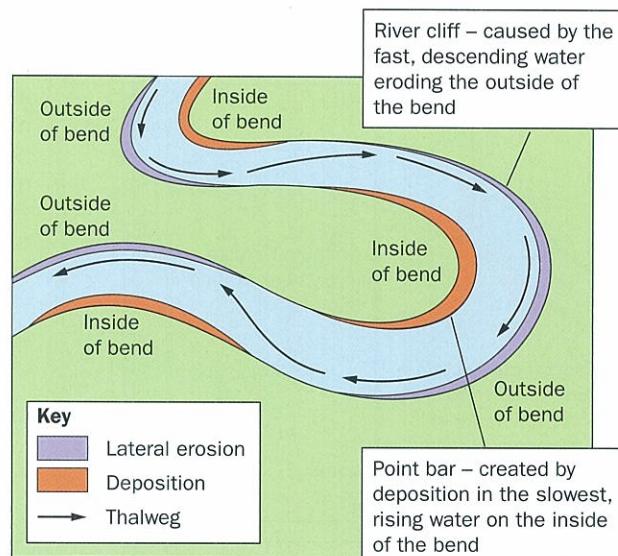
Meanders are related to pools and riffles because the meander wavelength is usually 8–10 times the river width, with a pool on the outside of each bend. In other words the distance pool to pool equates to a meander wavelength.



**Fig. 1.39** Pools and riffles on a meandering river channel

Meanders have an asymmetric cross section and the flow of water in three dimensions is complex.

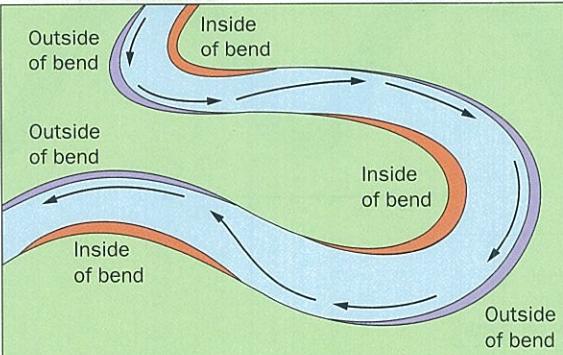
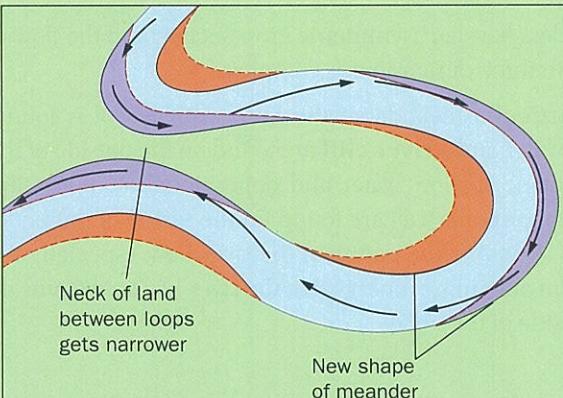
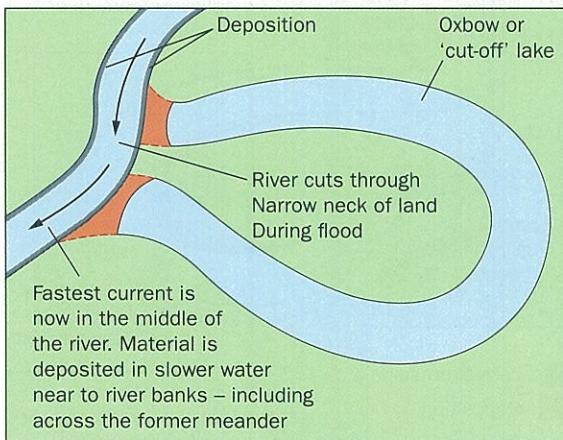
The form of a meander is the same wherever it is found. Deep water and a **river cliff** are found on the outside of the bend while shallow water and depositional features (slip-off slope or point bar) are found on the inside of the bend. This is related to the nature of the river flow, especially the different amounts of energy that the river has on the outside and inside of the bend.



**Fig. 1.40** A map of a typical meander

### Ox-bow lakes

Meanders become more sinuous (bendy) over time as erosion and deposition continue to change their shape. In the soft alluvium of a floodplain, lateral erosion can be so effective that the neck of the meander becomes narrower and narrower. Eventually (usually during the high energy conditions of a flood) the neck is breached and the meander cuts itself off. An ox-bow lake is the result.

Map	Description
<p>Stage 1</p> 	<p>A meander on a floodplain. Because the alluvium of the floodplain is soft and because the river is close to sea level (base level), lateral erosion predominates. Erosion is focused on the outside of the meander bend and deposition is on the inside of the bend.</p>
<p>Stage 2</p> 	<p>The meander becomes more sinuous. Continued erosion on the outside of the bend undercuts the river cliff, which retreats. Deposition of material on the point bar on the inside of the bend continues. Together, these processes move the whole meander sideways. The neck of the meander becomes narrower as the two river cliffs move closer together.</p>
<p>Stage 3</p> 	<p>An oxbow lake is formed. During a large flood, when the water is moving rapidly, erosion of the two river cliffs finally removes the neck of land between them. The river adopts a more direct line of flow because this increases the gradient of the river bed and makes the river flow more efficient. Deposition in the still water of the old meander cuts the meander off from the new course of the river. The oxbow lake is a temporary feature because the growth of vegetation eventually fills it up and turns it into an area of marshy ground – very much like the rest of the natural floodplain.</p>
<p><b>Key</b></p> <ul style="list-style-type: none"> <li>— Land lost to the river (eroded)</li> <li>— Land gained from the river (deposited)</li> </ul>	<p>→ Fastest current - - - Earlier course of the river</p>

**Fig. 1.41** The stages in the formation of an oxbow lake

**RESEARCH** Use old maps to see how much the meanders on a river near you have changed over time.

# The human impact

## How human activity can modify the natural hydrological cycle

By changing the operation of the natural system (inputs, stores, flows and outputs) in a drainage basin, human activity can have a significant impact on the way that the drainage basin operates.

By affecting the nature and amount of precipitation, evapotranspiration and river discharge, people can increase or decrease the impacts of river floods.

Direct human modification of the drainage basin system usually involves:

- changing the amount of precipitation entering the river's drainage basin
- storing water within the drainage basin by building dams or by groundwater recharge
- changing the channel characteristics of the river so that the speed of flow is affected
- transferring water between drainage basins
- **abstracting** water from the river for industrial, domestic and agricultural use.

Indirect human modification of the drainage basin system usually involves changing the nature of the drainage basin itself through:

- deforestation or afforestation
- changing the agricultural land use
- urbanisation – building towns and cities.

### Precipitation

Cloud seeding involves adding artificial particles to clouds so that large water droplets form around these **condensation nuclei** and raindrops then fall. Silver iodide and dry ice are commonly used and this cloud seeding has led to local increases in rainfall in Australia and the USA of between 10–30 per cent. There is only a limited amount of water in the atmosphere, so increasing rainfall in one place can lead to less rainfall elsewhere.

Cities produce air pollution, which includes particles of soot from vehicle exhausts, domestic fires and industrial chimneys. These extra condensation nuclei, together with the heat island effect (which produces warm, rising air and atmospheric turbulence), can produce up to 10 per cent more rainfall in cities than in nearby rural areas.

Human-induced climate change (global warming) also has an effect. Warmer seas produce more evaporation. More water vapour in the atmosphere leads to more rainfall. Heat

is energy, so a warmer atmosphere moves faster. Weather systems that produce rainfall, e.g. temperate depressions and tropical cyclones, could become more frequent as a result.

### Water storage

Dams have been built on rivers throughout the world. A large dam is defined as a dam over 15 metres high. Worldwide there are over 48 000 of these large dams. Dams store water and have a major impact on river discharge. They are built to:

- provide water for irrigation, for homes and for factories
- produce hydro-electric power (HEP)
- control flooding.

- 15.** (a) What is meant by 'irrigation' and why do many farmers use this technique?  
(b) Make a list of all the ways that water can be used in the home.  
(c) How is water used in factories?

Large dams can even out the flow of water in a river, ensuring that river levels remain high enough for water abstraction but stopping river levels rising above the bankfull stage, thereby reducing flooding. Significant amounts of water evaporate from large reservoirs. The Aswan dam in Egypt has reduced the annual flooding on the River Nile in Egypt but up to 30 per cent of the Nile's water is lost by evaporation from Lake Nasser, the reservoir created by the building of the dam. Because water abstraction from the River Nile downstream of the dam has increased, hardly any Nile water now reaches the Mediterranean Sea.

**RESEARCH** Make a list of the advantages and disadvantages of the building of the Aswan Dam for the people and economy of Egypt.

Artificial groundwater recharge is used to store water in underground aquifers. At times of high discharge, water is pumped from rivers into the ground via boreholes. This maintains or increases the height of the water table and boosts the discharge in streams fed by springs flowing from the aquifer. This stops the streams drying up during a dry spell. Water can also be extracted for human use, using the same boreholes used for the recharge. Artificial groundwater recharge is a strategy used in southern England, for example, where water is often in short supply during the summer months.

### Changing the nature of the river channel

Large rivers are often straightened and deepened in order to make them easier to navigate by barges. This is called

**canalisation** and it tends to increase the hydraulic radius of the river channel. These straight, deep channels move water more efficiently and this can lead to shorter lag times and increased flood peaks. The River Rhine has been extensively canalised and the flood surge, which used to take five days to move from Switzerland to the Netherlands, now takes only three days.

In urban areas, rivers are often confined to concrete channels or underground drains. This can lead to increased levels of flooding in nearby buildings.

## Transferring water between drainage basins

In north-east England there are three large industrial cities: Newcastle-upon-Tyne, Sunderland and Middlesbrough. They each have a high demand for water. A huge reservoir has been built on the **headwaters** of the River Tyne at Kielder and this supplies water, via the River Tyne, to Newcastle. Kielder can hold far more water than is needed by Newcastle, so a series of pipelines have been built to transfer water from the River Tyne into the River Wear (for Sunderland) and into the River Tees (for Middlesbrough). One large reservoir in a very sparsely-populated area is therefore supplying water to three large urban/industrial areas, allowing all three cities to develop their economy. The natural discharge of all three rivers has been changed as a result.

## Abstracting water from the river

River water is in demand for three main uses:

- Agriculture: in many parts of the world, rainfall is low and farmers need to irrigate their fields so that crops can grow.
- Industrial use: industry can use huge amounts of water for manufacturing (e.g. papermaking) or for cooling (e.g. power stations).
- Domestic use: in HICs people use large amounts of water each day for drinking, washing, flushing toilets, watering gardens and even washing cars. In LICs people use much less water, mostly for drinking.

**16.** Suggest why people in LICs use less water than people in HICs.

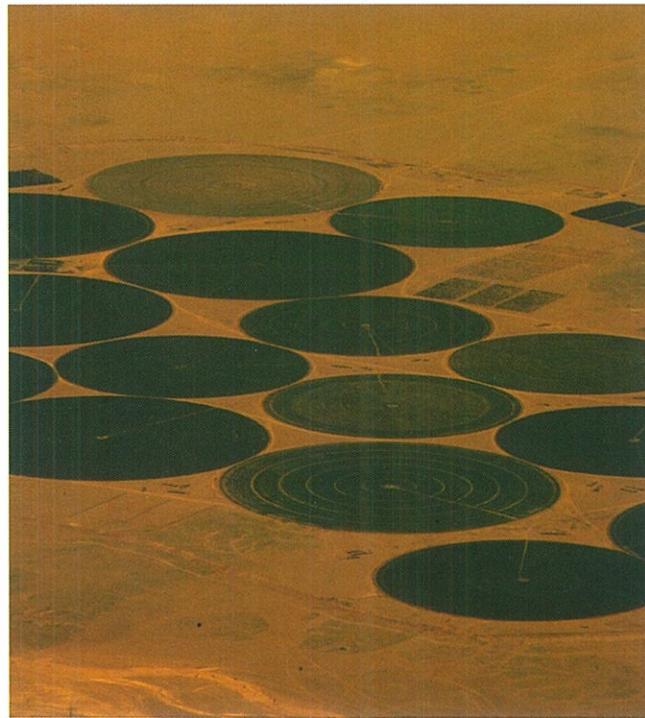
It is important that the use of water is sustainable – water use should not exceed water supply. If too much water is used, river levels fall and wetland areas dry out. This can have an impact on wildlife because habitats are reduced or destroyed.

## Centre-pivot irrigation

Centre-pivot irrigation is a modern technology that has the potential to use water in a very unsustainable way. A

borehole is drilled down to groundwater held in an aquifer. Water is pumped from the aquifer and sprayed onto crops via a long, wheeled boom that slowly rotates around the central borehole. This produces circular areas of cultivation in what might otherwise be a dry, brown landscape.

Near Lubbock, Texas, this technique has lowered the water table by about a metre a year since its introduction in the 1960s. This suggests that the use of groundwater in this way is unsustainable because water is being used up faster than it is being replaced. In Libya, there are many aquifers that filled with water when the Sahara desert was a rainy place. The Sahara became a desert around 7000 years ago and very little rain now falls there. Centre-pivot irrigation in Libya is also an unsustainable use of groundwater because here the groundwater is, in effect, a non-renewable resource. The same is true of centre-pivot irrigation schemes in other dry parts of the world.



**Fig. 1.42** Centre pivot irrigation circles in the Jordanian desert

Although water use per person is much greater in HICs than in LICs, water shortages can occur anywhere. Water is a renewable resource but when water use exceeds supply, long-term water shortages can result. This can have an impact on local people and on the potential for economic development. This leads to competition for the use of the available water resources and water has to be carefully managed. This can be an issue within one country or between countries.

## Case study: Water management issues within one country: south-west USA

In Nevada, USA, there is a large lake called Pyramid Lake. It is an important source of water in this semi-arid area. There is intense competition for the water from Pyramid Lake:

- The farmers around Fallon, Nevada, need water to irrigate their crops of alfalfa.
- The residents of Reno, a tourist city similar to Las Vegas, need water for domestic use. The city is growing and demand for water is increasing rapidly.
- Pyramid Lake is a nature reserve, much valued by the local Native Americans who believe they are spiritually connected to a rare fish species that lives in the lake. Water is needed to allow the fish spawning runs each year. Without the spawning runs the fish will become extinct.

Competition between the different **stakeholders** was so intense that legal action was taken. The federal authorities ruled that the Native Americans and the residents of Reno should have priority and the Fallon farmers lost their water supply, resulting in their fields drying out.

- 17.** (a) What is meant by a 'stakeholder'?  
(b) Did the federal authorities make the right decision about the use of water from Pyramid Lake? Justify your answer.

- 18.** Water wars are predicted in several parts of the world during the 21<sup>st</sup> century. Why might a country feel that it has to go to war to protect its water supplies?

## Deforestation and afforestation

Forests growing in a river basin tend to reduce the discharge of the river. Increased interception and increased transpiration mean that evapotranspiration can become a more important output from the drainage basin than river discharge. Forests also encourage infiltration and throughflow rather than overland flow, reducing the speed at which rainfall reaches the river. **Flood peaks** are lower in a basin that is forested. If the forest is removed, much more water goes into the river, increasing the discharge and the flood risk.

Population growth in Nepal, in the Himalayas, has led to pressure to cut the trees down to provide fuelwood and terraced fields on the steep hillsides. Over-grazing of the deforested land has led to soil erosion. The local rivers are tributaries of the Ganges which has received more discharge and more sediment as a result. The sediment clogs up the river channels and leaves less room for the water. Increased levels of river flooding in Bangladesh, where the Ganges reaches the sea, have been blamed on deforestation in Nepal.

Devastating floods on the River Chang Jiang (Yangtze) in China in 1998 (see page 29) prompted the authorities to institute an afforestation programme in the upper reaches of the river. The province of Yunnan used to be heavily forested but many of the forests were removed in the 1960s because of the need for land to produce food for the growing population. As on the Ganges, this led to increased flooding on the Chang Jiang. The afforestation programme has met resistance from some local people in Yunnan but it is going ahead. It will be several years before the growing trees have a significant effect on reducing river discharge and flood peaks.

## Case study: International water management issues: the River Euphrates

The River Euphrates rises in Turkey, flows through Syria and Iraq and empties into the Gulf. Between 1983 and 1990, Turkey built the Ataturk Dam on the river in order to generate electricity and irrigate crops in Turkey. Despite previous agreements on the use of water, Turkey stopped the flow of the river for a month in 1990 to allow the reservoir behind the dam to fill. Syria and Iraq both protested because their water supplies had been disrupted. Turkey allowed the flow of water to resume but water use in Turkey means that the flow of the Euphrates below the dam is one-third less than it used to be. The reduction in water supply has had a bad effect on Syria and Iraq, reducing their potential for economic development.

## Changing agricultural land use

Land uses that create impermeable surfaces or reduce vegetation cover tend to increase overland flow and river discharge. Pasture land allows rainfall to soak into the ground but has less evapotranspiration than the forest it may have replaced. Floodplains tend to be fertile and are often used for arable farming. Ploughing increases infiltration because it loosens the surface soil but in HICs, arable farming can also reduce infiltration because the use of heavy machinery for cultivation and harvesting squashes the soil, so there is more overland flow and flood peaks increase. This was a significant factor in the flooding on the River Rhine in 1995.

## Urbanisation

Covering large areas in concrete, tile and tarmac leads to an increase in overland flow, therefore floods are more likely, especially in places downstream of the urban area. The concrete drains and sewers of urban areas allow water to reach the river quickly, replacing natural throughflow with a much more rapid process. This reduces lag times and increases flood peaks. Building on a floodplain means that there is less room for the water when the river floods. The floodwaters will rise higher as a result.

## River flooding – recurrence intervals and the prediction of flood risk

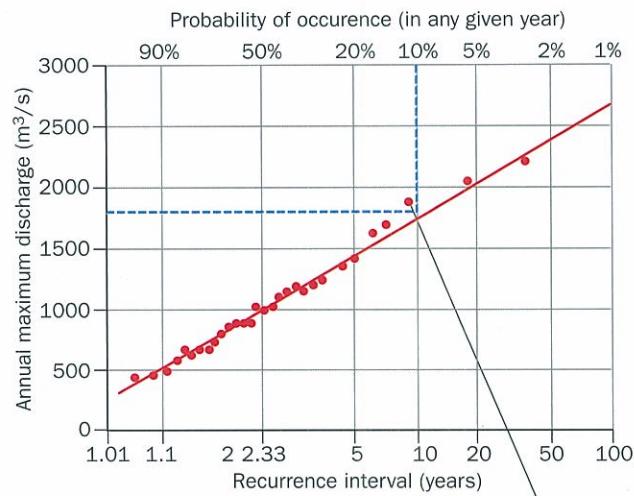
River flooding occurs when a river's discharge exceeds the capacity of the river channel. The river overflows its banks. River flooding is a significant hazard that affects many parts of the world. It is important that people are aware of the risk of flooding in the place where they live and work. It is also important to be able to give them accurate and reliable flood warnings.

### Flood risk analysis

In the UK the Environment Agency is responsible for flood risk analysis and for issuing flood warnings. Flood risk analysis is important because it tells homeowners and tenants what flood risk their property faces. Owners of high-risk properties need to be especially alert for flood warnings.

The Environment Agency works out the flood risk at a place by using 'magnitude and frequency analysis'. A scatter graph is produced using historical flood data from that place. The **magnitude** (size) of the flood is plotted against the **recurrence interval** of the flood, i.e. how often, on average, that size of flood is likely to occur. This is done on special semi-log graph paper and a straight best-fit line can be drawn. Using the **best-fit line** the size of the 5-year flood, 50-year flood, 100-year flood, 500-year flood, etc., can be calculated. An example is shown Fig. 1.43. The vertical scale is arithmetic but the horizontal scale is logarithmic, making this a semi-log graph.

As can be seen from Fig. 1.43, the magnitude and frequency analysis deals in probabilities. The '10-year flood' is the size of flood that can be expected every 10 years on average and there is a 10 per cent chance of a flood of this size happening in any one year. This means that once the 10-year flood has happened, there is no guarantee that it will be 10 years before it happens again. However, the use of recurrence intervals is useful when planning flood defences and when drawing flood risk maps.



A large flood of  $1800 \text{ m}^3/\text{s}$  has a probability of 10 per cent and a recurrence interval of about 10 years, meaning that there is a 10 per cent probability that a flood of this discharge will occur in a given year.

**Fig. 1.43** Magnitude and frequency analysis of flood risk

Current advice in the UK is that densely-populated urban areas should be protected against floods up to the height of the 100-year flood. The 'magnitude and frequency analysis' graphs can show the Environment Agency how high to build the walls and embankments in order to do this. This means that there will occasionally be floods that will come over the top of the defences. The Dutch have recently rebuilt the flood defences on the River Rhine to cope with the 1000-year flood, but this has cost a lot of money. Politicians in the UK have decided to pay for the damage caused by very rare floods rather than pay for very expensive flood defences to protect people from them. It's a question of what is cheapest over the long term. However, climate change could be making big floods more frequent. What is currently the 100-year flood might soon become the 20-year flood. This adds another level of uncertainty to flood risk analysis and planning.

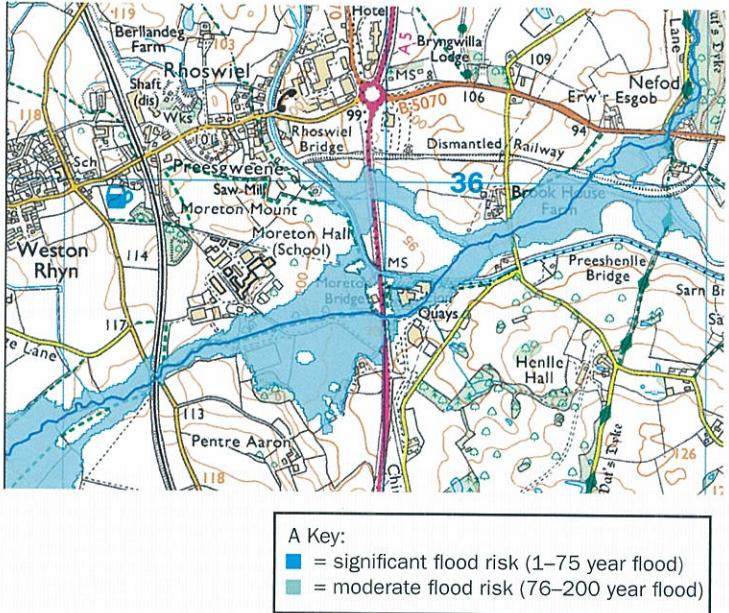
### Flood risk maps

On the Environment Agency's website it is possible to obtain flood risk maps for most places in the UK.

This flood risk map is very reassuring for most of the people who live in the area shown. Very few buildings are at risk. Some low-value agricultural land could be flooded but if the farmer gets sufficient warning, any grazing animals can be moved to higher ground and safety.

### Flood predictions and warnings

In the UK, the Environment Agency monitors rainfall and river levels and is able to produce flood warnings as a result.



**Fig. 1.44** Flood risk at Moreton Hall, Shropshire, UK

The details are as follows:

- Rainfall radar can plot the approach of depressions and other rain-bearing weather systems. These data are fed into the Agency's computer system.
- Tipping rain gauges throughout the drainage basin monitor the actual amount of rain falling and feed this information into the system.
- Along the river, automatic river discharge gauges monitor the rising river levels and this is added to the system data.
- The system's database includes a model of the way the drainage basin behaves at different times of the year and with different inputs of rainfall. This is based on past flood events, i.e. a whole series of past storm hydrographs.
- As a result the computer system can continuously compare the incoming data with past events and produce predictions of river levels at different points along the river. It can predict how high the flood peak will be and when it will reach different places.
- On the basis of these predictions the Environment Agency issues detailed flood warnings. People are then given time to prepare for the flooding.

## River flooding – the causes, impacts and management of river flooding

River flooding causes death, damage and disruption (both economic and social). Because of this, people try to manage

the flood hazard. Management involves a combination of prediction, prevention and amelioration. For management to be successful we have to fully understand the causes of flooding.

### The causes of river flooding

River floods are caused when rates of overland flow exceed the river's capacity to hold the water it is supplied with. The natural factors affecting overland flow have been dealt with earlier in this chapter but can be summarised as:

- heavy, persistent and/or intense rainfall
- rapid snowmelt
- impermeable soil and bedrock
- a lack of vegetation in the drainage basin
- cold temperatures which reduce evapotranspiration.

In addition, human activities can make flooding worse. These activities include:

- deforestation
- urbanisation
- mechanised farming
- acid rain (which destroys forests)
- global climate change.

### The impacts of river flooding

As with all natural hazards, the impacts of river flooding are:

- death – of people and animals
- damage – to buildings, infrastructure and farmland
- disruption – to people's lives. Disruption can be social (e.g. people are made homeless), or it can be economic (e.g. damage to businesses or factories which means that people are unable to continue making a living).

The impacts of river floods vary from country to country. As a general rule, in HICs the *economic cost* of the flooding is higher than in LICs but the *death toll* is usually higher in LICs than in HICs.

**19.** Suggest why the cost of flooding is greater in HICs but the death toll is higher in LICs.

### The management of river flooding

How well the flood hazard is dealt with depends on:

- The level of economic development of the place. This influences factors such as emergency service provision, infrastructure and the ability to recover from the flood.
- The willingness of the local people and their governments to spend money on flood preparation and alleviation.

- The accuracy and length of any warnings that are given.
- Flood management strategies can be grouped into three main categories:
- *Forecasts and warnings which allow the adoption of behavioural strategies* – people adjusting their lifestyles and taking personal responsibility for the hazard risk.
  - *Hard engineering solutions* – these usually involve building something.
  - *Soft engineering strategies* – working with nature rather than trying to dominate it.

## Forecasts and warnings which allow the adoption of behavioural strategies

- Make sure people understand the flood forecasting and warning service. This gives them time to move animals, move furniture and carpets, and evacuate people.
- Have an emergency plan, so that people know what to do once the warnings are given and once the flooding takes place. Each household needs to have its own plan and the whole town needs an overall plan.
- Organise at-risk houses so that they have tiled floors, moveable mats, drains in the floor, cupboards above flood level, plug sockets above flood level, wide stairs and space for storage upstairs.
- Take out insurance. A householder pays a set amount per year to the insurance company. If there is no flood, the insurance company keeps the money. If there is a flood, the insurance company pays the householder to repair the damage. The amount that has to be paid by the householder will depend on the level of the flood risk.

## Hard engineering strategies

- Dams and reservoirs can be built upstream. As long as they are not already full, the reservoirs can store some of the floodwaters.
- Platforms can be built on the floodplain before any buildings are constructed. This raises the buildings above flood level (but still reduces the room for water on the floodplain).
- Build embankments along the river. They are effective but they are expensive and don't always look very nice. Temporary flood barriers are an alternative solution but the preparatory work is permanent.
- Dredge the river. This lowers the bed and makes more room for water in the river channel. It is very expensive and cannot be a permanent solution as the river deposits fresh silt over time.
- Straighten the river. This allows the water to flow faster and so prevents the build-up of flood waters. It does cause bigger floods further downstream, however.

- Retention basins can be built. These are areas surrounded by an embankment into which floodwaters are diverted at times of crisis. The land-use within the retention basin is severely restricted as a result. These have been built beside the River Rhine near Strasbourg in an attempt to reduce flood levels downstream.
- Flood relief channels. Artificial channels can be built around a town to take away excess water and prevent the town flooding. Once again, it causes worse flooding downstream.



**Fig. 1.45** A hard engineering solution to flood risk. This is an artificial river channel in Nerja, southern Spain. The photo was taken during the summer dry season. The small inner channel is designed to cope with the normal winter flow of the river. The larger outer channel is designed to cope with extreme rainfall events which could cause flash floods, for which very little warning can be provided. The vegetation growing in the flood channel could be a problem as it takes up space and makes less room for the floodwaters.

## Soft engineering strategies

- Floodplain zoning. Only use the floodplain land for things that will not be affected too much by floods, e.g. sports pitches. Don't build houses in high-risk floodplain areas.

- Rely on 'washlands'. The land upstream is allowed to flood. This acts as a safety valve and protects the town. On the River Chang Jiang, Dongting and Poyang lakes serve this purpose.
- Plant trees in the upper part of the drainage basin. Trees encourage interception, evapotranspiration and infiltration. Forested areas have fewer floods.
- Wetland and riverbank conservation schemes. This involves protecting the natural floodplain areas which still remain. It gives the floodwaters a place to go and protects disappearing wildlife habitats, enhancing species diversity.

## Case study: River flooding on the River Chang Jiang, China

China is one of the largest countries in the world, both in terms of population size, land area and economic power. Its economic growth since 1980 has been phenomenal but the country is threatened by a variety of natural hazards which include earthquakes, typhoons and flooding.

China has many large rivers with the Chang Jiang (Yangtze) being the third longest in the world at 6380 km. Every year the summer monsoon rains, combined with snowmelt from the Himalayas, cause the river to rise to very high levels. Despite embankments, flooding is common.



**Fig. 1.46** The location of the Chang Jiang River in China

Flooding on the Chang Jiang has caused many problems. Its valley is home to 400 million people. It

- River restoration schemes. This returns the river and its floodplain to its natural state providing sustainable environmental gain - but there is often an economic cost. In the Netherlands, some river floodplains have been returned to their original state and nature reserves have replaced farmland. Flood protection has been enhanced. The Netherlands is a rich country that can afford to do this and the farmers have been compensated.

floods annually but in 1931, 1934, 1954 and 1998 the floods were particularly catastrophic. 300 000 people died from its floods during the 20<sup>th</sup> century. The worrying trend is that the floods seem to be getting worse and the 1998 flood set new records.

### Physical causes of flooding on the Chang Jiang

Flooding on the Chang Jiang is an annual event, caused by snowmelt in the Himalayas and the summer monsoon rains. In 1998 the rains lasted a month longer than usual and the 'El Niño' effect was blamed for this.

**RESEARCH** Find out what the El Niño effect is and how it can lead to increased rainfall in China and other areas on the west side of the Pacific Ocean.

### Human causes of flooding on the Chang Jiang

As on most rivers, human activities have made the impact of the floods worse:

- China's urban population has been growing rapidly. Many of the cities are sited beside the river. More people and more property are at risk than in the past.
- To counteract the pressure for rural-to-urban migration, factories have been built in the village communes to provide jobs for the country folk. Many of these factories are on the floodplain and are not as well protected from floods as those in the cities. These factories and the workers' houses are at risk.

- More buildings on the floodplain mean less room for the floodwater so the flood levels rise higher.
- Deforestation in the headwaters of the river in the 1960s means that there is less interception, less evapotranspiration and less infiltration. This leads to more surface run-off and bigger flood peaks.
- Mismanagement of the deforested land, e.g. overgrazing, has led to soil erosion and more silt being washed into the river channel. There is, therefore, less room for the water.
- Canalisation of the river to improve river transport has straightened the river, speeding up the flow, reducing the lag time and increasing the flood peak.
- Flood protection embankments have constrained the river. This means that the river can hold more water but when the banks break the flooding is rapid and more deadly – people have less time to escape.
- In the old days, Dongting and Poyang Lakes near Wuhan acted as safety valves. Floodwater from the river was diverted into the lakes, reducing the potential flood peak. More recently, farmers have been reclaiming **polders** from the lakes to create new farmland. This means the lakes are much smaller and there is less room in the lakes for the floodwaters. Flood peak levels are increased.
- Global warming could have resulted in more rainfall in China.

## The impacts of the 1998 Chang Jiang floods

The Chang Jiang floods of 1998 were some of the worst floods on this river in the last one hundred years.

The monsoon rains were not more intense than normal but lasted for a month longer. At one time the river was 45 metres high. What were the impacts of these devastating floods?

- 240 million people in seven of China's provinces were affected by the floods in some way.
- 4000 people were drowned.
- Thousands of farm animals died.
- Huge areas of crops were destroyed. These included food crops such as rice and industrial crops such as cotton.
- To protect Wuhan, the largest city in the area, many of the river's flood protection embankments had to be deliberately breached. Large areas of the countryside were flooded as a result, destroying houses and factories in the village communes.
- 14 million people were homeless for months until their houses could be repaired or replaced.
- People were out of work for months while factories were repaired.
- Great thicknesses of sticky clay were deposited onto the fertile fields. This clay had to be removed before farming could re-commence.
- The total cost to China's economy was enormous.

## Management of flooding on the Chang Jiang

Several schemes have been developed to reduce flooding on the Chang Jiang. These include both 'hard' and 'soft' engineering projects.

## The Three Gorges Dam: a hard engineering solution

Downstream of the city of Chongqing, the Chang Jiang flows through a deep, narrow section of its valley known as the 'Three Gorges'. This is an ideal site for a dam because the reservoir is very big but is contained in the narrow valley and does not spread out over a huge lowland area. The dam has been built at Sandouping and the reservoir is 660 km long and 1 km wide, extending upstream almost as far as Chongqing.

The Three Gorges dam is the largest hard engineering project ever undertaken on a river. Construction started in 1994 and the dam was completed in 2006. The project was finally completed in 2009 when the reservoir completely filled up. The dam is 2.3 km long and almost 200 metres high. A series of gigantic ship

locks has been built at the north-east end of the dam and an 18 000 megawatt H.E.P station has been built inside the southwest end of the dam. It has cost in excess of US\$ 38 billion to build.

## What are the benefits of the scheme?

- At least 50 million people have been protected from the sort of catastrophic flooding that occurred in 1998, including those living in the mega-cities of Wuhan and Shanghai.
- Millions of hectares of farmland have been protected from flooding and provided with guaranteed irrigation water. This will raise grain and oil-seed production.

- Water supplies to the 13 million people living in Shanghai are now secure.
- It is generating 10 per cent of China's electricity, equivalent to 15 nuclear power stations. This is clean HEP and its production will not contribute to air pollution or to climate change. The power produced will boost economic growth, especially in central and eastern China, including the cities of Wuhan and Shanghai.
- The Chang Jiang is now navigable by ships of up to 10 000 tonnes, as far upstream as Chongqing. There is expected to be a 500 per cent increase in river traffic and this will also boost economic growth.

## What are the disadvantages of the scheme?

- The reservoir has flooded 150 towns and cities and 1300 villages. 1.2 million people have been resettled in new settlements close to their old homes but the compensation did not cover the cost of their new homes.
- The reservoir is heavily polluted by toxins from flooded mines and factories. This has damaged the river's fragile ecosystem and species such as the White Flag River Dolphin and the Siberian Crane are endangered.
- The landscape itself could be a problem. As the water seeps into the rocks of the steep valley sides, landslides are expected. This is also an earthquake region and if the dam were to break the resulting flood would be unbelievably devastating.
- The Chang Jiang is laden with silt. This will be deposited in the reservoir, reducing its capacity. It will have to be dredged or flushed out on a regular basis. In the past, farmland downstream was fertilised with a thin layer of silt each year. This has been lost and more chemical fertilisers are needed.

- Over 1000 cultural and archaeological sites have been flooded, including the Zhang Fei temple.

## Afforestation: a soft engineering solution

Upstream of Chongqing, the Chang Jiang runs through a hilly area on the borders of Yunnan and Sichuan provinces. This used to be heavily forested but many of the trees were cut down in the 1960s for fuel, timber and farm land. The new fields are used to grow crops like buckwheat but the terraces are poor and soil erosion is a problem. Animals are grazed here too. There is a now a big programme to get the local people to replant the trees wherever possible. The advantages are:

- Trees encourage interception, evapotranspiration and infiltration. This will help to reduce flooding, both locally and downstream.
- Forested areas have less soil erosion. This will be good for the local area and will reduce the amount of silt further down the river. This also reduces flooding and will reduce the rate of sedimentation in the Three Gorges reservoir.
- Trees can be harvested for food, fodder, fuel and timber.

However, the disadvantages are that the local farmers are losing their arable and grazing fields. Many of the trees planted are fast growing conifers which are less useful than the natural forest and do not stimulate biodiversity.

**20.** 'The Three Gorges Dam has caused more problems than it has solved'. To what extent do you agree with this statement?

# Key concepts

The key concepts listed in the syllabus are set out below. For each one a summary of how it applies to this chapter is included.

**Space:** the drainage basin is an excellent example of the concept of space. The inputs, flows and outputs of the drainage basin system all operate within and across the space provided by the drainage basin. The nature of the drainage basin space determines the way in which the system operates to influence the functioning of the streams and rivers in the drainage basin. The river landscape is another example of the concept of space. The different river landforms are arranged logically throughout this space, from the upper valley to the lower valley of the river.

**Scale:** spatial scale is an important concept when studying rivers and their landscapes. Individual landforms are found at the local scale while drainage basins occupy the regional scale and the hydrological cycle operates at the global scale. The timescale is important when considering how quickly water moves through a drainage basin, how changes that are made to the drainage basin can affect these timescales and how these changing timescales can modify the nature and magnitude of river floods.

**Place:** distinctive river landforms are found in similar places within drainage basins. The source of a river is usually in a hilly place while the mouth is often beside the sea. Floodplains are places which provide people who live on them with opportunities and challenges.

**Environment:** rivers are part of the natural environment and they interact with people in a variety of ways. Water abstraction needs to be managed sustainably to ensure that supplies do not run out. Flood risk is a challenge which needs to be managed sensibly, considering the whole drainage basin and not just one place.

**Interdependence:** the water cycle operates at a range of scales and its interaction with human systems at each of these scales is complex. People need to understand the processes and links that operate in each drainage basin system if they are to successfully exploit the opportunities that it provides to them and manage the threats that it presents.

**Diversity:** every drainage basin and river landscape has its own distinctive character but they all obey overarching physical laws. Despite this, the human response to the opportunities and challenges that rivers provide is variable. This variation is often to do with the level of economic development of the country or society concerned.

**Change:** river basins and the landforms in them are constantly changing. This change is not only a response to the physical processes operating there (e.g. erosion, transportation and deposition) but also to the human activities going on there (e.g. water abstraction and flood risk management). Geographers should aim to understand the physical processes, the human activities and the way that the interaction between them leads to change.

# Exam-style questions

- 1 Study Fig. 1.47 which shows the annual hydrograph of the River Severn at Bewdley.

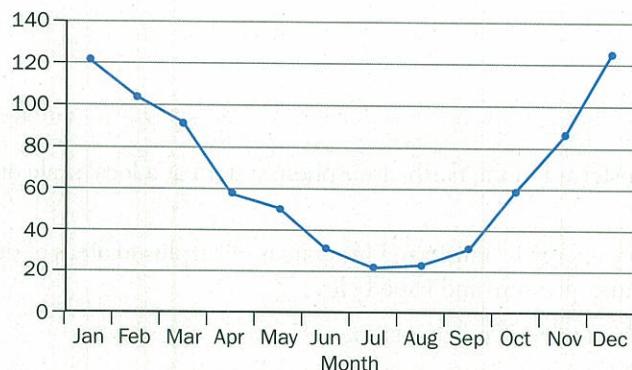


Fig. 1.47

- (a) Using Fig. 1.47, identify the:
- Mean monthly discharge of the River Severn in October? [1]
  - The lowest mean monthly discharge of the River Severn and the month in which it occurs. [2]
- (b) Briefly describe the pattern of the annual discharge of the River Severn. [3]
- (c) Suggest how seasonal changes in evapotranspiration could cause the variations in river discharge shown in Fig. 1.47. [4]
- 2 (a) (i) Define the terms overland flow and throughflow as they apply to the movement of water in a drainage basin. [4]
- (ii) Briefly explain how the shape of a storm hydrograph can be affected by overland flow. [3]
- (b) Explain how vegetation type can affect the flows and stores of water in a drainage basin. [8]
- (c) With the aid of examples, assess the extent to which human activities can increase the impact of river floods. [15]