THEME 2

Chapter 1
River processes and landscapes

River processes

▶ **Figure 1** A number of different river processes are evident in this river.

Erosional processes

- **Hydraulic action** – water crashes into gaps in the soil and rock, compressing the air and forcing particles apart
- **Abrasion** – the flowing water picks up rocks from the bed that smash against the river banks
- **Attrition** – rocks carried by the river smash against one another, so they wear down into smaller and more rounded particles
- **Corrosion** – minerals such as calcium carbonate (the main part of chalk and limestone rocks) are dissolved in the river water

▲ **Figure 3** Four processes of river channel erosion.

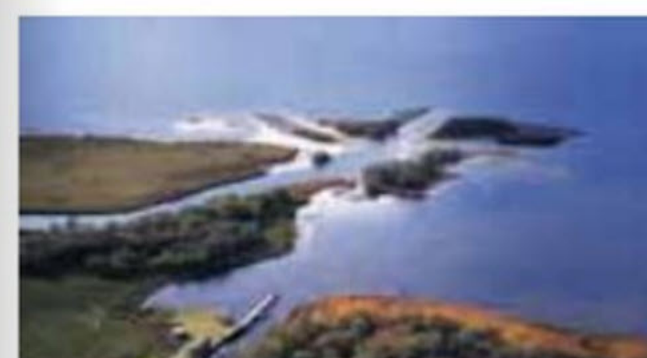
From the moment water begins to flow over the surface of the land, gravity gives it the power to erode the landscape. The gravitational energy of the flowing water enables the river to **transport** its **load** of boulders, gravel, sand and silt downstream. Where energy levels are high, the main river process is erosion. At other times of the year, or in other parts of the river where energy levels are lower, the main process is **deposition**.

Erosion occurs where the river has plenty of energy so, for example, where the river is flowing quickly or when the river is full of water after heavy rain. Rivers that are flowing across gentle slopes (such as the river in Figure 1) tend to flow with greatest force on the outer bend of each curve (or **meander**). Water is thrown sideways into the river bank, which is eroded by both **hydraulic action** and **abrasion**. The bank gradually becomes undercut. The overhanging soil slumps into the river channel where this new load of material can be picked up and transported downstream by the flowing water.

Transportation process	Sediment size or type	Typical flow conditions	Description of the process
Solution	Soluble minerals such as calcium carbonate	Any	Minerals are dissolved from soil or rock and carried along in the flow
Suspension	Small particles e.g. clay and silt	Suspension occurs in all but the slowest flowing rivers	Tiny particles are carried long distances in the flowing water
Saltation	Sand and small gravels	More energetic rivers with higher velocities	The sediment bounces and skips along
Traction	Larger gravels, cobbles and boulders	Only common in high energy river channels or during flood events	The bed load rolls along in contact with the river bed

▲ **Figure 2** The transportation of sediment.

The process of deposition occurs where the river loses its energy. For example, where a river enters a lake and its flow is slowed by the body of still water. Deposition also occurs in very shallow sections of a river channel where friction between the river bed and the water causes the river to lose its energy and deposit its load. The process of deposition creates layers of sand and gravel that are often sorted by sediment size because the coarsest sediment is deposited first.



▲ **Figure 4** The river channel, which flows from the left, has split into a number of smaller distributaries as it flows into a lake. Derwent Water, the Lake District.

Activities

1. Study Figure 1. Use evidence from the photograph to suggest what river processes are occurring at A, B and C.
2. Draw four diagrams or cartoons to illustrate the ways in which a river transports material.
3. Study Figure 4 and explain how erosion, transportation and deposition have each played a role in the formation of this landform.
4. Study Figures 1 and 4. Use evidence in these photos to explain the difference between abrasion, hydraulic action and attrition.

Distinctive landscapes of upland rivers

The river in Figure 5 shows typical features of a river flowing over steeper gradients. Much of the force of the water is directed downwards. **Vertical erosion** cuts into the river bed. The river cuts a narrow valley with steep V-shaped sides. The flow of water within the river channel also swings from side to side, creating some sideways erosion. Over time this process means that the V-shaped valley is cut, or incised, into the hillside to form **interlocking spurs** rather like the teeth of a zip.

Rivers flowing over steep gradients have enough energy to erode and transport a large quantity of material. The load on the river bed here is large and angular. The rocks of the river bed may show evidence of abrasion in the form of smoothly cut potholes or scour holes. As a river flows downstream, the process of attrition gradually reduces the overall size of the load.

▲ **Figure 5** Ashes Hollow, Shropshire is a typical V-shaped valley.

Activities

1 Study Figure 5. Describe how each of the following features was formed:
   a) V-shaped valley sides
   b) large angular boulders in the stream bed
   c) interlocking spurs
2 Study Figure 6. Describe the process that created the features on this river bed.

▲ **Figure 6** Scour holes on the bed of the River Wye, mid Wales.

Enquiry

Do waterfalls only occur in the upland regions of the UK? Use the web link on this page to investigate the interactive map.

a) Describe the location of the UK's waterfalls.
b) What proportion is located in upland regions – over 400 m above sea level?

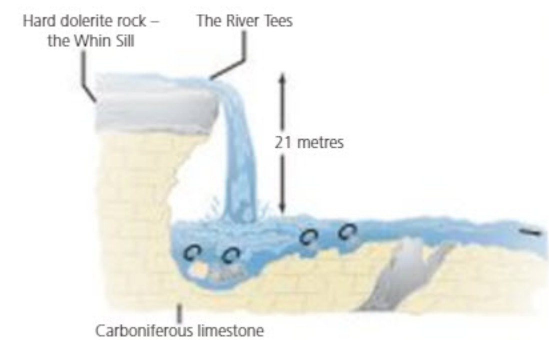
http://www.world-of-waterfalls.com/europe.html
An interactive map showing the location of waterfalls across the UK.

How are gorges and waterfalls formed?

High Force is a waterfall in the upland section of the River Tees. Below the waterfall is a narrow valley with almost vertical sides. This feature is known as a **gorge**. The rocks here are alternating layers of dolerite, which is an igneous rock, and limestone. The dolerite is very resistant to erosion whereas the limestone is eroded more easily. It is the geology of this landscape that has caused the waterfall and gorge to form.

As the river plunges over the dolerite, it pours onto the softer limestone below. A combination of hydraulic action and abrasion erodes this rock relatively easily, creating a **plunge pool**. The river water is slightly acidic so the limestone is also eroded by corrosion. Abrasion at the back of the plunge pool undercuts the layers of dolerite. Eventually this overhang will fracture and the rocks will fall into the plunge pool where they are broken up by attrition. So each step is gradually cut back and the waterfall retreats backwards along the river's course. It is this process of **retreat** that has cut the gorge.

▼ **Figure 7** How the waterfall and gorge at High Force are formed.



1. Acidic water flowing from Cross Fell can corrode the limestone.
2. A 'cap rock' of dolerite is resistant so erosion is relatively slow.
3. An overhang of jointed limestone is susceptible to collapse and retreat.
4. Hydraulic action and corrosion attack the limestone.
5. Abrasion deepens the plunge pool.
6. Attrition breaks down the eroded rock fragments.
7. Fragments of dolerite swirl around in hollows to create pot-holes by abrasion.
8. Small outcrops of dolerite create an irregular river bed of rapids and smaller waterfalls.

▲ **Figure 8** High Force waterfall on the River Tees.

Activity

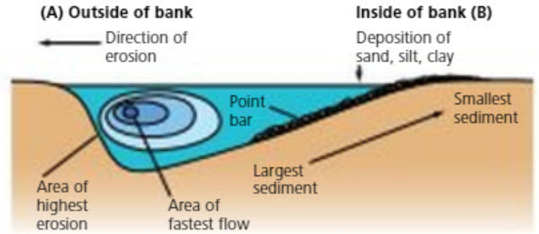
3 a) Make a copy of Figure 7.
   b) Add the labels below Figure 7 to relevant places on your diagram
   c) Explain why the retreat of the plunge pool has, over thousands of years, created a gorge. You could draw a series of diagrams to show this.

How are river meanders formed?

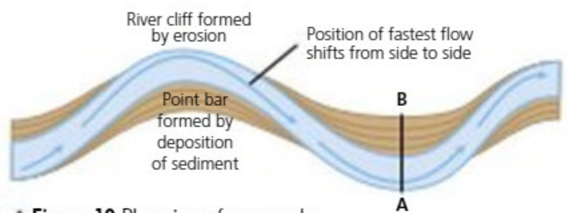
Rivers flowing over gentle gradients tend to swing from side to side. The water flows fastest on the outside of the bend of each meander. This causes erosion of the banks rather than the bed, a process known as **lateral erosion**. The slower flowing water on the inside of each bend loses energy and deposits its load. The material is sorted, with the larger gravel being deposited first, then the sand and finally the silt. This process creates a river beach or **point bar**. Meandering rivers such as the Greatham in Figure 12 flow across a wide **floodplain**. This flat landform has been created over many thousands of years by the processes of lateral erosion and deposition.

Activity

1 Use Figure 11 to:
  a) Give the six-figure grid references for
    i) one river cliff
    ii) one point bar.
  b) Describe the relief in square 3208.



▲ **Figure 9** Cross-section through a meander.



▲ **Figure 10** Plan view of a meander.

▼ **Figure 11** Meanders on the River Tees, near Hurworth-on-Tees, 10 km west of Yarm. Scale 1:25 000.

The estuary of the River Tees

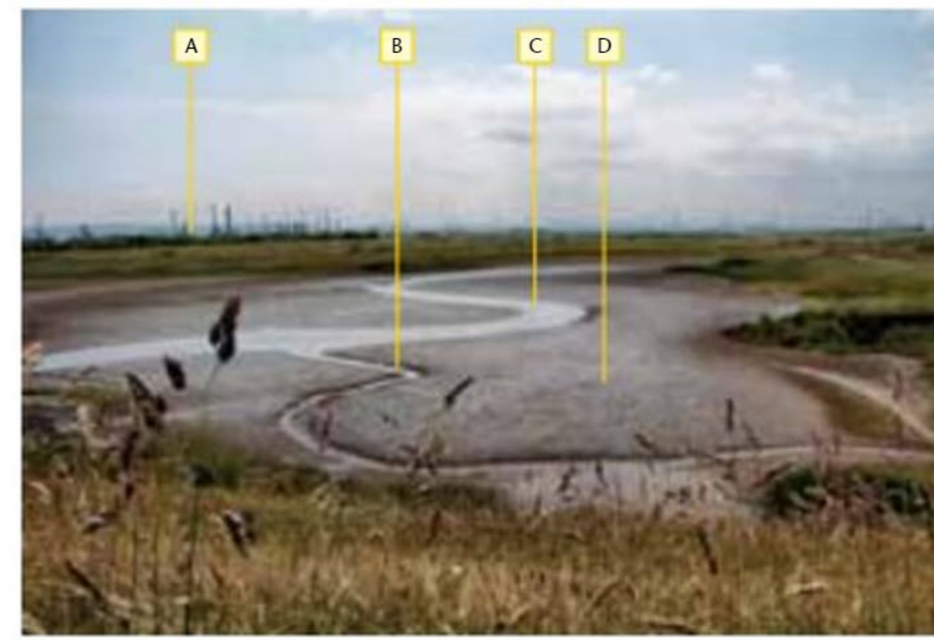
The River Tees flows through an estuarine landscape for its final few kilometres before it reaches the North Sea. This distinctive landscape is made up of several features that include:

- Natural landforms such as floodplains, meanders and **ox-bow lakes** which are old meander loops that have been detached from the river channel by erosion.
- Habitats such as mud flats and salt marshes which attract wading birds.
- Wide, flat flood plains that have been drained and used for large industrial buildings.

The landscape of the river channel in the estuary is constantly changing as the flow of water changes:

- The power of the tide varies daily and throughout the year.
- The **discharge** of the river is also variable, depending on the amount of precipitation in the catchment.

Where the water is at its stillest, in the narrow creeks of the salt marsh, silt and mud from the river are deposited. The mixing of river water with salt water from the sea encourages deposition of mud particles. The mud flats between the creeks are covered at high tide and exposed at low tide.



▲ **Figure 12** The estuarine landscape close to the mouth of the River Tees.

Activities

2 Meanders erode laterally, or sideways, over time.
  a) Draw a sketch map showing the course of the river in Figure 11.
  b) Draw a second sketch showing the course of the river after erosion and deposition have altered the shape of the river meanders. Justify your prediction.
  c) Identify an area of the map where one of the meander bends could, in time, form an ox-bow lake.

3 Use what you have learned in this chapter to:
  a) Create labels for the features at points A to D on Figure 12.
  b) Compare the river features and processes in Figures 5, 8 and 12.

Investigating downstream changes

Rivers can change in shape and character as they flow downstream. It is possible to pose geographical questions about these changes. For example, when investigating change at the small scale:

How does river velocity change across a point bar and how does this affect sediment size?

Or, when investigating change at a larger scale:

How do cross-sectional area and river velocity change as you move downstream?

Choosing sample sites

The UK's rivers vary from just a few hundred metres in length to rivers like the River Severn which, at 369 km, is the UK's longest river. In an enquiry about how a river changes as it flows downstream it is important to make sure that your sample points are far enough apart to show change. For a river that is 10 km long you could either collect data at 1 km, 5 km and 10 km, or at 3 km, 4 km and 5 km. The first sampling strategy would provide a representative sample of the whole of the river, whereas the second would only provide evidence of small-scale changes in just one short section of the river.

Activity

1 Explain why sampling at 3 km, 4 km and 5 km would not be representative of change along a whole river that is 10 km in length.

▼ **Figure 13** Sample sites on a meandering river.

Calculating cross-sectional area

To measure the cross-section of a river channel you will need to set a horizontal line across the river and carefully measure down from this line to the ground. This is shown in Figure 13 where the horizontal yellow line represents the survey line from X to Y and the four vertical lines represent the first four measurements. Collect data when the river is low but take measurements for the dry land on either side of the river. Then, when your results are plotted on a graph, you can estimate the amount of water in the river when the river channel is full and about to flood.

Step 1 Stretch a tape measure at right angles across the river from one bank to the other, keeping it parallel to the surface of the water.

Step 2 Divide the width of the river by 10. This will create 11 equally spaced survey points. For example, in a river that is 4 metres wide you will record the depth every 40 cm (1/10th) of the way across. This is an example of systematic sampling (see page 45).

Step 3 At each survey point measure the depth of the river. Make sure that your depth and width readings are both recorded in the same units (for example, both in metres).

Cross-sectional area (CSA) in square metres = width (m) multiplied by mean depth (m).

Survey site	1	2	3	4	5	6	7	8	9	10	11
Distance from bank (m)	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
Distance from survey line to ground (m)	0.25	0.68	0.71	0.65	0.67	0.64	0.58	0.52	0.48	0.33	0.22
Depth of water (m)	0	0.28	0.31	0.25	0.27	0.24	0.18	0.12	0.08	0	0

▲ **Figure 14** Depth measurements taken in the river in Figure 13 at 0.4 m intervals.

Activity

2 Use Figure 14.
  a) Plot the profile of this river on graph paper. Remember to work downwards from your horizontal axis.
  b) What is the mean water depth?
  c) Calculate the cross-sectional area.
  d) If water levels rose by 20 cm, what would be the new cross-sectional area?

How do I calculate range, median and interquartile range?

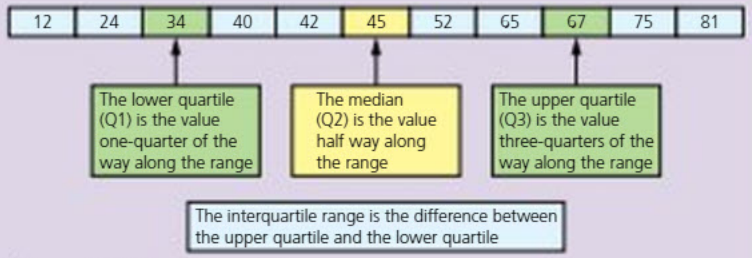
The flow of water in the river channel has enough energy to transport sediment. As the water speed slows, for example, in shallow water on the point bar, energy is lost and sediment is deposited.

To test whether this process is happening in your river, you will need to sample some pebbles and record their size. Students collected a sample of 11 pebbles from sites A, B and C in Figure 13. Their aim was to discover how the size and range of pebbles changed across the point bar.

To calculate the range, median and interquartile range, you need to put your data into rank order. The data for site A is shown in Figure 16 in rank order.

Site	Pebble sizes (mm)										
A	45	52	12	67	34	75	42	81	65	40	24
B	44	37	28	56	61	43	38	28	35	42	36
C	37	34	26	40	24	35	29	42	38	18	20

▲ **Figure 15** Pebble sizes (mm) collected at random at sites A, B and C in Figure 13.



▲ **Figure 16** Pebble sizes for site A arranged in rank order.

Activity

3 Use Figure 15.
  a) For each sample site, calculate the:
    i) range
    ii) median
    iii) interquartile range.
  b) What conclusions can you draw from these results?

THEME 2

Chapter 2 River management

How are river landscapes affected by geology?

Climate, geology and human activity all play an important part in the river landscapes of the UK. The **porosity** and **permeability** of the rocks beneath our feet help to determine how much water we see in the UK landscape. **Porous** rocks have tiny spaces known as pores between the grains of rock. Porosity is a measure of how much water can be stored in these pore spaces. Rocks such as sandstones can hold water in their pore spaces as a **groundwater store**. Permeability is a measure of how easily water can travel through a rock. **Permeable** rocks allow water to pass through them. Water easily travels through the vertical and horizontal joints and cracks that are common in permeable rocks such as sandstone and limestone. **Impermeable** rocks have few pore spaces or joints so water tends to flow over them on the surface of the land. Most igneous rocks, such as granite and metamorphic rocks such as slate, are impermeable. Clay, which is a sedimentary rock, is also impermeable. In regions where the geology is impermeable, water can be stored at the surface. Lakes and rivers are natural **surface stores** of water. Rivers can be dammed to control flooding and create reservoirs for water supply. There are 168 large dams (defined as being more than 15 m high and holding at least 3,000,000 cubic metres of water) in the UK.

▲ **Figure 1** The River Elan flows through an upland area of Wales. Rocks are impermeable and soils are thin.

▲ **Figure 2** The Penygarreg reservoir and the Craig Goch dam in the Elan Valley.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aberystwyth	97	72	60	56	65	76	99	93	108	118	111	96
Cwmystwyth	192	139	158	108	97	116	116	135	151	187	206	213
Birmingham	74	54	50	53	64	50	69	69	61	69	84	67
Norwich	55	43	48	41	42	58	42	54	47	68	70	53

▲ **Figure 3** Monthly precipitation totals for UK weather stations along a west–east transect through Wales and England.

Activities

1 Using Figures 1 and 2, suggest two different ways that human activity has affected the landscape of the River Elan.

2 a) Describe the landforms visible in Figure 1 or 2 and the processes that formed them (see page 113).

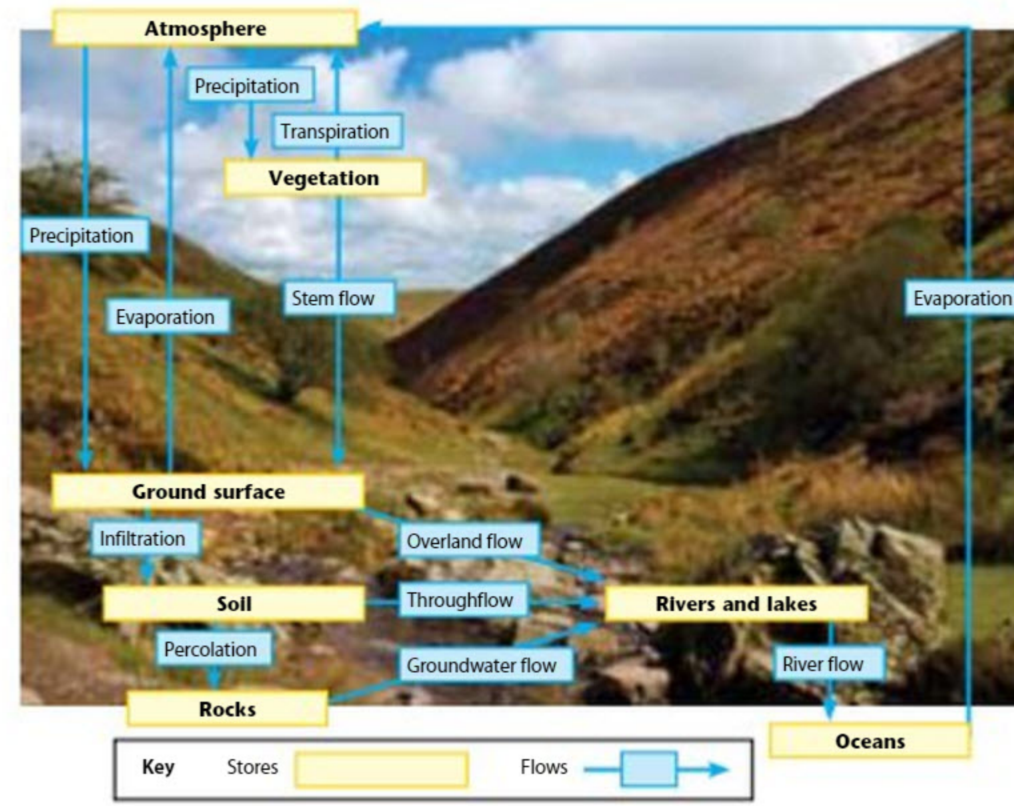
3 Study Figure 3.
a) Draw four precipitation graphs.
b) Describe how precipitation changes from west to east across Wales and England.
c) Give two reasons why the Elan Valley may have been chosen to build the Craig Goch Dam.

Where are the water stores and flows in a drainage basin?

Very little precipitation falls directly into rivers. Most falls elsewhere within the **drainage basin** which is the area of land that is drained by the river and its **tributaries**. Figure 4 shows flows of water through a typical drainage basin. Water either flows over the surface as **overland flow** or flows into the soil – a process known as **infiltration**. Once in the soil, water moves slowly downhill as **throughflow**. Some water percolates deeper into the ground and enters the bedrock where it continues to travel as **groundwater flow**. Rates of infiltration, throughflow and groundwater flow will depend on a number of factors which include the:

- size and shape of the drainage basin and the steepness of its slopes
- amount of rainfall throughout the year and the intensity of rain storms
- amount and type of vegetation cover
- permeability and porosity of the soil and underlying rocks.

▼ **Figure 4** Stores and flows of water in a natural drainage basin.



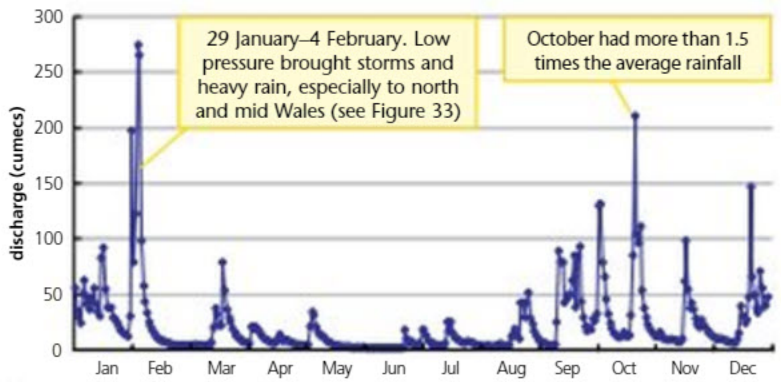
Activities

4 Use Figure 4 to name:
a) three surface stores of water
b) two places water is stored below the surface.

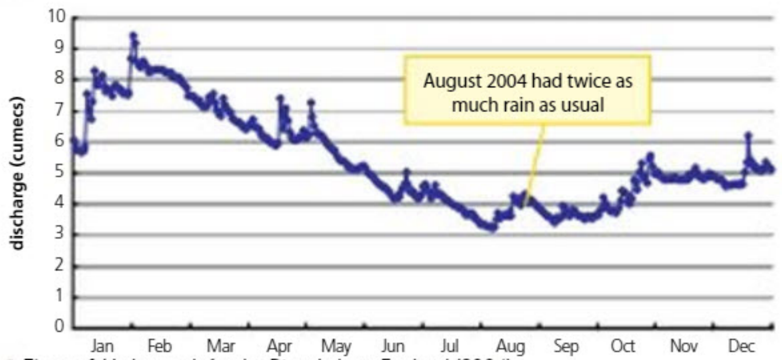
5 Suggest why precipitation falling into a drainage basin of impermeable rocks is likely to reach the river much more quickly than rainwater falling in an area of porous rocks.

How does geology affect flows and stores of water in the drainage basin?

Geology is a major influence on how quickly water flows through a drainage basin. It also influences the amount of water that can be stored within the drainage basin. The amount of water in a river is its **discharge** and this is measured in cubic metres per second, or **cumecs**. The annual pattern of a river is known as its **annual regime**. Study Figures 5 and 6. They show the annual regime in 2004 for two rivers that have similar sized catchment areas. However, the geology of the two drainage basins is quite different and this affects the flow of water through each basin.



▲ **Figure 5** Hydrograph for the River Dyfi, Wales (2004).



▲ **Figure 6** Hydrograph for the River Itchen, England (2004).

Factfile

River	River Dyfi	River Itchen
Location	West Wales	South East England
Total average rainfall	1,834 mm	838 mm
Geology	100% impermeable rocks	90% chalk which is porous
Size of drainage basin (above the gauging station)	471 km²	360 km²
Landscape	Steeply sloping hills and mountains reaching a maximum of 907 m above sea level	Rolling hills. Maximum height 208 m above sea level
Land use	60% grassland (sheep pasture); 30% forest; 10% moorland	Mainly arable (cereal) farmland with some grassland
Human factors affecting run-off	There are virtually no human influences on run-off	Run-off is reduced by some abstraction for water supply. Some water is used to recharge groundwater in the chalk aquifer

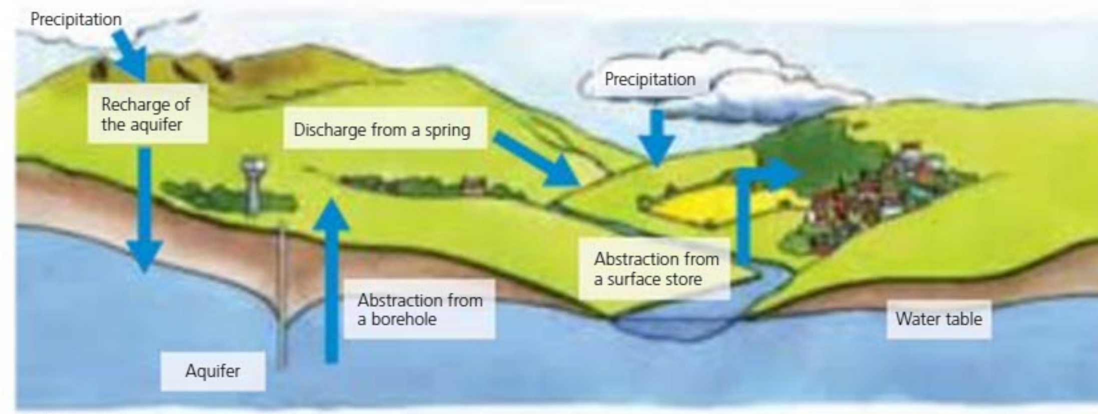
▲ **Figure 7** Factfile on the River Dyfi and River Itchen.

Activities

1 Compare Figures 5 and 6. Describe:
   a) one similarity
   b) three differences.
2 Use Figure 7 to suggest how each of the following factors may have affected the flow:
   - rainfall
   - total geology
   - landscape
   - land use.
3 Imagine you work for a water company. Suggest how each river could be used for water supply.

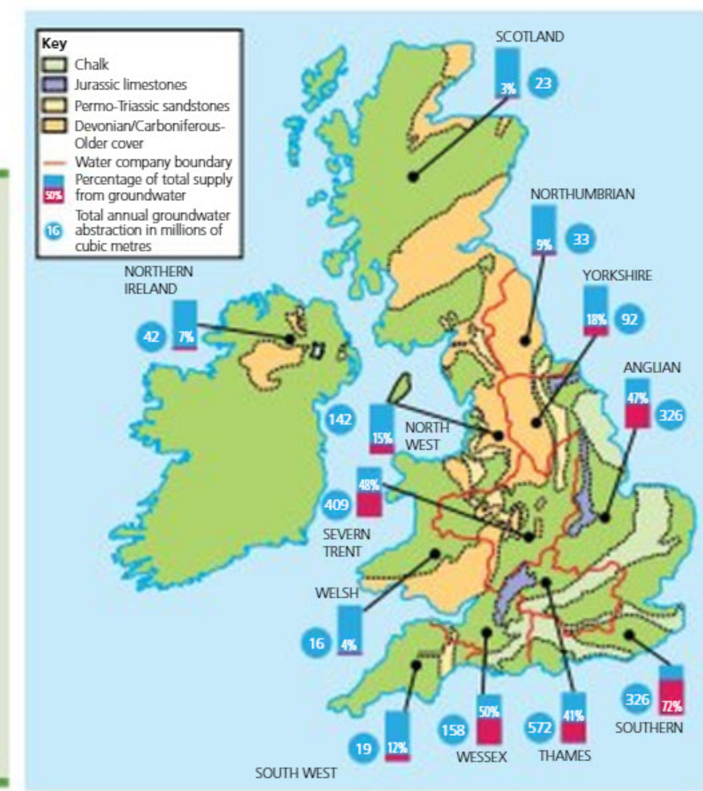
The abstraction of water

Some bands of porous rock can hold huge quantities of water. These groundwater stores are also known as **aquifers**. Examples are chalk and some types of sandstone. Water that enters an aquifer is **recharge**; water that leaves an aquifer is discharge. When water is taken from either a surface or groundwater store, we say the water is **abstracted**. If water is taken from a store faster than it can be recharged then **over-abstraction** is taking place. The last significant drought in the UK was in 2005 and 2006. Low precipitation during the winter months failed to recharge some aquifers. Water levels dropped in rivers in the south east of England.



▲ **Figure 8** A cross-section to show how water moves between surface and groundwater stores.

▶ **Figure 9** Major aquifers in the UK. Located bar graphs indicate the percentage of water supply that comes from groundwater supply. The remainder will come from surface stores (rivers and reservoirs).



Activities

4 Define the following terms:
   - discharge
   - abstraction
   - over-abstraction.
5 Use Figure 9.
   a) Make a table of the 12 water companies and put them in rank order by the percentage of their water supply that comes from groundwater.
   b) Describe the distribution of water companies that take less than 10 per cent of their supply from groundwater. What does this tell you about rock type in these regions?
   c) For each company, calculate the actual amount of water that is abstracted from groundwater stores.

Why do rivers flood?

In the UK we experience two types of flood:

- **Flash floods**, like the Boscastle flood event of 2004, when high volumes of rain fall in a very short period of time, causing a sudden rise in river levels. Flash floods sometimes occur in the summer in the UK when the ground is hard and baked dry. With these soil conditions, the rainfall is so intense that it cannot soak into the ground quickly enough so runs overland instead.
- Seasonal floods, like the Somerset Levels flood event of 2014, when river levels rise due to seasonal variations in rainfall. These types of flood usually occur after a long period of rain, when the ground is already saturated and cannot absorb any more water. Floods may also occur in the UK when snow melts but the ground is frozen so water cannot infiltrate the soil.

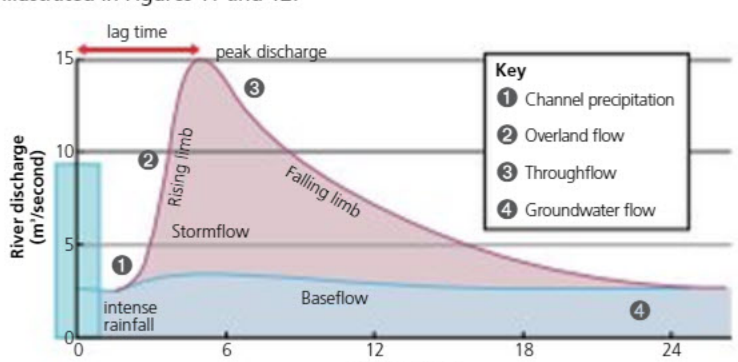
Do human actions increase flood risk?

Flooding occurs when water cannot infiltrate the soil. Paving over the soil creates an impermeable surface and reduces infiltration, so the growth of urban areas increases the risk of flooding. It is thought that paving over front gardens to create parking spaces may increase the risk of flash floods in urban areas. Vegetation helps to remove water from the soil before it reaches a river so cutting down trees or leaving fields bare in winter can increase the risk of seasonal floods. On the other hand, replanting upland areas with trees, a process known as **afforestation**, may help to reduce the risk of floods further downstream. It is thought that afforestation in mid Wales could help to reduce floods at Shrewsbury or Bewdley (see pages 134–5).

GEOGRAPHICAL SKILLS

How do you analyse a hydrograph?

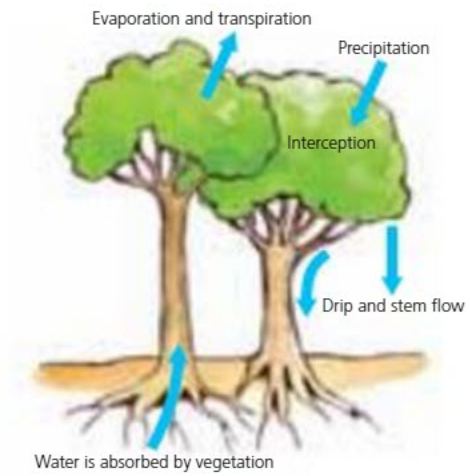
A flood **hydrograph** shows the discharge of a river over the period of a flood. The example in Figure 10 shows how a small river might respond to a flood event. The blue bar represents a sudden downpour of rain, like the one at Boscastle in 2004. In this example it takes two hours for overland flow from the drainage basin to reach the river channel. At this point the amount of water in the channel rises rapidly and reaches its maximum or **peak discharge**. The time between the peak rainfall and the peak discharge is known as **lag time**. The lag time and height of the peak discharge depend on the features of the drainage basin. In drainage basins where infiltration is reduced, the lag time will be shorter and the peak discharge larger. For example, urban drainage basins have a lot of tarmac and concrete which are impermeable surfaces. Artificial storm drains have to be installed to quickly remove surface water otherwise urban streets would flood after each rainfall event. Some of these factors are illustrated in Figures 11 and 12.



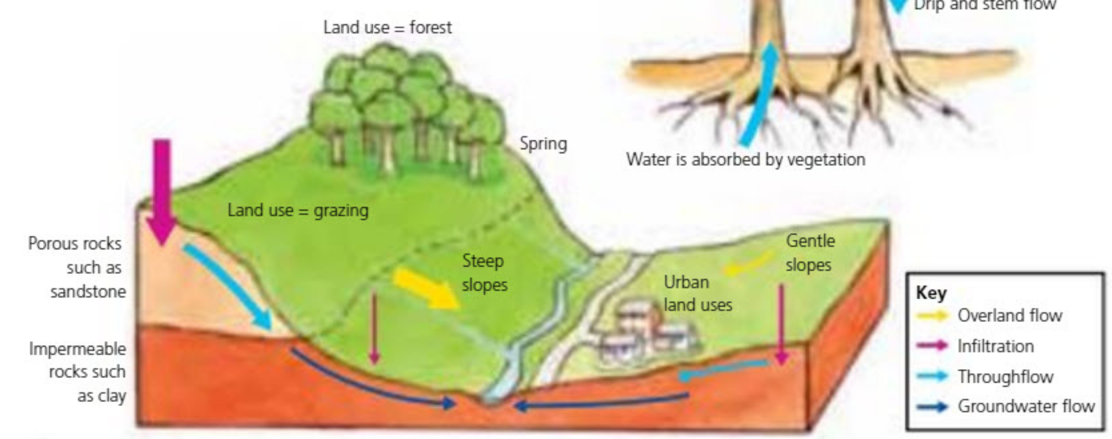
▲ **Figure 10** A simple flood hydrograph.

Activity

1 Use Figure 11 to explain how cutting down a large forest could affect lag time and peak discharge in a nearby river.



▶ **Figure 11** Forests reduce overland flow and throughflow.



▲ **Figure 12** Factors that influence infiltration and overland flow in the drainage basin.

Activities

2 Study Figure 10.
 a) Use times and discharge figures from the hydrograph to describe:
  i) the shape of the rising limb and the lag time
  ii) the shape of the falling limb and baseflow.

3 Use Figures 4, 10, 11 and 12 to help you copy and complete the following table.

Drainage basin factor	Impact on infiltration	Impact on overland flow and throughflow	Impact on lag time
Steep slopes			
Gentle slopes			
Porous rocks			
Impermeable rocks			
Urban land uses			
Planting more trees			

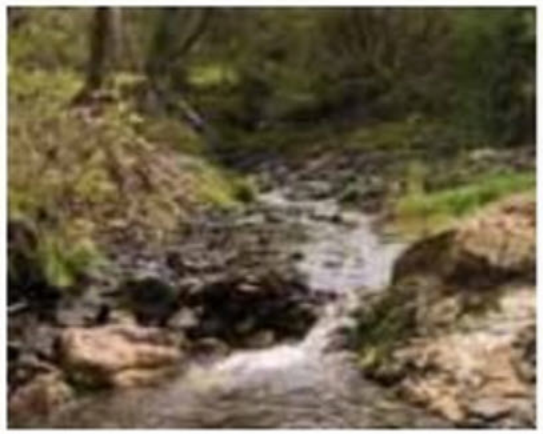
Enquiry

Can you predict the response of different drainage basins to a sudden downpour of rain?

a) Sketch a pair of flood hydrographs to show the difference between similar sized drainage basins – one of which has urban land uses and one of which has lots of forests.
b) Draw a second pair of hydrographs to compare the response of rivers in a drainage basin that has porous rocks compared with one that has impermeable rocks.
c) Discuss your hydrographs with a colleague. Justify the shapes on your hydrographs. Make sure you can explain why you have predicted the shape of the rising and falling limbs and the possible length of the lag time.

Why did the River Valency flood?

The drainage basin of the River Valency, in Cornwall, normally gets 100–120 mm of rainfall during August. But in just four hours on the afternoon of 16 August 2004, 200 mm of rainfall fell causing a flash flood. The force of water rushing through the town caused the collapse of 5 buildings. Thankfully nobody was killed.



▲ **Figure 13** The River Valency in its upper course close to Tresparrett (Grid square 1491).

How did human and physical factors contribute to the flood?

The River Valency is less than 10 km from its source to its mouth. The source of the river is at 280 m above sea level. The high source and short length make the river's gradient rather steep. The total size of the drainage basin is around 26 km^2. The rocks of the drainage basin are mainly slates, which are impermeable. The river has a number of small tributaries which all flow through steep V-shaped valleys.

There are no large towns in the drainage basin. Boscastle itself covers less than 1 km^2. The upland part of the drainage basin is used for grazing. Some of the valleys are wooded. Trees help to remove some water from the soil before it reaches the river. However, during flood events, tree branches that are overhanging the river can be broken off. These branches then restrict the flow of water in the river, especially if they get caught against the piers of bridges.

Activities

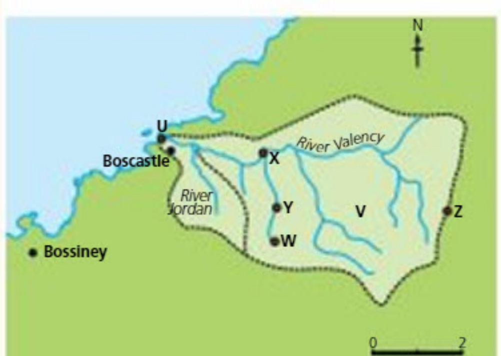
1. Make a sketch of Figure 13.
2. Label three features that help to explain why this river floods so easily.

GEOGRAPHICAL SKILLS

Using geographical terms

You should always try to use the correct technical terms when you are writing a geographical report. Using geographical terms will improve your communication skills because their correct use will:

- make your writing more accurate and concise
- give your writing the correct scientific style and tone.



▲ **Figure 14** The drainage basin of the River Valency.

Activity

3 a) Make a sketch of Figure 14.
b) Match the following key terms to features U, V, W, X, Y and Z on Figure 14.
- Catchment area
- Source
- Tributary
- Confluence
- Watershed
- Mouth.

c) Write a simple definition for each of these terms.

▲ **Figure 15** An Ordnance Survey extract of the catchment area of the River Valency. Scale 1:50 000.

narrow valleys		overland flow enters the tributaries very quickly
small areas of woodland		there is a very short time lag between the rainfall and the flood
steep slopes		water cannot soak away into the ground
lots of streams indicate that the rocks are impermeable	… so …	the flow of water is restricted and funnelled so river levels rise quickly
upland areas (250–270 metres) are very close to Boscastle		only a little water is absorbed or slowed

▲ **Figure 16** Reasons for the sudden rise of the River Valency during the flood in 2004.

Enquiry

Analyse the factors that led to the Boscastle flood of 2004.

a) Match the pairs of statements shown in Figure 16 to make five sentences that help to explain how the character of this drainage basin led to the flooding in 2004.
b) Use the OS map to find five different grid squares which provide evidence for your five sentences. For example, you could choose 0989 to match with 'upland areas are very close to Boscastle … so …'
c) Using Figure 14 as a simple outline, draw your own sketch map of the drainage basin of the River Valency. Add your five statements to appropriate places on the map as annotations.

How should rivers be managed?

In the UK it is the responsibility of the Environment Agency to warn people about flood hazards and to reduce the risk of both river and coastal floods. They estimate that in England and Wales around 5 million people live in areas that are at risk of flooding.

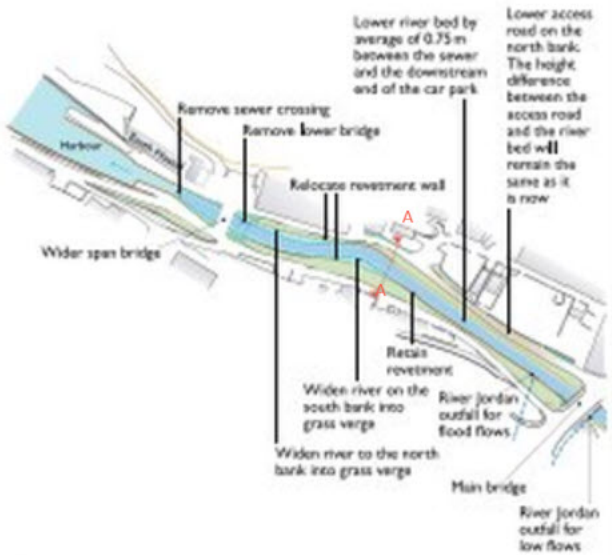
How has the River Valency been managed since the 2004 flood?

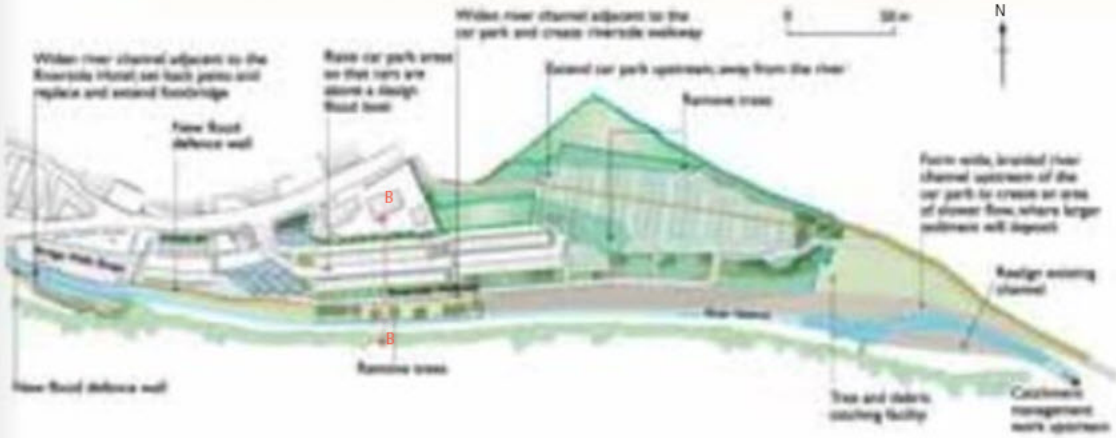
After the flood of 2004, the Environment Agency was responsible for designing a flood defence scheme for Boscastle. The defences cost £4.6 million and took two years to complete (2006–8). Many of the important features of this scheme are shown in Figure 18. One of the main features has been to widen and deepen the river channel so that it can carry more water. Making this kind of physical alteration to the river channel is known as **hard engineering**. It involves artificially controlling the course of the river.

Engineers were aware that during the flood, the road and foot bridges in the town became blocked by large branches that had been washed downstream. They decided to deepen the river bed under the main bridge and to replace the other two bridges with new structures. These new bridges have much wider spans so it is more difficult for them to become blocked with debris.

The National Trust owns a large part of the lower section of the valley of the Valency. In the past, the river was straightened and dredged so that its water could be used to power water mills. The National Trust and Environment Agency are now restoring parts of the river to take on a more natural form. For example, just before it enters the town the river has been given a wider, shallow channel. This should slow the flow of water and encourage deposition of gravel in a natural **braided** pattern. During another large flood, this 'natural' section of river would help trap boulders and other load before it entered the town where it could cause damage. Using the natural features of a river in this way is known as **soft engineering**.

▲ **Figure 17** The section of river between the main bridge and the harbour has been lowered by 75 cm. The river has also been widened.





▲ **Figure 18** A plan of the Boscastle flood defences designed by the Environment Agency and built 2006–8.

◄ **Figure 19** Workmen using a JCB to dig out the rocky bed of the river under the main bridge during 2007.

◄ **Figure 20** One of the new footbridges and a view east along the widened river. The car park is behind the building in the left of the photo.

Activities

1. Use Figure 18 to describe the flow of the River Valency through Boscastle.
2. Use Figure 18 to explain why the Bridge Walk shops were at risk during the 2004 flood.
3. Explain how each of the following features shown in Figure 18 will reduce the risk of future floods:
   a) lowering the river bed
   b) widening the river channel
   c) removal of trees next to the river
   d) replacing two of the bridges with wider spans.
4. Use Figures 17–20 to give examples of different types of:
   a) hard engineering
   b) soft engineering.

The distinctive landscape of the Somerset Levels

The Somerset Levels is a distinctive flat landscape covering 250 square miles. The Levels are only 8 m above sea level and much of this landscape would be flooded twice a month by high spring tides if it wasn't for flood defences at the coast. The Romans built flood defences and they dug ditches to improve the drainage. Over the years, rivers have been dredged and water pumped out, changing the wetland into productive farmland used for livestock and arable crops. Some wetland remains and is conserved as nature reserves. The flat land of the Somerset Levels is vulnerable to:

- coastal flooding by high tides and storm surges, for example in 1919
- river flooding after prolonged periods of rain, for example in 2014.

What caused the 2014 floods?

High rainfall totals over the winter of 2013–14 saturated the soils with water. More rainfall during January and February 2014 ran overland into the already flooded rivers. At each high tide, the rivers backed up because flood water couldn't escape quickly into the Bristol Channel. Local people claimed that the rivers and drainage ditches of the Levels hadn't been cleared of silt and mud since the 1990s. This reduced the capacity of the river channels to hold water. Overhanging trees slowed down the rivers' discharge.

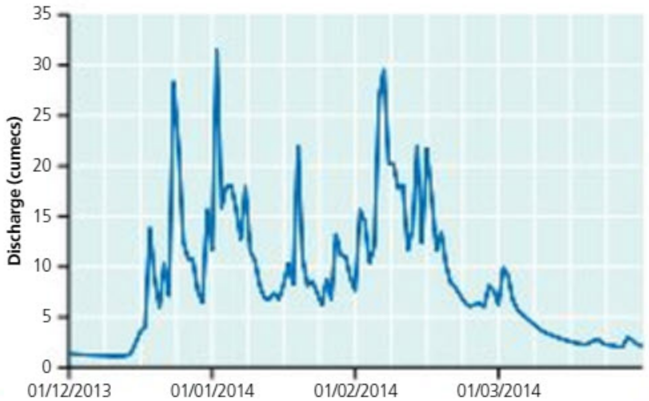
▲ **Figure 21** Map showing the location of the Somerset Levels and the flooding of 2014.

www.metoffice.gov.uk/public/weather/climate-historic/#?tab=climateHistoric

This website gives access to historic weather data from 40 weather stations across the UK including Yeovilton in Somerset.

http://nrfa.ceh.ac.uk

This is the National River Flow Archive. You can view and download discharge data for many UK rivers. Use this data to create hydrographs like Figure 22.



◀ **Figure 22** Discharge in the River Tone at Bishops Hull (December 2013 to end March 2014).

Activity

1 Use Figure 21 to:
   a) Describe the drainage patterns in the Somerset Levels
   b) Estimate the proportion of the Levels that were flooded in 2014.

Year	Tidal/ coastal	River
1885	✓	
1919	✓	
1968		✓
1981	✓	
1990	✓	
2005		✓
2007		✓
2008		✓
2012		✓
2014		✓

▲ **Figure 23** Historic flood events in the Somerset Levels.

Year	Month	Precipitation (mm)
2013	Jun	25.7
	Jul	40.4
	Aug	15.2
	Sep	67.6
	Oct	115.8
	Nov	42.9
	Dec	121.4
2014	Jan	166.4
	Feb	131.2
	Mar	38.4
	Apr	62.2
	May	59.6
	Jun	79.0
	Jul	56.8
	Aug	74.6
	Sep	3.2
	Oct	99.8
	Nov	108.0
	Dec	34.8
2015	Jan	75.4
	Feb	41.8
	Mar	22.0
	Apr	25.8
	May	55.2

▲ **Figure 24** Monthly precipitation totals at Yeovilton (2013–15).

▲ **Figure 25** Large areas of the Somerset Levels were under water for weeks in 2014.

Activities

2 a) Explain why the 2014 floods happened. You should be able to identify physical and human factors.
   b) Study Figure 23. What is happening to the frequency of floods in the Levels?
   c) Suggest two different reasons that might explain this frequency pattern.

3 Use Figure 22 to describe the discharge pattern of the River Tone.

4 a) Draw a graph to represent the monthly precipitation patterns at Yeovilton shown in Figure 24.
   b) How unusual was the rainfall pattern during the period November 2013 to February 2014?
   c) Compare your completed graph to Figure 22. Use these two graphs and your understanding of tidal movements to suggest reasons for the peaks in discharge.

Enquiry

Analyse winter discharge patterns of rivers in the Somerset Levels. Use the National River Flow Archive website for your investigation. How do patterns in the last winter compare to Figure 22? Suggest reasons for any similarities or differences.

How should we react to the Somerset floods?

During January and February 2014, the local authorities, Environment Agency and UK Government reacted to protect people from the floods. The immediate responses to the flooding were:

- Thirteen large pumps from Holland were used to remove 7.3 million tonnes of water per day from the flood plain. The pumps worked day and night for six weeks. The fuel to run the pumps cost £1.5 million.
- Residents of flood-damaged homes were given emergency help and insurance advice.
- Teams were brought in to start emergency repairs to infrastructure such as rail and road networks, electricity supplies, telephone systems and sewers.
- Livestock was rescued and moved to other areas.

In mid-2014 the UK Government announced a £100 million recovery programme for the Somerset Levels. The aims of the Somerset Levels and Moors Flood Action Plan are shown in Figure 27.

▲ **Figure 26** Pumps from Holland were used to pump water back into Somerset's rivers from the floodplain.

The Somerset Levels and Moors Flood Action Plan

Medium-term aims – up to 2020

- A dredging operation on the Rivers Parrett and Tone costing £6 million.
- Embankments will be built around vulnerable villages. £180,000 was spent protecting the ten houses in Thorney. Ten other sites will be identified and protected by the year 2020.
- Raising the height of the A372 road and repairing 44 km of damaged roads.
- Better preparation and planning to protect residents and business owners. Ideas such as stored sand bags, knowledge of the location of vulnerable people, emergency livestock movement and improved communication systems would be developed.

Longer-term aims – up to 2035

- Building a flood barrier at Bridgwater by 2024. The estimated cost is £32 million. This would reduce the impact of high tides that prevent flood water from escaping from the Levels.
- Investigate the costs and benefits of building a £16 million flood storage scheme upstream from Taunton. This would capture and hold back rainwater from draining into the River Tone. A large-scale tree-planting programme in the upper catchment would be part of this scheme.

▲ **Figure 27** The Somerset Levels and Moors Flood Action Plan.

▶ **Figure 28** Dredging and bank stabilisation on the River Parrett.

Factfile: Impacts of the floods

- Half of all businesses in Somerset were affected either directly or indirectly by flooding.
- Damage to residential property cost up to £20 million.
- Costs to local government, the police and rescue services totalled £19 million.
- The rail line between Taunton and Bridgewater was closed for four weeks, costing the local economy £21 million.
- Over 80 roads were submerged for weeks with a cost of £15 million to the local economy.

Activities

1 Draw and label a sequence of simple cross-sectional diagrams to show how dredging of the rivers would make them more efficient and reduce the risk of flooding.
2 Evaluate the arguments for and against continued dredging of rivers in the Levels.
3 Use the information on pages 132–3 to analyse the Somerset Levels and Moors Flood Action Plan. Do this by completing a table like the one below:

	Advantages	Disadvantages
Economic		
Social		
Environmental		

Enquiry

Who should pay for the Somerset Levels and Moors Flood Action Plan? Discuss the responsibility of the following groups before making your recommendation:

- Those directly affected by flooding.
- All the residents of Somerset.
- The tax payers of the UK.

Our computer models suggest that the dredging programme will make the rivers 90% effective in flushing out flood water. Currently the silt build up since 2009 makes them only 60% efficient.

Ashley Gibson, Somerset Water Management Partnership

I would urge the authorities not to take dramatic action until they have considered the impact of climate change and sea level rise. A 12 cm rise in sea level could easily make the proposed Bridgwater barrage a waste of money.

Lord Krebs, Climate expert

Part of the blame must be down to the Environment Agency. Why on earth did they cut back on the dredging programme in the first place?

Ian Liddell-Grainger, MP

I object to paying an extra £25 a year in local taxes to fund flood prevention. The council should not allow building on flood plains. I have heard that over 900 homes have been built on vulnerable land in Somerset since 2001.

Resident of Glastonbury not affected by the flood

Dredging has an impact on the habitat in and around the river. The fish are severely disturbed during dredging and the water is murky for days after. Reed beds alongside the river are ripped up so birds and small mammals lose habitat.

Royal Society for the Protection of Birds

The Environment Agency are taking a lot of the blame for reducing the dredging programme in recent years but government cutbacks in public spending required them to lose 1,700 jobs. We can't have it all ways.

Western Morning News

It would have been cheaper to maintain the rivers properly instead of cutting back the dredging process in 2009. The clean-up and all the repairs will cost the tax payer millions.

National Farmers Union

We must allow the rivers to flood naturally. Some of the wetland habitats are unique. Sometimes nature needs to come before economics and people.

The Somerset Wildlife Trust

▲ **Figure 29** Different views from stakeholders on what should be done.

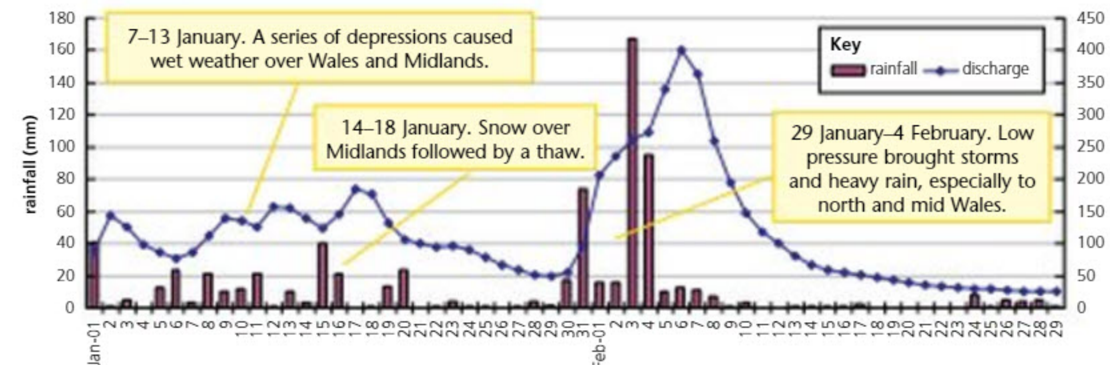
How is the River Severn managed?

The River Severn is Britain's longest river. A serious flood in 2000 prompted flood defences to be built at Frankwell, Shrewsbury. These included earth embankments, concrete flood walls and demountable flood barriers. These flood defences were completed in 2004 at a cost of £4.6 million. The demountable barriers (seen in Figure 30) are made of aluminium panels. They can be slotted together before the flood arrives. The demountable barriers successfully held back 1.9 metres of flood water during a flood in February 2004 and 74 properties were protected. But not everywhere is protected. Land uses in Shrewsbury have been zoned. Land uses that have a low value, such as car parks and playing fields, are not protected. These zones provide safe areas for water to be 'stored' during a flood event, as shown in Figure 30.

▲ **Figure 30** A total length of 700 m of flood embankments and walls has been built where the river enters the town to prevent floods in Shrewsbury. A further 155 m of river bank is protected using demountable defences.

▲ **Figure 31** Guildhall and Frankwell car park, SY3 8HQ, the same location as shown in Figure 30.

◀ **Figure 32** Historic floods (2000–15) on the River Severn.



▲ **Figure 33** Flood hydrograph for the River Severn at Bewdley (January–February 2004). Rainfall data is for Capel Curig, North Wales.

Activities

1. Describe the course of the River Severn.
2. Suggest why planners might prevent the building of new homes on the flood plain of the River Severn.
3. Suggest why local residents might prefer demountable barriers to walls and embankments.
4. Explain why flood zoning is used in Shrewsbury. Consider the economic and environmental benefits.

Enquiry

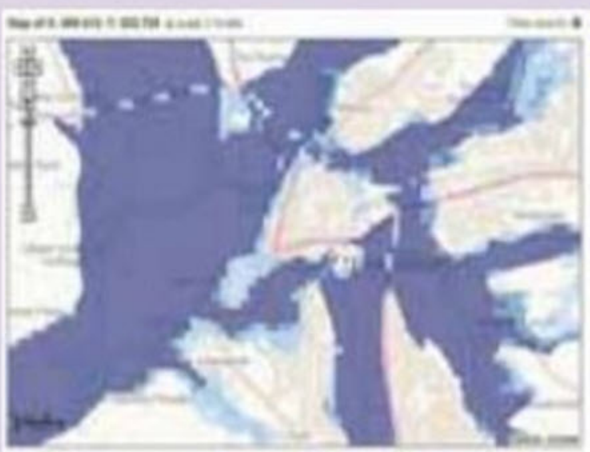
How do weather events affect seasonal flood patterns?

a) Carefully describe the shape of the flood hydrograph between 29 January and 29 February. Use Figure 10 on page 124 to help your description.
b) Describe how each of the three weather events described in the labels affected the flow of the river. Focus on the time lag as well as the gradient of each rising limb.
c) Suggest how the Environment Agency uses rainfall data from Wales to warn householders in Bewdley about future flood events.

Virtual Preparation for your fieldwork enquiry?

The starting point for every good enquiry is a good enquiry question or hypothesis. In order to ask the most useful and searching questions, you need to do some preparation – ideally by exploring your study area in a virtual environment before the fieldtrip. Google Street View is often a good place to start. If you are investigating communities that are vulnerable to river flooding, then Street View will allow you to explore the area and identify different land uses close to the river. It should help raise some questions in your mind, such as what land uses are common close to the river? A virtual visit will help you prepare for your sampling strategy too by helping to identify accessible sites.

The Environment Agency operates a simple geographic information system (GIS) that shows flood hazards in both river and coastal communities. Follow the Weblink below and click on 'Find out if you're at risk' within the 'Prepare for a flood' section. You can now search the atlas using postcodes. You could use this site to prepare for an enquiry into flood hazards.



www.gov.uk/check-if-youre-at-risk-of-flooding
The Environment Agency GIS that shows flood hazards

◀ **Figure 34** A screenshot for the Environment Agency flood maps GIS. It shows that central Tewkesbury is at risk of being surrounded by water from the rivers Avon and Severn during a flood.

Activity

1 Discuss the following questions. All are possible starting points for an enquiry into flood risk.
   a) How would you go about answering each question?
   b) Which question might create the most interesting and useful enquiry? Justify your choice.
      - How often does the river flood here?
      - How many homes are at risk of flooding?
      - How is land used in the flood risk zone?
      - What is the relationship between land use and frequency of flooding?

Enquiry

How vulnerable to flooding are different towns along the River Severn?

Use the following postcodes to examine the flood risk to towns along the River Severn (the postcodes are in order, going from source to mouth):

SY16 2LN SY21 7DG SY3 8HQ
DY12 2AE GL20 5AP

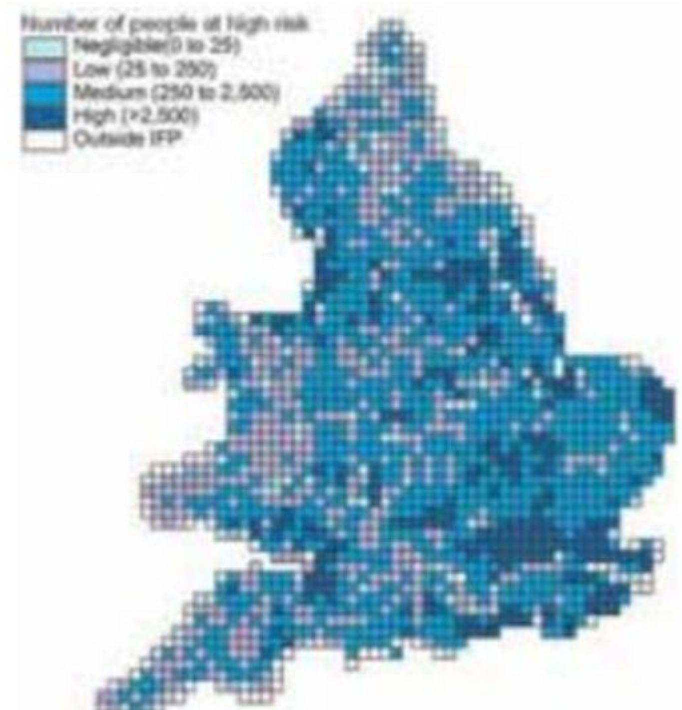
a) For each town identify:
   i) the extent (area) that is at risk
   ii) which main roads are at risk of flooding
   iii) whether residential areas are at risk or not
   iv) whether the town has any flood defences.

b) Based on your findings, suggest which of these towns most needs new flood defences.

Should we change our approach to river and floodplain management in the future?

In 2004, the UK Government commissioned a scientific report on the future of river and coastal floods in the UK. The scientists considered how climate change and growing populations might affect the risk of flooding by the year 2080. The main findings of the 'Foresight Report' are:

- The number of people at high risk of flooding could rise from 1.5 million to 3.5 million.
- The economic cost of flood damage will rise. At the moment flooding costs the UK £1 billion a year. By 2080 it could cost as much as £27 billion.
- One of the main causes of the extra flood risk is climate change. The UK's climate is likely to become stormier with more frequent heavy rain. Sea level rises will increase the risk of coastal floods.
- About 10 per cent of the UK's housing is already built on the floodplains of rivers and these homes are at risk of river floods. Hundreds of thousands of new houses will be built in the next 20 years and many of these could also be at risk.
- River floods could cause massive health risks if the flood water contains untreated sewage or chemicals that have been washed off farm land.
- Towns and cities will be at risk of flash floods, even if they are not built near a river. Drains that are supposed to carry away rainwater will not be able to cope with sudden downpours of rain. This kind of flooding could affect as many as 710,000 people.



▲ **Figure 35** Number of people at risk of river and coastal floods in 2080, assuming that carbon dioxide emissions remain high.

Activities

1 Use Figure 35 to describe the distribution of areas where there are high numbers of people at risk of flooding.
2 Outline how future floods are likely to affect people living:
   a) in coastal areas
   b) close to rivers
   c) in towns and cities.
3 What are the main reasons for extra flood hazards in the future?

What should be done to reduce the risk of future floods?

Householders should be encouraged not to pave over their gardens. Paving and tarmac are impermeable. Rainwater goes straight down into storm drains and into the river rather than soaking slowly into the soil. Advice needs to be given so that gravel and permeable surfaces are used instead of tarmac. We also need to replace old storm drains which are too old and small to cope with heavy rain storms. However, motorists won't like that because it will mean digging up urban roads!

Planner

The scientists who wrote the 'Futures Report' into flooding identified that poor land management had increased the risk of river floods. For example, over the last 50 years farmers in upland areas of England and Wales have added drains to their fields to improve the amount of grass that can be grown. However, these field drains have had an effect on the flow of rivers further downstream. We are involved in a scheme to restore the old peat bogs in upland Wales. Between 2006 and 2011 we are going to block a total of 90 km of old land drains on the hills close to Lake Vyrnwy. We are using bales made from heather to block the drains. This will slow down the overland flow and force water to soak back into the soil. Not only will this help reduce the risk of floods but it will also improve the moorland ecosystem and will help to protect rare birds of prey like the merlin and hen harrier.

Spokesperson for RSPB

Hard engineering schemes, like the flood walls and embankments in Shrewsbury, speed up the flow of water. These schemes may funnel water along to the next community living further downstream and actually increase their risk of flooding. What we need to do is to return river valleys to a more natural state. We should use floodplains as temporary water stores so that flooding can occur away from built-up areas.

River scientist

Homes can be made more flood proof with measures such as putting plug sockets higher up the walls and replacing wooden floors and carpets with tiles.

House builder

I'm really pleased with the new flood defences. My property has flooded in the past but was protected during 2007. The Shrewsbury flood defence scheme cost £4.6 million but I think it was worth it.

Resident in Shrewsbury

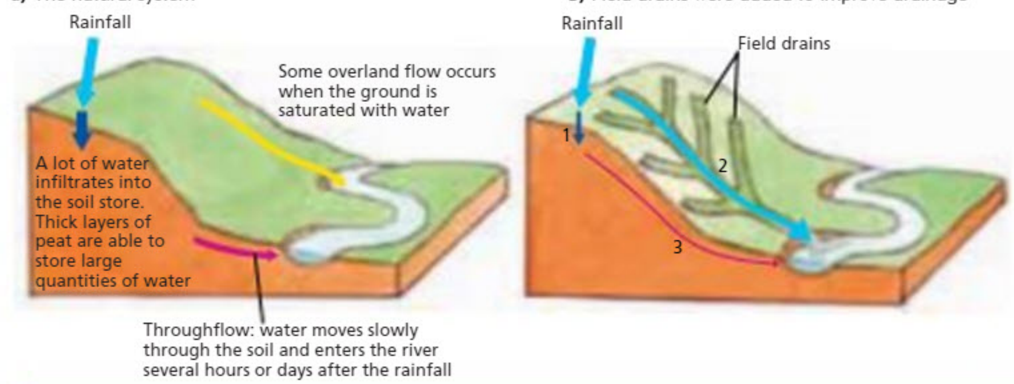
We need to build an extra 3 million homes in the UK by 2020. Almost half of them are in the Midlands and the south of England which are the same areas hit by flooding in 2007. Some of these houses will have to be built on greenfield sites. However, we should restrict building on floodplains in the future.

Government housing minister

▲ **Figure 36** Alternative points of view on solving the flood problem.

▼ **Figure 37** The movement of water through upland drainage basins in mid Wales was altered when field drains were added. The size of the arrows is in proportion to the amount of each flow.

a) The natural system **b)** Field drains were added to improve drainage



Activity

1 Study Figure 37.
 a) Make a copy of the second diagram.
 b) Add labels that explain water flows at 1, 2 and 3.
 c) Explain how the differences in the two diagrams would affect the flow of water in the river downstream.

Enquiry

You have been asked to advise Tewkesbury Council on flood prevention. What do you think should be done to prevent future floods in the town?

a) Use what you have learned in this chapter, and the points of view in Figure 36 to complete a copy of the table.

Possible solution	Short-term benefits and problems	Long-term benefits and problems	Who might agree and disagree with this solution
Building flood defences like those in Shrewsbury			
Restoring bogs and moorland in mid Wales by blocking drains			
Tighter controls on building on floodplains and paving over gardens			
Allowing rivers to flow naturally and spill over onto the floodplain			

b) Now you need to recommend your plan. What do you think should be done and why do you think your plan will work? Use the following table to plan your answer.

Key questions to ask yourself	My answers
Is my plan realistic and achievable?	
Which groups of people will benefit from my plan?	
How will the environment be affected?	
Why is this plan better than the alternatives?	

Investigating the impacts of flooding

It's not safe to do fieldwork during a river flood. However, it is possible to do fieldwork in an environment that is at risk of flooding – as long as the fieldwork is done when the river is in low flow conditions. Your fieldwork enquiry might try to assess flood risk, or the impacts of flooding, by posing a question like one in the box below.

Which areas of this town are at the greatest flood risk?

What might be the social, environmental and economic impacts of a flood here?

Does this town need better flood protection?

Designing your enquiry

Imagine you are about to investigate the risk of flooding – somewhere like Shrewsbury in Figure 38. This site is at risk of flooding because it is located next to the river and there are no flood defences here.

You will need to collect data from at a number of different survey sites. First, you will need to record the distance (from the river) and height (above the river bank) of each site. You may be able to use an app on your phone to do this – alternatively you can use a large-scale OS map. Before you begin, you will need to design data collection sheets so that data is recorded in the same way at each site. Your data collection sheet will be easier to use if it contains closed questions (see page 46) and boxes that you can tick. Study Figure 38 carefully. Apart from distance and height, what other data do you think you could collect?

▲ **Figure 38** Questions to ask yourself when investigating flood risk. The photograph shows a car park in Shrewsbury that is next to the River Severn.

Activity

1 a) Discuss the questions posed around Figure 38. Add three more questions that could be investigated during fieldwork into flood risk.

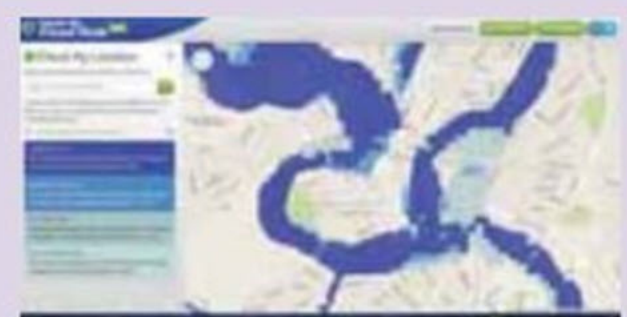
b) Use Figure 38 to design a data collection sheet. Think about how you might record each of the following using closed questions and ticked boxes:
- land use
- population density
- habitats
- vulnerable groups of people

Using GIS to identify flood-prone areas

Figure 40 is a screenshot from a website which uses information from the Environment Agency to identify flood-prone locations. The blue shading varies from high risk (shown in darker blue) to very low risk (shown in very pale blue). In order to carry out an enquiry into flood risks in an urban area like Shrewsbury, you would collect data along transects. Each transect would begin at the edge of the river and move through areas of decreasing flood risk. In Shrewsbury, transects of 300 m would be long enough to cross a range of risk levels. Ideally, the transects should be straight, but will have to follow roads and pathways in built-up areas. Stop and record information every 25 m along the transect route.

Location	Postcode	Description
Dingle Gardens	SY1 1JL	Public open space and ornamental gardens
Coleham Primary School	SY3 7EN	A primary school for around 400 children
Shrewsbury Abbey	SY2 6BA	A historic building. There has been a church on this site since 1083
Asda, Shrewsbury	SY3 7ET	A large supermarket
Frankwell Quay car park	SY3 8HQ	A large car park close to the town centre
Greenhous West Mid Showground	SY1 2PF	A flat open space that is used for agricultural shows, antique fairs and car boot sales
Travis Perkins	SY1 2PP	A large shop selling building materials

▲ **Figure 39** How many of these locations in Shrewsbury are at risk of flooding? What might the impact of a flood be at each location?



▲ **Figure 40** Screenshot from the checkmyfloodrisk website showing a flood risk map of Shrewsbury.

www.checkmyfloodrisk.co.uk

This site displays flood risk information provided by the Environment Agency.

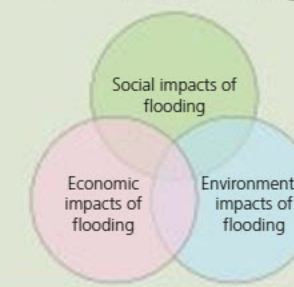
Activity

2 Imagine your local town is flooded.

a) Write a list of all the possible impacts of the flood. Think about the different stakeholders: property owners, tenants, schools, businesses, customers, commuters, and how each would be affected.

b) Draw a large Venn diagram with three circles like the one shown below. Work with a partner to fit the impacts on your list into the diagram.

c) Classify your list of impacts as short-term, medium-term or long-term.



Enquiry

Which parts of Shrewsbury are at risk of flooding?

Use www.checkmyfloodrisk.co.uk to search the postcodes in Figure 39. For each site:

a) Is the site at risk of flooding? If so, what is the level of risk?

b) What might the impact of a flood be at each location? Does this site contain land uses or groups of people who are particularly vulnerable to flooding?

Using GIS to process flood enquiry data

Step 1 Be safe. Do not go near the river if there is immediate risk of flooding.

Step 2 Decide what information to collect and what scores to use. Figure 41 shows an example of a data collection sheet.

Step 3 Stop at each survey site, every 25 m along the transect, and record:

a) The latitude and longitude and the altitude of the site (using your phone app).

b) A score (out of 10) for each possible impact of a flood.

Step 4 Total the mark (out of 30 in this example) for the social, environmental and economic impacts at each site.

Transect 1 Location .... Altitude .... Latitude .... Longitude					
Social impact		Environmental impact		Economic impact	
Number of people affected		Pollutants entering environment		Type of economic activity	
Many	10	Toxic/hazardous	10	Large retail	10
Some	5	Some pollution	5	Small retail	5
None	0	None	0	None	0
Vulnerability of people affected (e.g. elderly, children)		Destruction of/damage to habitats		Number of people employed	
Many vulnerable groups affected	10	Many habitats affected	10	Many people (30+)	10
Some vulnerable groups affected	5	Some habitats affected	5	Some (1–30)	5
None	0	Few habitats affected	0	None	0
Disruption to community life (e.g. schools/health services)		Damage to built environment		Level of impact on business	
Vital service affected	10	Historic buildings affected	10	Complete shutdown	10
Non-vital service affected	5	Modern buildings affected	5	Some activities continue	5
None	0	None	0	None	0
Total social impact score		Total environmental impact score		Total economic impact score	

▲ **Figure 41** Example data collection sheet.

Transect and Location	Latitude	Longitude	Altitude	Total social impact Score	Total environmental impact Score	Total economic impact Score

▲ **Figure 42** Table to collate results.

Activity

1 a) Use Figure 41 to score the impacts of a flood on some places you know well, for example, your school, the street you live in, some buildings in your local town centre.

b) Compare your scores with that of a friend for the same places. How do they compare?

c) If you have different scores, you will have to explain how you decided on that score. Try and convince them why your score is the right one, but be prepared to compromise!

Representing data using GIS

Step 1 Collate your results in a spreadsheet. Once you have input all your data, including latitude and longitude, save it as a .csv file.

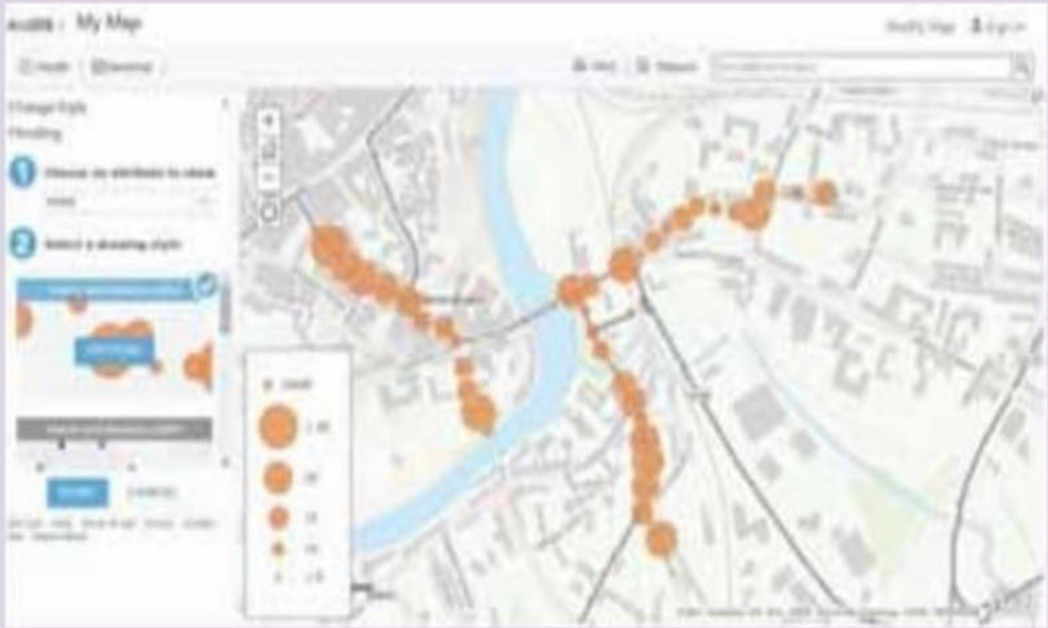
Step 2 In your internet browser, visit ArcGIS Online and click on 'MAP' at the top of the screen.

When ArcGIS Online is showing the map, drag and drop the .csv file onto the map. The GIS will automatically recognise the latitude and longitude data and locate your data on the map. The GIS will also select one category (shown as an 'attribute' in ArcGIS) from the data set and present that data using located proportional circles (see Figure 43).

Step 3 The category or drawing style can be changed on the menu on the left of the screen (see Figure 43).

- Change category being displayed using (1) Chose an attribute to show.
- Change the way in which the data is displayed using (2) Select a drawing style.

Step 4 Click on 'Done'. The menu on the left-hand side of the screen will change. Clicking on any of the data points on the map will display a pop-up box displaying all of the data collected at that point.



▲ **Figure 43** Screenshot of the ArcGIS Online map showing social impact scores.

www.arcgis.com

ArcGIS online is a cloud-based GIS platform where you can view existing data and add your own content. Your school will need to subscribe to the site before you can use it.

Enquiry

Use www.checkmyfloodrisk.co.uk to identify a local area at risk of flooding. Choose the location for your transects and identify the social, environmental and economic impact data you wish to record. Carry out the fieldwork enquiry and record the information in a .csv file. Upload onto www.arcgis.com and add the Environmental Agency Flood Risk layer.

a) Where are areas of highest/lowest impact?

b) Consider the following statement: 'The economic impacts of flooding are always the most significant.'

Use your data to discuss the validity of this statement. Remember to justify your answer.

How do waves erode our coastal landscapes?

Waves provide the force that shapes our coastline. Waves are created by friction between wind and the surface of the sea. Stronger winds make bigger waves. Large waves also need time and space in which to develop. So, large waves need the wind to blow for a long time over a large surface area of water. The distance over which a wave has developed is known as **fetch**, so the largest waves need strong winds and a long fetch.

The water in a wave moves in a circular motion. A lot of energy is spent moving the water up and down. So waves in deep water have little energy to erode a coastline. However, as a wave enters shallow water, it is slowed by friction with the sea bed. The water at the surface, however, surges forward freely. It is this forward motion of the breaking wave that causes the erosional processes described in Figure 3.

Activity

1 Make a copy of Figure 1 and add the following labels in appropriate places.
- Waves in deeper water
- Circular motion
- Breaking wave
- Water thrown forward
- Friction with the sea bed.

▲ **Figure 1** The motion of water in a wave.

The repeated pounding of large waves at the foot of a cliff can cause enormous damage through the process of hydraulic action and abrasion. The repeated hammering effect of the waves on this narrow zone creates a **wave-cut notch**. Cliffs that are already weakened by joints or cracks can suddenly collapse in a rock fall which is a type of **mass movement**. The collapse causes the line of the cliffs to **retreat** inland. The **wave-cut platform** in Figure 2 has been formed by the gradual retreat of the cliffs.

▶ **Figure 2** The rocky wave-cut platform of the Glamorgan Heritage Coast.

Erosional processes

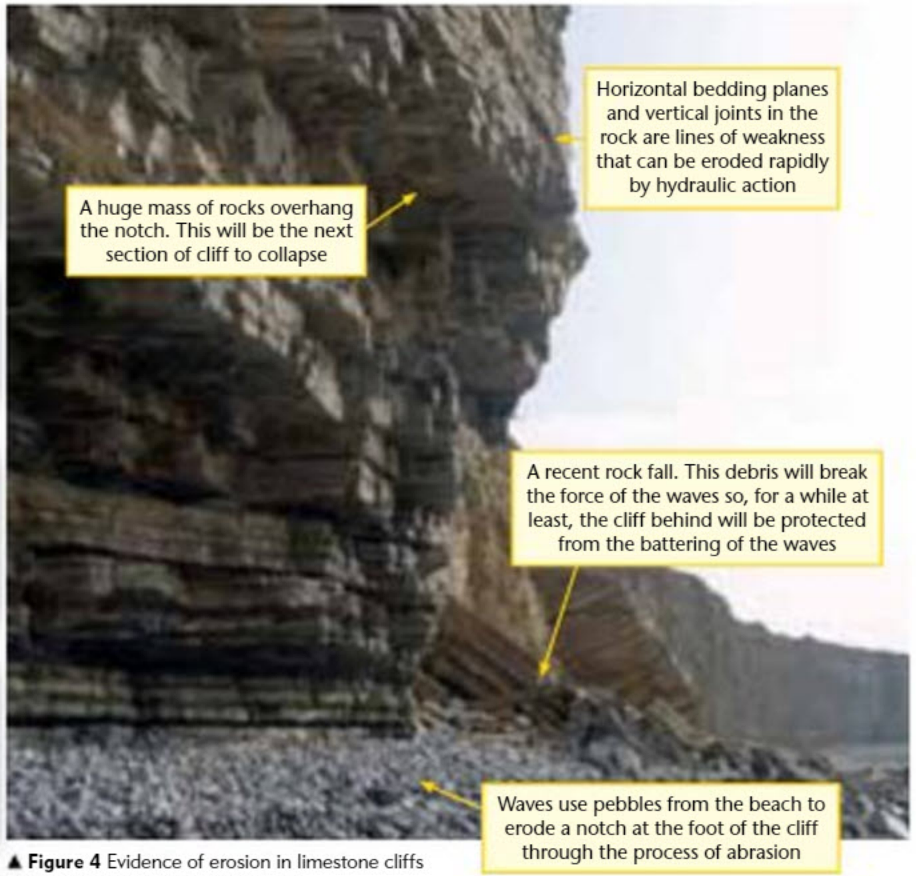
Hydraulic action – waves crash against the cliff, compressing the water and air into cracks and forcing the rocks apart.

Abrasion – waves pick up rocks from the sea bed or beach and smash them against the cliffs.

Corrosion – minerals such as calcium carbonate (the main part of chalk and limestone rocks) are slowly dissolved in sea water.

Attrition – sand and pebbles are picked up by the sea and smash against one another, wearing them down into smaller and more rounded particles.

▲ **Figure 3** Four processes of coastal erosion.



▲ **Figure 4** Evidence of erosion in limestone cliffs on the Glamorgan Heritage Coast.

Activities

2 Study Figures 2 and 3.
  a) Use the correct erosion terms to complete the annotations below.
  - Joints in the rock are widened in the process of .... which is when ....
  - Boulders on the beach are rounded because ....
  - This pothole has been scoured into the rock by ....

  b) Make a simple sketch of Figure 2 and add your annotations (above) to the sketch.

3 Consider Figure 4 and its annotations.
  a) Write a list (or draw a timeline) that puts the events acting on this cliff in the correct sequence.
  b) Make another list (or timeline) suggesting what will happen to this cliff in the next few years.
  c) Over the next 100 years this coastline will retreat by about 20–40 metres. Draw a story-board to show how this process of retreat creates the rocky wave-cut platform in front of the cliff.

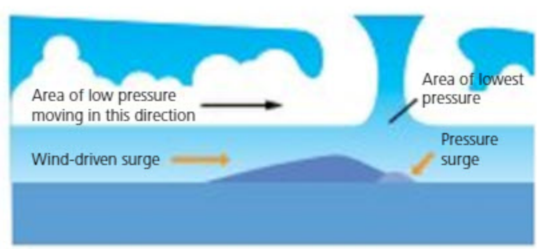
Erosion and coastal flooding during extreme weather events

During the winter of 2013–14, several low pressure systems rolled over the UK, bringing wind and rain. The storms caused flooding in many areas of the UK, including Somerset. High winds and waves battered the UK coastline. Erosion is more rapid during these extreme weather events, as you can see in Figure 5.

The storm surge of December 2013

Low pressure in the atmosphere has the effect of raising sea levels. When air pressure falls by 1 millibar (mb), sea levels rise by 1 cm. So, a deep depression of 960 mb will cause sea levels to rise by 50 cm. Strong winds create large waves that are pushed in front of an advancing area of low pressure, creating even higher water levels. This effect is known as a **storm surge**, and is shown in Figure 6.

▲ **Figure 5** Rapid coastal erosion of the cliffs at Hemsby, during the 2013 storm, caused the collapse of seven homes.



▲ **Figure 6** Storm surge due to low pressure.

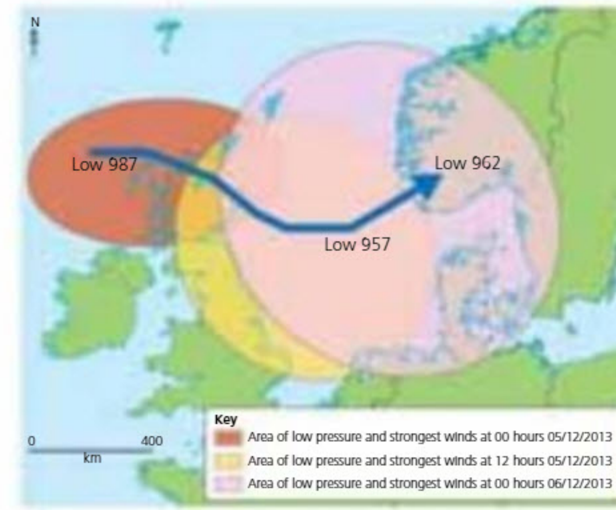
1,000 sandbags were distributed to home-owners in Aldeburgh, Suffolk.	In the Humber region, 400 homes were affected by flood water.
Seven houses were destroyed in Hemsby, Norfolk when the cliff beneath them collapsed into the sea.	In Great Yarmouth, Norfolk, residents of 9,000 homes were advised to evacuate overnight.
The sea wall was breached at Jaywick, Essex. Firefighters and 10 rescue boats helped to evacuate 2,500 homes.	Boston, Lincolnshire was flooded; 223 people were evacuated from their homes.
In Kent, 200 homes were evacuated in Faversham and another 70 in Seasalter.	The sea wall at Scarborough, Yorkshire, was damaged.

▲ **Figure 7** The locations affected by the 2013 storm surge.

If a storm approaches the coast at high tide, an event that happens twice a day, then the risk of flooding is increased. The UK's North Sea coastline is particularly vulnerable to storm surges. The southern part of this sea is shallow and shaped like a funnel. When low pressure travels southwards across the North Sea, the bulge of the storm surge can increase in height as water is forced through this shallow funnel.

During December 2013, coastal communities along the North Sea coast faced the worst storm surge since 1953. Some of its effects are shown in the Figures 5 and 7. Nevertheless, the Environment Agency said 800,000 homes had been protected by:

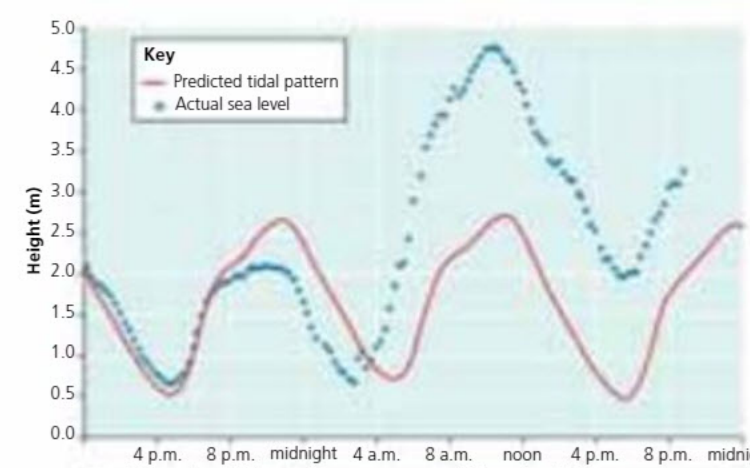
- accurate weather forecasts that gave time for people to evacuate their homes
- coastal defences that held back some of the storm surge.



▲ **Figure 8** The course of the December 2013 North Sea storm.

Activities

1. Explain why the shape of the North Sea increases the risk of storm surges in Essex, Kent and the Thames Gateway areas.
2. a) Make a sketch map of Figure 7.
   b) Use an atlas to add the eight labels describing the effects of the storm surge to the correct locations on your sketch.
3. Use Figure 8 to describe the location of areas affected by the storm as it moved across the UK.
4. Analyse Figure 9.
   a) At what times was high tide expected on 5 December?
   b) At what time did the storm surge reach Lowestoft?
   c) How much higher was the storm surge than the expected height of high tide?



▲ **Figure 9** Sea levels at Lowestoft, Suffolk, during the storm surge.

Enquiry

How did the 2013 storm surge compare to the 1953 event?

Use the internet to research the main causes and effects of the 1953 North Sea storm surge.

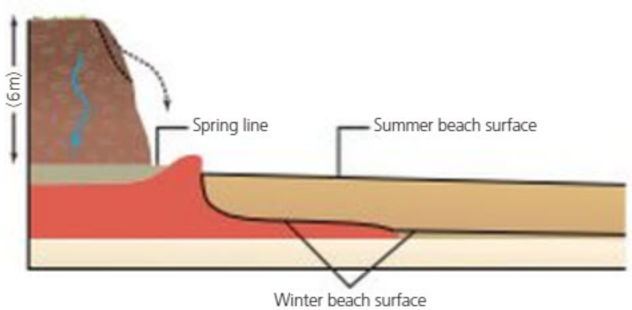
a) Compare the causes.
b) Compare the effects.

How are coastal processes affected by geology?

On a map, the blue line showing the coastline of the UK looks like a fixed and permanent feature. In reality, beaches and estuaries are a constantly changing environment as the tide moves in and out. Even solid cliffs can suddenly collapse when they are battered by storms like the one in December 2013.

Coastal retreat is particularly rapid on some sections of the North Sea coast of England. In the East Riding of Yorkshire, cliffs are retreating at an average of 2 metres per year. This is due to geology. The cliffs here, and in North Norfolk, are made of layers of sand, silt and clay deposited at the end of the ice age (see page 190). These young sedimentary rocks have not been compacted as much as older rocks and they are unconsolidated – which means the grains of sediment are not 'glued' together very well. This makes them much less resistant to erosion than older sedimentary rocks such as the carboniferous limestone cliffs seen in Figures 2 and 4 on page 144–5.

▲ **Figure 10** The extent of the ice sheet during the most recent glacial period. The UK's fastest rates of erosion are in the East Riding of Yorkshire and North Norfolk coastlines.



1. Rain water percolates through the cliff, increasing the mass of the slope and triggering landslides.

2. Water seeps out of the cliff at the spring line. The sands can slide over the clay above this bedding plane.

3. During winter, waves erode into the glacial till, undermining the toe of the slope.

▲ **Figure 11** Cross-section through the cliffs at Happisburgh, North Norfolk. These cliffs are made of loosely compacted layers of sand, silt and clay deposited at the end of the ice age.

Activities

1 Use Figure 10 to:
  a) Describe the extent of the ice sheet across the UK.
  b) Explain why parts of the UK's North Sea coast are vulnerable to erosion.

2 a) Make a copy of Figure 11.
  b) Add the annotations 1–3 to suitable places on your diagram.
  c) Use the diagram to explain why the rock type and structure of the cliffs at Happisburgh make them vulnerable to erosion and mass movement.

Figure 11 helps to explain why the cliffs at Happisburgh in Norfolk are not very resistant to erosion by waves. Once the toe of the slope has been eroded by the sea, the whole slope becomes unstable. It is then at risk of mass movement – a process by which the whole cliff face can slide or slump onto the beach. The chance of slumping is increased by periods of heavy rain which adds mass to the cliff. Rain water also erodes small V-shaped notches called **gulleys** in the upper slopes of the cliff.

After the 1953 storm surge, a lot of money was spent building better coastal defences along the North Sea coast, including at Happisburgh. However, the erosion here has continued and a succession of coastal defences has failed to protect the village at the top of the cliff. In 2009, a trial programme called Pathfinder offered £11 million to help 15 coastal communities cope with erosion by moving away from danger rather than build more coastal defences. The Happisburgh Pathfinder scheme is the largest, costing £3 million.

www.northnorfolk.org/pathfinder

This site describes the Pathfinder scheme in North Norfolk

▲ **Figure 12** The coastline at Happisburgh in 2011.

Activities

3 Historical records show that the cliffs here retreated by 250 m between 1600 and 1850. What is the average rate of erosion per year?

4 Read the following annotations and decide where they fit best on Figure 12.
  - Waves have eroded the toe of the cliff here
  - The vegetation on this slope proves that it hasn't slumped for several months
  - Concrete blocks on the beach may protect the cliff from wave erosion
  - Evidence of gulley erosion by rain water on these slopes.

Enquiry

How should we respond to erosion when it threatens villages like Happisburgh?

a) Use the Weblink to discover how the Pathfinder project works.
b) Debate whether any other actions would have been sustainable.

Cliff landforms in resistant rock types

We have seen that young sedimentary rocks such as those at Happisburgh have a weak structure which makes them vulnerable to erosion. By contrast, older sedimentary rocks are compacted and consolidated, meaning they are more resistant to erosion. Limestone coastlines, like those in Figure 13, tend to form almost vertical cliffs. However, bedding planes and joints in the rock are lines of weakness in these cliffs. These lines are more easily eroded than the massive blocks of stone in between them. Erosion along these lines can lead to the formation of caves, **sea arches** and **stacks**.

▲ **Figure 13** The Green Bridge of Wales, Pembrokeshire. A natural sea arch formed in a carboniferous limestone cliff.

Activities

1. a) Make a sketch of Figure 13.
   b) Label the following features on your sketch:
      - cave
      - bedding planes
      - sea arch
      - stack
2. Explain why, even though all of the rocks in Figure 13 are the same, the landscape is so varied.

▼ **Figure 14** Durdle Door, a natural arch, on the Jurassic coastline.

Enquiry

1. How might the landscape in Figure 13 evolve over time? Discuss how the processes of wave action and mass movement might affect this coastline. Draw a story-board to show how you expect it might change.
2. Interpret the landscape in Figures 14 and 16. How have geology, marine processes and mass movement made this landscape?

a) Make a sketch of Figure 14.
b) Write suitable labels and annotations for each of the boxes.

Headlands and bays on the Jurassic Coast

The Jurassic coastline of Dorset is made up of alternating bands of sandstone, limestone and clay. The sandstones and limestones are quite resistant to erosion and make tall, almost vertical cliffs. The clays are much more easily eroded. Figure 15 shows how these bands of rock lie parallel to the coast.

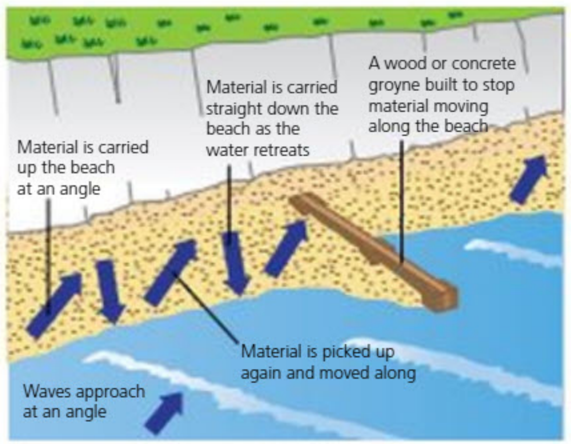
Where the sea has been able to erode a hole through the resistant limestone, it has then scoured out a shallow, rounded bay (known as a **cove**) in the much less resistant clays behind. This has created a very distinctive landscape of cliffs, arches and coves. Figure 15 shows an arch and Figure 16 shows a cove.

▲ **Figure 15** Alternating bands of chalk, Whealdon clay and Purbeck limestone in Dorset.

▲ **Figure 16** Man o'War Rocks and St Oswald's Bay on the Jurassic Coast near Lulworth.

Beach and sand dune processes

Beaches are dynamic environments. In other words, the energy of the wind and waves is constantly moving sediment around and changing the shape of the beach. Where the waves approach the beach at an angle, some of the sediment is transported along the coastline in a process known as **longshore drift**. However, most sediment is simply moved up and down the beach. Each wave transports sediment up the beach in the **swash** and back down again in the **backwash**. All of this movement uses a lot of the wave's energy, so a wide, thick beach is a good natural defence against coastal erosion.



▲ **Figure 17** Transport of sediment by the process of longshore drift.

▲ **Figure 18** The beach at Borth seen from the cliffs to the south of the pebble ridge.

The sand and pebbles on a beach usually come from the local environment. Neighbouring cliffs may supply some sediment if they are being actively eroded by wave action. A lot of finer silts and sands are transported to the coast by rivers. This sediment is then deposited in the estuary or on an **offshore bar** at the mouth of the river. It will be washed onshore by the swash of the waves and deposited on the beach.

At Borth, on the Ceredigion coast, there is a pebble ridge making a **spit** on the southern side of the estuary. These pebbles came from cliffs to the south. Figure 20 shows the processes that are supplying and transporting material on this coastline.

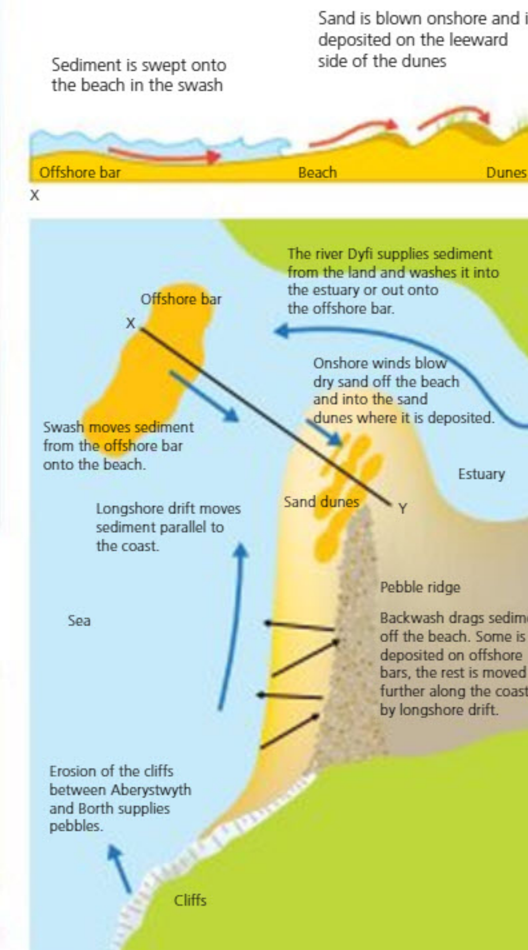
▲ **Figure 19** The sand dunes at Ynyslas seen from Aberdyfi on the north side of the Dyfi estuary.

Activities

1. Describe the landforms seen at A, B and C on Figures 18 and 19.
2. Study Figures 17, 18 and 20. Use an annotated diagram to explain the formation of the pebble ridge on which the village of Borth is built.

Enquiry

Interpret the landscape in Figure 19. How have erosion, transportation and deposition all helped to make this landscape? Write a story-board to explain the evolution of this landscape.



▲ **Figure 20** The transport of beach sediment at Borth and Ynyslas on the Ceredigion coast.

Investigating landscape change

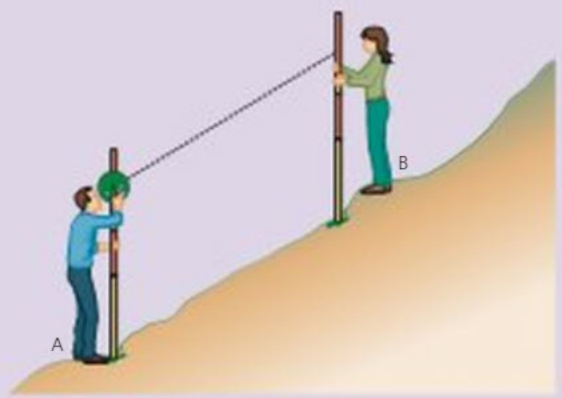
The coastline is a constantly changing landscape. Change can be very gradual and occur over many decades. Change over long periods can be measured by comparing primary fieldwork data with historical photographs or maps. However, the shape of a **beach profile** (its cross-sectional shape) can sometime change overnight. For example, rapid change occurs when beach sediment is eroded or deposited by an extreme storm event. Rapid change to a beach profile may be recorded by comparing measurements taken on two separate days.

Collecting primary evidence of a beach profile

The size and shape of beaches can be recorded by taking beach profile measurements, as shown in Figure 21.

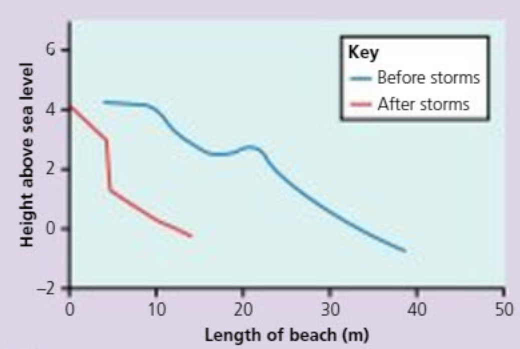
- Person A stands at a safe distance from the edge of the sea holding a ranging pole.
- Person B stands holding a second ranging pole further up the beach. They must stand at the **break in slope** where there is a change in the angle of the beach.
- The distance between the two ranging poles is measured using a tape measure.
- The angle between markers at the same height on each ranging pole is measured using a clinometer.

Repeat this process at each break of slope until the top of the beach is reached.



▲ **Figure 21** How to carry out a beach profile.

When all the data has been collected you can plot the distances and angles for each break on a graph to show the profile of the beach. Data collected on different dates can then be compared.



▲ **Figure 22** Beach profiles for different dates at Slapton Sands, Torcross.

Activity

1 Use Figure 22.
   a) Describe how the beach profile changed after the storms. You will need to refer to the height and length of the beach.
   b) How might you calculate the area of the beach by using several profiles?

Investigating the concept of place

Coastal locations provide an opportunity to investigate how people think about the environment – whether it be the physical environment of a natural coastal landscape, or the human environment of a seaside resort. This will involve collecting qualitative data (see page 45) by using, for example:

- bi-polar surveys (see page 14)
- and questionnaires (see page 46).

Place

Place is a geographical concept which is used to describe what makes somewhere special, unique or distinct. Each place includes many different features of the human and physical environment such as landscape features and landmarks, local styles of building, ecosystems and habitats, or local historical and cultural features. Each of these features may be relatively common across the UK. However, it is the unique combination of these geographical features that creates an identity for any one place.

Posing questions for an enquiry

Study Figure 23, it shows the seaside resort of Rhyl on the North Wales coast. How do people of different ages think about this place: what features do they like and dislike? What words would they use to describe the unique or special features of this place? How many would be positive and how many would be negative? Do tourists to Rhyl have the same ideas about this place as local people? You could use a mixture of open and closed questions to investigate these ideas. If you record the approximate age of each person you could then sort your results to see whether younger people have a different view of the place than older people. Or whether tourists have a different view to local people.

▲ **Figure 23** Like many UK seaside resorts, Rhyl has an ageing population and suffers from the decline of tourism, seasonal employment and a shortage of high-paid jobs.

Activities

2 Study Figure 23.
   a) List the human and physical features of this environment.
   b) How do these features compare to other seaside towns?
   c) Create a bi-polar survey that could be used to assess people's views about this environment. Test it on colleagues in your class.

Enquiry

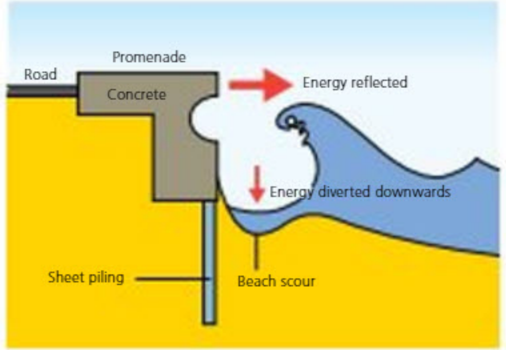
Design an enquiry for Rhyl.

a) Create an over-arching enquiry question about place.
b) Describe how you would collect the qualitative data you need and design data collection sheets.

How do we manage our coasts?

The usual way to manage coastlines has been through a combination of hard and soft engineering strategies. **Hard engineering** means building structures that prevent erosion and fix the coastline in place. The concrete sea wall and boulders in Figure 1 are a typical example. Wide beaches soak up a lot of wave energy and are a natural defence against coastal erosion. **Soft engineering** strategies mimic this by encouraging natural deposition to take place along the coastline. In Figure 3 you can see that an artificial rock reef has been built parallel to the coastline. This encourages deposition on the beach behind.

▲ **Figure 1** The sea wall at Sea Palling, Norfolk is an example of hard engineering.



▲ **Figure 3** Sea walls can cause erosion of sediment from the beach.

Activity

1 a) Make a sketch of Figure 1.
 b) Label two hard engineering features on your sketch.
 c) Explain why boulders have been positioned at the top of the beach.

▲ **Figure 2a and b** There are a total of nine artificial reefs at Sea Palling. Notice how sand has been deposited behind the reef, joining it to the beach.

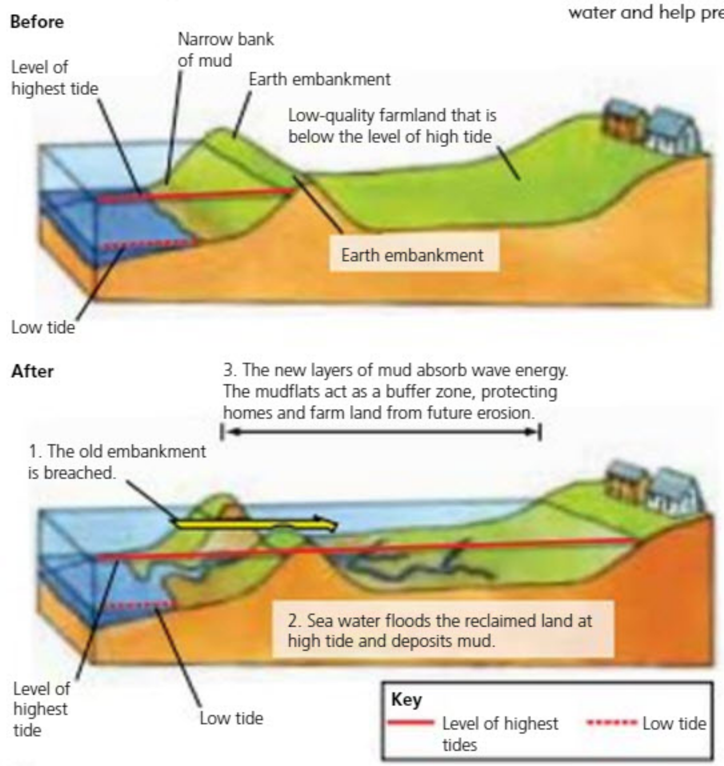
The importance of the inter-tidal zone

Estuarine landscapes, such as the one in Figure 4, contain many tidal creeks, salt marshes and mud banks. These features are exposed at low tide but at high tide they can store huge quantities of water. This is the **inter-tidal zone** and it acts as a natural buffer during storms – soaking up wave energy during a storm surge before the waves can reach more valuable land further inland.

Why is there a need for managed realignment?

There is a much narrower inter-tidal zone in the UK than there used to be:

- Many salt marshes were reclaimed in the past to create new farm land. Old earth embankments have kept the sea off these low-lying fields for centuries.
- Some salt marshes are being eroded by the sea. This is a particular problem along the Essex and Thames gateway coastlines where the land is subsiding so sea levels are rising faster than elsewhere in the UK.



▲ **Figure 5** How managed realignment creates wide inter-tidal zones that act as natural stores for flood water at high tide.

Managed realignment can be used to create new inter-tidal zones of salt marsh. The process begins by punching holes through the old earth embankment. The invading sea water moves slowly across the land at high tide. As it flows in, it deposits mud. As it flows out, it creates tidal creeks like those in Figure 4. This process recreates natural mudflats and salt marshes that will store water and act as a buffer to erosion in future flood events.

▲ **Figure 4** The inter-tidal zone of the Lune estuary, Lancashire. Tidal creeks and mud flats, here at low tide, can store huge quantities of water and help prevent flooding and erosion.

Activity

2 a) Make a sketch of Figure 4.
 b) Annotate your sketch to explain why the inter-tidal zone is an important natural defence against erosion and flooding.

Enquiry

Should we create more inter-tidal zones along the UK's coastline? Outline the arguments for and against managed realignment.

Is everyone in favour of managed realignment?

Managed realignment is an example of 'retreating the line' which is an option available in all Shoreline Management Plans, but it is a controversial choice. In 2014 the UK's largest realignment sea defence scheme was completed at Medmerry, West Sussex. This scheme has effectively redrawn the coastline 2 km further inland! The scheme began with the destruction of the existing sea wall, allowing some land to flood naturally at high tide. The newly flooded area will be able to absorb the energy of the waves and will reduce the risk of coastal flooding. A new 7 km sea wall has been built further inland. The Environment Agency says homes are much better protected as a result. However, at £28 million, the scheme was not popular with everyone.

▲ **Figure 6** The location of the Medmerry realignment scheme.

▲ **Figure 7** Medmerry seen from the air.

Has the Medmerry scheme been successful?

During the winter of 2014–15, weeks of rain and fierce storms lashed the south coast. Allan Chamberlain, estate director at the adjacent Medmerry Holiday Village, was shocked by how successful the scheme was. 'It's the first winter in years we haven't had to deal with surface flooding. The rainwater drains into the new marsh beautifully.' The bonus for the Holiday Village and the nearby Bunn Leisure Homes complex is that the new nature reserve is attracting even more tourists. Bookings are up and the tourist attractions can stay open for longer now that the area is largely flood free. Other, somewhat unexpected gains relate to farming. Cattle will be grazed on the salt marsh. This produces a flavour of beef that is highly prized. It is worth more to farmers than the beef usually sold in supermarkets. Also, there are plans for a fish nursery in the new estuarine environment. This could boost the fishing economy in neighbouring Selsey.

Once you give land back to the sea, there's no getting it back, so if this doesn't work, we will have given up that land for nothing. I would like to see the Environment Agency look at other alternatives such as constructing rock barriers out in the ocean in front of the coast to break wave energy.

Ben Cooper – a resident of nearby Selsey

Three productive farms producing oilseed rape and winter wheat will have to be sacrificed to the sea. The UK is not self-sufficient in food. The idea of letting perfectly good agricultural land disappear into the sea is wasteful and short-sighted.

Local farmers

We need to protect our fishing industry. If we set quotas as low as the scientists would like, our fishing industry would collapse. We have set quotas low enough to conserve fish stocks but high enough to keep people in jobs.

Bunn Leisure Holiday Homes

We have had to endure terrible flooding this winter and we are quite upset about the whole thing. Why is the Environment Agency spending £28 million on creating a coastal nature reserve at Medmerry when they could use the money to dredge rivers and reduce the risk of flooding where we live instead?

Somerset residents badly affected by floods in 2013/14

▲ **Figure 8** Opposition to the Medmerry scheme.

Activities

1. Use Figure 6 to describe the location of Medmerry.
2. Summarise the benefits of realignment at Medmerry for:
   a) local homeowners and businesses
   b) the environment including wildlife.
3. Explain why some local people may have opposed realigning the coast here.

Enquiry

How sustainable is the decision to re-align the coast at Medmerry?

Explain how the sustainability of this scheme could be measured over the next 50 years.

Shoreline Management Plans

Coastal communities expect the government to help protect them from erosion and coastal floods. However, managing the coastline is very expensive. Furthermore, there is no legal duty for the government to build coastal defences to protect people or their property. It is the responsibility of the local councils of England and Wales to prepare a **Shoreline Management Plan (SMP)** for their section of coast. In deciding whether or not to build new coastal defences (or repair old ones), the local council needs to weigh up the benefits of building the defences against the costs. They may consider factors such as:

- How many people are threatened by erosion and what is their property worth?
- How much would it cost to replace infrastructure such as roads or railway lines if they were washed away?
- Are there historic or natural features that should be conserved? Do these features have an economic value, for example, by attracting tourists to the area?

Option	Description	Comment
Do nothing	Do nothing and allow gradual erosion.	This is an option if the land has a lower value than the cost of building sea defences, which can be very expensive.
Hold the line	Use hard engineering such as timber or rock groynes and concrete sea walls to protect the coastline, or add extra sand to a beach to make it more effective at absorbing wave energy.	Sea walls cost about £6,000 per metre to build. Sea-level rise means that such defences need to be constantly maintained, and will eventually need to be replaced with larger structures. For this reason hard engineering is usually only used where the land that is being protected is particularly valuable.
Retreat the line	Punch a hole in an existing coastal defence to allow land to flood naturally between low and high tide (the inter-tidal zone).	Sand dunes and salt marshes provide a natural barrier to flooding and help to absorb wave energy. They adapt naturally to changing sea levels through a process of erosion at the seaward side and deposition further inland.
Advance the line	Build new coastal defences further out to sea.	This requires a huge engineering project and would be the most expensive option. The advantage would be that new, flat land would be available that could be used as a port or airport facility.

▲ **Figure 9** The options available to local councils when they prepare a Shoreline Management Plan.

◀ **Figure 10** Wooden groynes on Borth beach in 2008.

Activity

1 Use Figures 10 and 11.
   a) Describe these structures.
   b) Suggest how they have helped to protect Borth from erosion and flooding.

Management at Borth, Ceredigion

The village of Borth is built on the southern end of a pebble ridge, or spit, that sticks out into the Dyfi estuary. Sand is trapped on the beach by wooden groynes. The sand absorbs wave energy and prevents waves from eroding the pebble ridge. However, the groynes are in poor condition and are at the end of their working lives. What should be done?

The Ceredigion SMP divides the coast up into small management units (MU). Figure 13 shows the extent of five of these MUs.

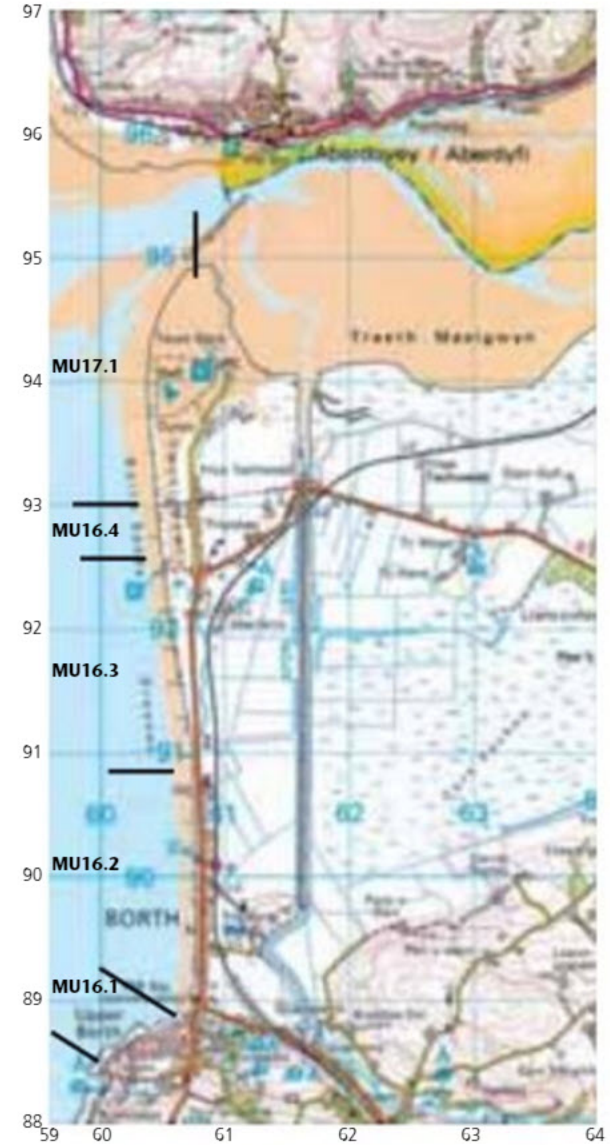
▲ **Figure 11** The wooden sea wall at the top of the pebble ridge (2010).

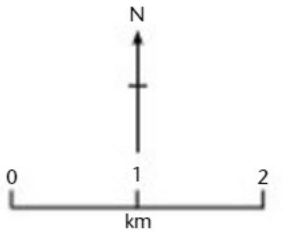
Activities

2 Work in pairs.
Use Figure 12 to provide map evidence which suggests that this coast is worth protecting. Copy and complete the table below and add at least five more pieces of evidence.

Management Unit	
16.2	Railway station at 609901 would be expensive to replace
16.3	
16.4	The campsite in 6192 provides local jobs
17.1	

3 Which is the best SMP option for Management Unit (MU) 16.2?
Use information from Figure 9 and evidence in Figure 12 to help you make your choice.





◀ **Figure 12** An Ordnance Survey extract of Borth, 1:50,000.

What coastal management is appropriate for Borth?

Ceredigion Council decided that there were two possible options for Management Unit (MU) 16.2 that needed further consideration. Read the points of view in Figure 14 before deciding what you would do.

Do nothing	Loss of property and economic loss in the short term. Change to Borth Bog.	Consider further
Hold the line	Current policy which protects property and businesses. Coastal processes disrupted with reduced longshore drift.	Consider further
Retreat	Retreat would affect homes that are immediately behind the existing line of defence.	Not considered further
Advance	No need to advance the line except to improve the tourist facilities.	Not considered further

▲ **Figure 13** The initial decision of the Ceredigion Council for MU16.2.

Scientist

Sand from the southern end of the beach is gradually being eroded by longshore drift, moving it northwards. This process is happening faster than new sand is being deposited. The beach is getting thinner and is less able to protect the pebble ridge (on which Borth is built) from erosion. If the council does nothing then the pebble ridge will be breached by storm waves and the town of Borth, and Borth Bog (Cors Fochno) will be flooded by the sea. This could happen in the next 10 to 15 years. The peat bog at Cors Fochno will be covered in sea water at high tide and its existing ecosystem lost. Over the next few years erosion will punch more holes through the pebble ridge. A new spit of pebbles will eventually form further to the east. The sand dunes at Ynyslas will probably be cut off and form a small island.

B&B owner

The beach and landscape of the spit, including the sand dunes at Ynyslas, are an important economic asset to the village. It's this natural environment that attracts thousands of holidaymakers each year. If the council does nothing then my home and many others will be flooded and local people will lose their livelihoods.

Scientist

The peat bog at Cors Fochno should be protected from flooding. It is a nationally and internationally important ecosystem. It has protection as a Special Area of Conservation and is also recognised by UNESCO. 'Do nothing' is an unacceptable option.

Local councillor

We calculate that property in Borth village is worth £10.75 million. On top of this there are many local businesses which would lose their income from tourism if we do nothing. The cost of holding the line is around £7 million. However, we are concerned that building new groynes will prevent longshore drift. We need to consider the impact of that. Currently the sediment moves to Ynyslas where it provides a natural defence to the whole estuary (including the larger village of Aberdyfi) from south-westerly storms.

▲ **Figure 14** Views on the future management of MU16.2.

Activities

1. Using a table, summarise the economic, social and environmental impacts of doing nothing or holding the line in Management Unit 16.2.
2. State which option you would recommend. Explain why you think your option is best for this stretch of coast.

Enquiry

Which is the best SMP option for Management Unit 17.1?

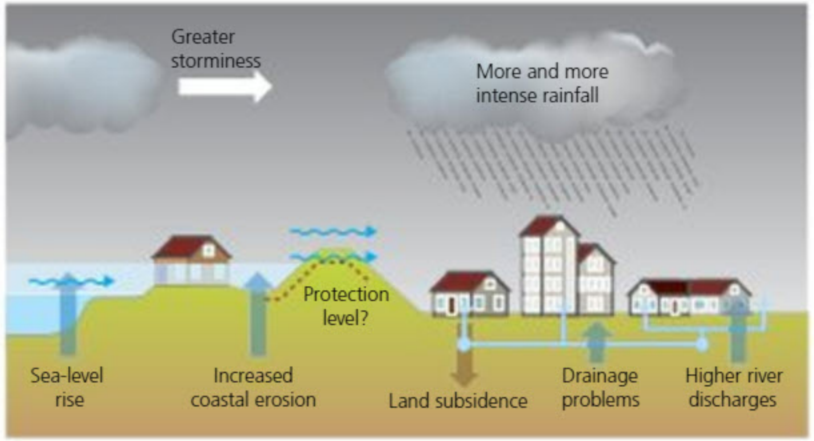
Analyse information from Figure 12 and evaluate the views in Figure 14 to help you justify your choice.

How will climate change affect coastal communities in the UK?

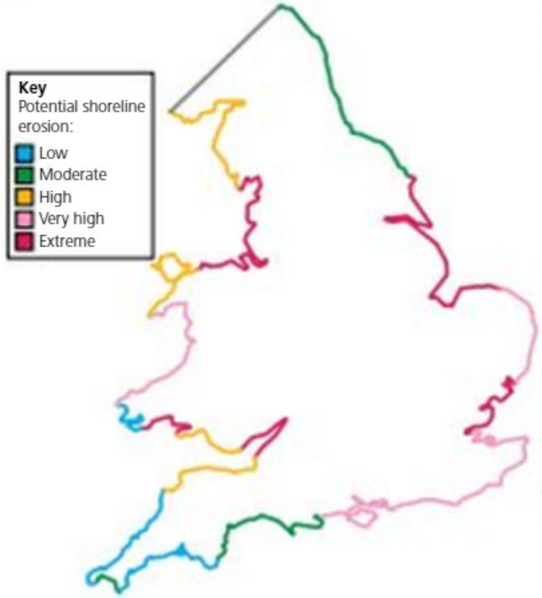
Rising sea levels will increase the rate of coastal erosion. More farmland will be lost and more expensive sea defences will be needed to 'hold the line' against erosion of our towns and cities. Climate change also means a warmer atmosphere, which means more storms like the devastating storm surges that flooded Jaywick in 1953 and 2013.

Year	2007	2032	2057	2082	2107
Rise in sea level (cm)	0	13	35	65	102

▲ **Figure 15** Predicted sea level rise at Jaywick, Essex.



▲ **Figure 16** Some of the impacts of climate change on our coastline by 2050.



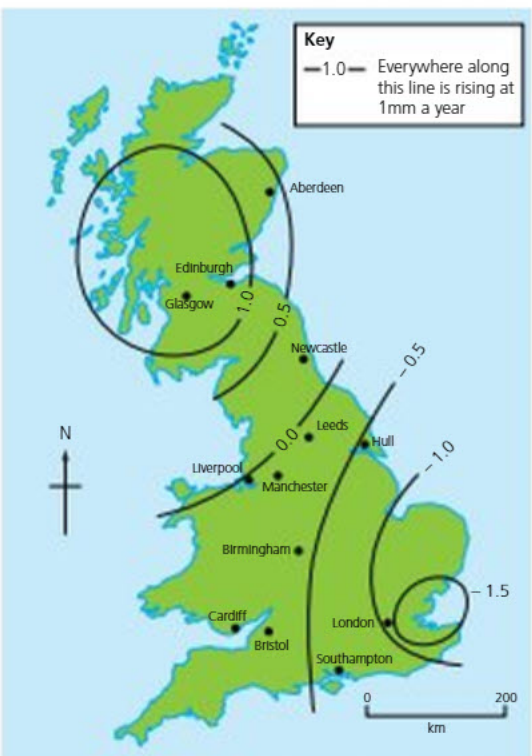
◀ **Figure 17** Coastal erosion if carbon dioxide emissions continue to increase and sea levels rise.

Activities

1. Use Figure 16 to describe five different impacts of sea-level rise on coastal communities in the UK.
2. Use Figure 17 and an atlas to name:
   a) five counties in England facing problems of extreme coastal erosion
   b) three counties in Wales facing very high rates of erosion.
3. a) Use Figure 15 to draw a graph of the predicted sea level rise at Jaywick.
   b) Give two reasons to explain why sea levels are rising here.

How could climate change affect London and the Thames Gateway?

One of the most vulnerable coastlines in the UK is the estuarine landscape of the River Thames to the east of London. This coastline, known as the Thames Gateway, is at risk from storm surges (like those in 1953 and 2013) that push sea into the narrow funnel-like coastline between Essex and Kent. This coastline has been sinking ever since the end of the ice age in the UK about 10,000 years ago – a process called **postglacial rebound**. As a result, the Thames Gateway is sinking at about 2 mm a year relative to current sea levels. Climate change means that sea levels in the Thames estuary are rising at about 3 mm a year. So the combined effect of sea level rise and postglacial rebound means that sea levels here are rising at 5–6 mm per year.



▲ **Figure 18** The amount of postglacial rebound (mm per year). Positive numbers mean the land is rising relative to the sea and negative numbers mean the land is sinking.

Year	Type of risk that caused closure		Total closures
	Tidal	River flood	
1983	1	0	1
1984	0	0	0
1985	0	0	0
1986	0	1	1
1987	1	0	1
1988	1	0	1
1989	0	0	0
1990	1	3	4
1991	2	0	2
1992	0	0	0
1993	4	0	4
1994	3	4	7
1995	2	2	4
1996	4	0	4
1997	1	0	1
1998	1	0	1
1999	2	0	2
2000	3	3	6
2001	16	8	24
2002	3	1	4
2003	8	12	20
2004	1	0	1
2005	4	0	4
2006	3	0	3
2007	8	0	8
2008	6	0	6
2009	1	4	5
2010	2	3	5
2011	0	0	0
2012	0	0	0
2013	0	5	5
2014	7	41	48

▲ **Figure 19** Closures of the Thames Barrier to protect against storm (tidal) surges (1983–2014).

Activities

1 Use Figure 18 to describe the parts of the UK where:
   a) land is rising fastest
   b) land is sinking fastest.

2 a) Use the data in Figure 19 to produce a graph of closures.
   b) Describe the trend of your graph.
   c) Explain why this graph could be seen to be more evidence for climate change.

Holding the line

The Thames flood barrier was completed in 1982. It is situated to the east of the City of London so protects large parts of London from tidal surges coming up the river from the North Sea. It protects 1.25 million people from tidal floods. However, it is now thought that the barrier is not large enough to protect London from future floods. The Thames Estuary 2100 Plan (TE2100) suggests that, by 2100, London needs to be protected from a possible flood that would be 2.7 metres higher than current flood levels.

Factfile: Property at risk of tidal flooding on the Thames floodplain

- Over 500,000 homes
- 40,000 commercial and industrial properties
- 400 schools
- 16 hospitals
- 35 tube stations
- Over 300 km of roads

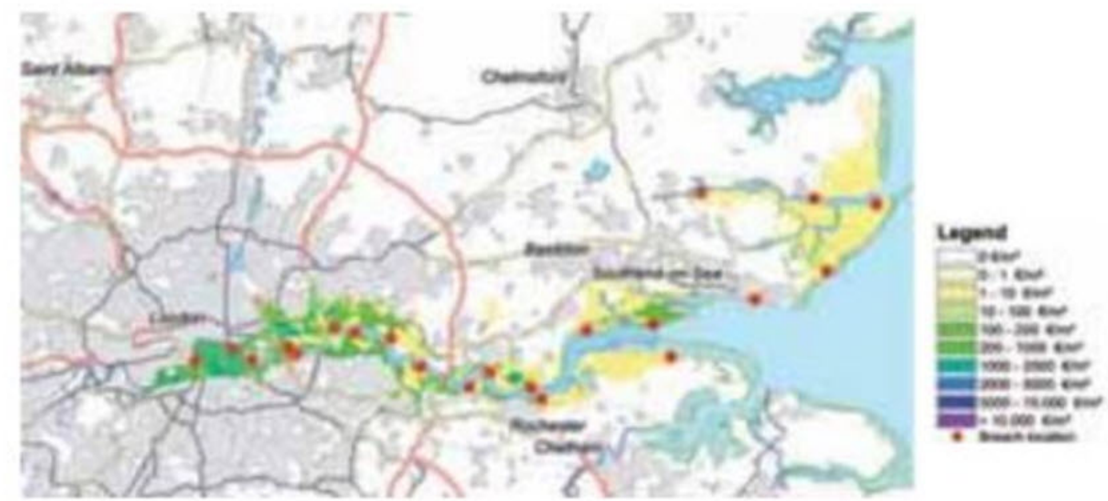
The TE2100 Plan uses three strategies to protect London and the Thames Gateway:

- Continue to renew and replace existing embankments, sea walls and sluices in the Thames Gateway.
- Increase the amount of inter-tidal habitat in the Thames estuary by 876 hectares. These salt marshes will help to store flood water as it moves up the estuary during a tidal surge. These storage areas would be created by managed realignment projects like the one at Tollesbury, Essex.
- Consider building a new, larger barrier at Long Reach to the east of the existing barrier. The construction of this new barrier would cost between £6 billion and £7 billion.

Activities

3 Use Figure 20 to describe:
   a) the distribution of breaches
   b) the amount and value of flooded land.

4 Explain why the cost of flood damage in Essex would be lower than that in London.



▲ **Figure 20** The cost of flood damage in 2050 after a flood similar to the 1953 storm surge if sea levels continue to rise and flood protection is not improved. Red dots show where coastal defences would be breached.

Enquiry

How should London and the Thames Gateway be protected in the future? Some people are sceptical about managed realignment. Justify why the TE2100 Plan proposes to combine a new flood barrier with managed realignment.

Why are some coastal communities more vulnerable than others?

A report by the Joseph Rowntree Foundation suggests that some of the most vulnerable people, living in isolated communities of the UK, will be the most affected by rising sea levels.

The report argues that poverty is a factor that makes some communities more vulnerable to sea level rise and coastal flooding than others. Poverty means that the local council has fewer resources available to reduce the threat of and the impacts of sea level rise.
The report suggests that vulnerability to coastal flooding increases where communities have:

- a higher proportion of people claiming benefits;
- a fast turnover of people through economic migration;
- a high proportion of poor-quality housing;
- an over-reliance on tourism, resulting in seasonal employment and low incomes.

▲ **Figure 21** Coastal floods in Great Yarmouth, December 2013.

Skegness, Lincolnshire

Skegness is one of the better-known seaside resorts in England. It is situated within the largely rural area of East Lindsey and has poor road and rail links. Skegness has one of the largest concentrations of caravan parks in Europe. Some static caravans are the permanent homes for retired residents and people on low incomes.

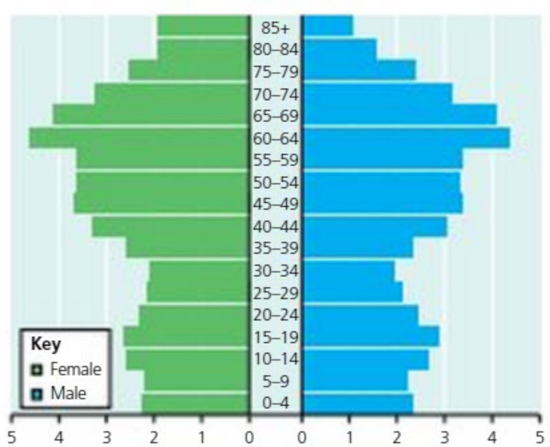
Great Yarmouth, Norfolk

Great Yarmouth is a medium-sized port and is an important seaside resort. It has a high proportion of elderly and retired residents. Unemployment rates are higher in Great Yarmouth than in the rest of the east of England. The economy of the port is in decline and the nearby North Sea gas fields have begun to reduce production.

GEOGRAPHICAL SKILLS

Interpreting population pyramids

Population pyramids are a specialist form of bar graph. Each bar represents males or females in a specific age category. The bars may represent actual population numbers or percentage figures. Interpreting the shape of a pyramid can tell you a lot about the structure of a population. Pyramids with a wide base have a youthful population and those with a wide top have an ageing population. Interpreting the structure is the first step in analysing possible issues that may be facing the population. For example, does an ageing population have sufficient health care and social services suitable for this age group?



▲ **Figure 22** Population pyramid for East Lindsey, Lincolnshire (2011).

www.ons.gov.uk/ons/interactive/uk-population-pyramid---dvc1/index.html
An interactive population pyramid for the UK showing change between 1971 and 2085.

Llanelli, Gwent

Unemployment in Llanelli is higher than the national average and the town has been particularly hard hit by the economic recession of 2008–9. Derelict industrial sites along the coastline are now the focus of several regeneration schemes. The town has a higher than average proportion of elderly residents. A high number of migrants from Eastern Europe have settled in the town.

Benbecula, Outer Hebrides

With a population of 1,200, the population and economy of this remote Scottish island have been in decline since the mid-1970s because of the closure of a military base. The lack of jobs for younger people has also contributed to the decline and to the ageing of the island's population. The island's coastal drainage system was built in the 1800s and is not very efficient. It struggles to cope with the combined effects of heavy rainfall and high tides.

Indicator	Skegness	Lincolnshire	England
% of working population in professional/ management jobs	14	18	23
% of working population claiming work-related benefits	18	13	13
% of adult population with no academic qualifications	33	26	22
% of the adult population who are in very good health	38	43	47

▲ **Figure 23** Socio-economic statistics for Skegness.

▲ **Figure 24** Skegness has a large concentration of static caravans.

In such communities, local people may lack the funds to make structural changes to their homes (e.g. to make them flood resistant). They may not be able to afford to move away. Coastal local authorities with areas of high deprivation may not be able to afford the resources for climate change preparation. Government policy means that there is an ever-increasing expectation that individuals and communities should help themselves to prepare for the likely increase in sea level rise. For disadvantaged residents, the threat of sea level rise is simply not a major issue at this moment in time. They have other things to focus on.

▲ **Figure 25** An extract (adapted) from the Joseph Rowntree Report summary statement.

Activities

1 Compare the four communities described on these pages. Describe three similarities that link at least two of these communities.
2 a) Describe the structure of the population structure for East Lindsey.
  b) Use the Weblink to compare this population structure to that of the UK.
  c) What does this suggest is needed in East Lindsey?
3 Explain why every local authority may not be able to afford the resources needed to prepare for sea level rise.
4 Use Figure 23 to:
  a) Identify the overall pattern shown in the table.
  b) The figures in the table date from the National Census in 2011. The worst impact of sea level rise is not expected to happen until 2050. Should the local authority use the data to appeal for additional outside help when planning for sea level rise? Justify your answer.

Enquiry

Who should be responsible for protecting communities in the UK from the effects of sea level rise?

'Government policy means that there is an ever-increasing expectation that individuals and communities should help themselves to prepare for the likely increase in sea level rise'. How far do you agree with this statement? Discuss this in groups.

How might climate change affect coastal communities around the world?

By 2030 it is estimated that 950 million people around the world will live in the **Low Elevation Coastal Zone (LECZ)** – that is, coastal areas that are less than 10 metres above sea level. Climate change presents a triple threat to people living in LECZs:

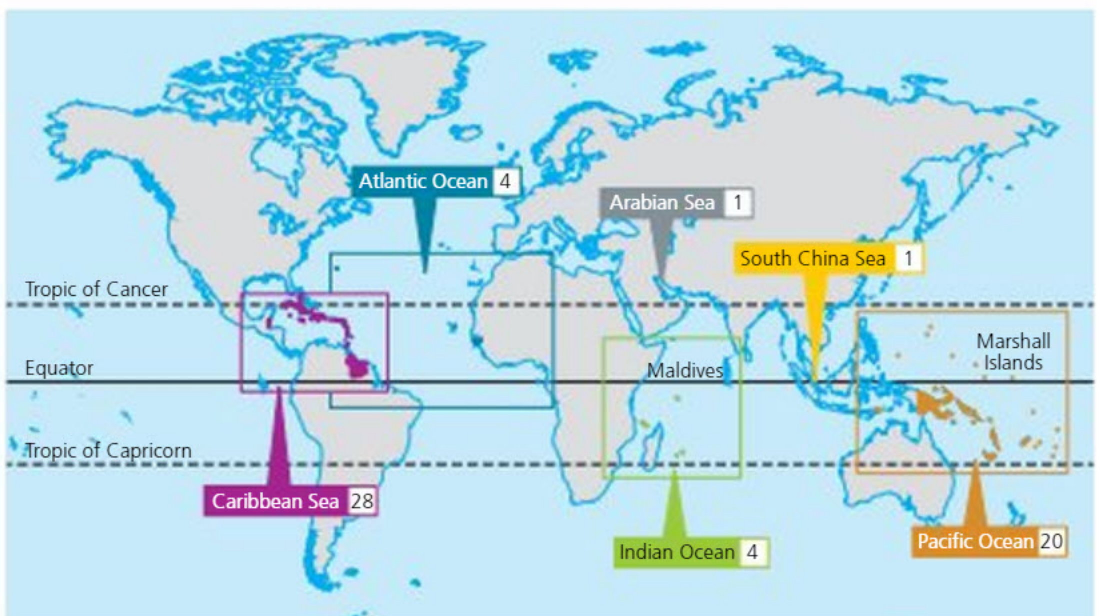
- Sea level rise increases the risk of coastal flooding at high tide.
- Heavier rainfall increases the risk of flash floods in urban areas with poor drainage (see page 174).
- More violent storms and hurricanes increase the risk of coastal erosion and storm surges.

The worst-affected coastal communities could be those living on the world's major river deltas. People living here are affected by subsidence of the soft land as well as by sea-level rise. Millions of people live on deltas in Bangladesh, Egypt, Nigeria, Vietnam and Cambodia.

In 2013 the World Bank identified 136 coastal cities that are at greatest risk from climate change. Mumbai, home to 18.4 million people, is one. Built on a low-lying island, much of Mumbai is only 10 metres above sea level. Other cities, like New York, Singapore and New Orleans, are also at risk. Many cities identified by the World Bank are in developing countries where the poorest members of society are at most risk of natural hazards. This is because the poorest neighbourhoods, like those in Figure 29, are often in low-lying areas and built alongside waterways or seafronts that are vulnerable to flooding. As sea levels rise, some people may have to leave their homes. They will become **environmental refugees**.

Activity

1 Use Figure 26 to describe:
 a) the distribution of SIDS
 b) the location of:
  i) the Maldives ii) the Marshall Islands.
 c) Suggest why people living in isolated places like these are vulnerable to natural hazards.



▲ **Figure 26** Small Island Developing States (SIDs) such as the Maldives in the Indian Ocean and the Marshall Islands in the Pacific are very low-lying. A 1 m rise in sea level by 2100 would flood up to 75 per cent of the land in each of these two nations.

Factfile: Small Island Developing States (SIDS)

- There are currently 58 SIDS with a combined population of 65 million people.
- Many SIDS are very small and some are located in remote and isolated parts of the world. Most SIDS are vulnerable to climate change and natural disasters.
- Standards of living among small islands differ widely, with GDP per capita ranging from $51,000 in Singapore to $830 in Comoros.

City	Population (%) at risk in LECZ	Land (%) at risk in LECZ	Population 2015	Population 2030
Cotonou, Benin	94.7	85.4	682,000	979,000
Warri, Nigeria	90.8	92.0	663,000	1,298,000
Alexandria, Egypt	85.1	68.8	4,778,000	6,313,000
Port Harcourt, Nigeria	64.4	61.9	2,344,000	4,562,000
Dakar, Senegal	61.6	47.6	3,520,000	6,046,000

▲ **Figure 27** Selected African cities in the low elevation coastal zone (LECZ).

▲ **Figure 28** Poor neighbourhoods in Cotonou, Benin are built on stilts along the waterfront.

Activities

2 Study Figure 28.
 a) Describe the housing carefully.
 b) Suggest why the poorest members of society live in neighbourhoods like this.
 c) Suggest how this community will be affected by climate change.

3 a) Calculate the actual number of people expected to be living in the LECZ in each of the cities in Figure 27.
 b) Using Figure 26 and an atlas, suggest why each of the cities in Figure 27 is so vulnerable to climate change.

Enquiry

Analyse why it may be more difficult for the governments of SIDs to cope with climate change than a larger country like India.

Is it too late to save the Maldives?

The Republic of Maldives, in the Indian Ocean, is made up of 1,190 islands. It has a population of 350,000. Most of the islands are uninhabited, with over one-third of the population living in Malé, the capital city. Eighty per cent of the land area is under one metre above sea level. Nowhere is above 3 metres. No place on earth is more vulnerable and threatened by sea level rise. The GDP of the Maldives ranks the country as 165th out of 192 nation states (2013).

For more than three decades politicians from the country have tried to persuade world leaders to take climate change more seriously. In the 2015 Geneva Climate Change Conference, Dunya Maumoon, the minister of foreign affairs for the Maldives, asked the global community to take concrete action. He said, *'2015 should be remembered, not for stories about sea level rise, but ones about how we rose up together to stop it.'* The fact is, it's probably already too late.

▲ **Figure 29** The location of the Maldives.

▲ **Figure 30** Is this the future for the Maldives?

Factfile: The effects of sea level rise on the Maldives

- A rise in sea level of 0.5 m by the year 2100 would mean that 77% of the land surface of the Maldives will be underwater.
- A rise in sea level of 1 m by the year 2100 would make the islands uninhabitable by 2085.

How is sea level rise affecting the islands?

Frequent flooding of the islands over the past 30 years has caused ongoing problems for the Maldives. Most of the problems occur when the highest spring tides coincide with storms across the northern India Ocean.

▲ **Figure 31** The capital city of the Maldives, Malé, is surrounded by sea.

The impact of flooding across the Maldives

Malé – a capital city surrounded by sea walls:
In 2008 Japan offered $60 million in aid to fund a 3 m sea wall for Malé. The sea wall has been completed and will hold back the advance of the sea for the medium term. All the other islands remain vulnerable. The sea wall needs constant repair, the cost has to be paid for through local tourist taxes.

Drinking water is in short supply:
Sea level rise is already beginning to put stress on the scarce freshwater resources of the Maldives; 87% of the population can currently be supplied by collecting rainwater. Groundwater sources across the chain of islands have been contaminated by salt-water intrusion and are now undrinkable. Bringing in supplies from abroad is unsustainable.

The tourist industry under threat:
Tourism is by far and away the most important industry. It accounts for 90% of government tax revenue. The damage caused by the 2004 tsunami-related sea surge destroyed many prize beaches and ruined some luxury resorts. For a year, tourist numbers dropped dramatically as the islands implemented a recovery programme. Tourist numbers have since recovered, but the industry may have been given a taste of what's to come.

▲ **Figure 32** The impact of flooding across the Maldives.

Islands that float

Floating islands will be moored to the seabed using cables to minimise environmental impact. This idea has been put forward by a Dutch company. One of the islands will be used to create an artificial golf course. Golfers will access the floating 'golf island' by a tunnel on the seabed. There will be a spectacular underwater clubhouse for golfers to relax in after their game. The artificial islands will be built in India or the Middle East and towed to the Maldives.

▲ **Figure 33** How might the Maldives develop tourism in the future?

Sea level rise forces castaways to move to Australia

The Maldivian President said his government was considering Australia as a possible new home if the Maldives disappear beneath rising seas. He explained that Maldivians wanted to stay but moving was an eventuality his government had to plan for. Australia may need to prepare for a mass wave of climate refugees, seeking a new place to live.

▲ **Figure 34** Sea level rise may create environmental refugees.

Activities

1. Describe the location of the Maldives.
2. Study the two newspaper headlines shown in Figures 33 and 34. Both were published in 2012. They offer very different radical solutions to the problems faced by the Maldives.
   a) Discuss how sustainable each idea would be.
   b) Discuss which is the most likely to be turned into reality.

Enquiry

What should the Maldives Government do?

a) List five different ideas for action – place your ideas in priority order.
b) Justify why you think ideas one and two need to be put into action as soon as possible.

THEME 2

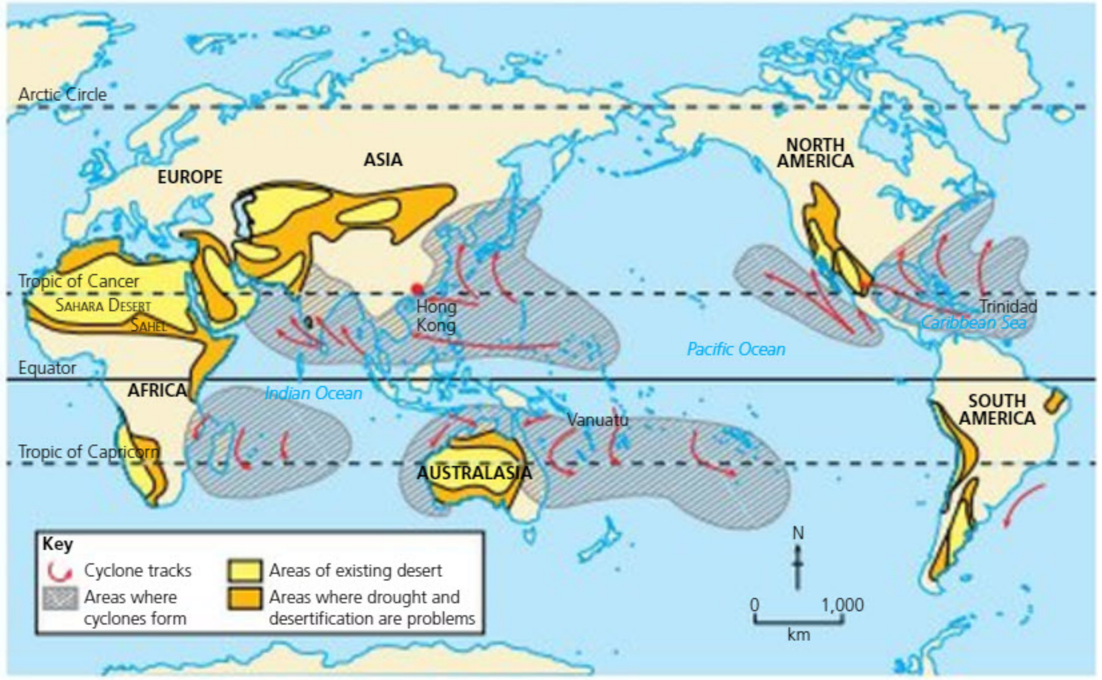
Chapter 5 Extreme weather

Investigating global patterns of extreme weather

In March 2015, the Pacific island of Vanuatu was devastated by the destructive power of a **cyclone**. Homes and crops were destroyed by the extreme winds and rain. Eleven people lost their lives. At the same time in California, USA, farmers were managing limited water supplies during the third consecutive year of **drought**. The hot, dry weather caused wildfires that burnt out of control. How can such extremes of weather exist at the same time? What causes them?

Activity

1 Study Figure 1.
  a) Describe the location of cyclones that affect
    i) Australasia
    ii) North and South America
    iii) South East Asia.
  b) Compare the direction of storm tracks in the northern and southern hemispheres.
  c) Name two countries that are at risk of both cyclones and drought.
  d) Describe the location of areas affected by drought in the northern hemisphere. How are these areas different to those that are vulnerable to cyclones?



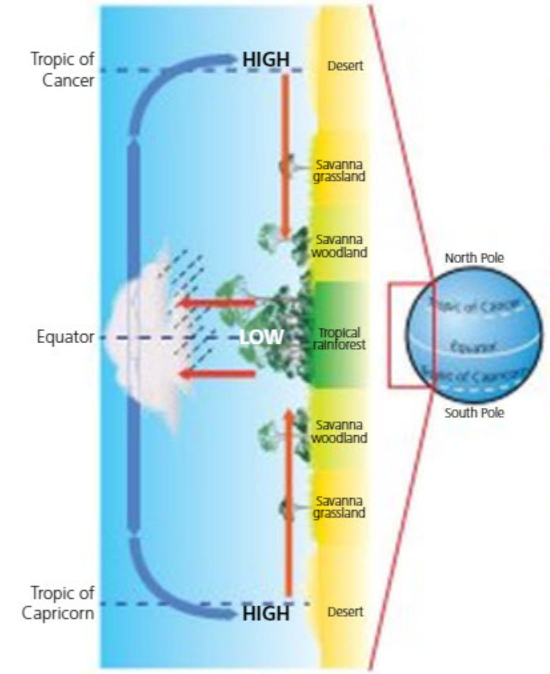
▲ **Figure 1** The global distribution and location of areas affected by cyclones and drought.

Activity

2 a) Make a copy of Figure 2 on page 173. Use the text boxes to annotate your diagram. Place your annotations in appropriate places on the diagram.
  b) Use your completed diagram to explain why there is rainforest at the Equator and desert at latitudes 30° to the north and south.

What is happening in our atmosphere to cause extreme weather?

We can begin to understand extreme weather by considering the intensity of the sun's heat on the ground at different latitudes on the Earth. The climate close to the Equator (within five degrees of latitude) is hot throughout the year. The Sun heats the Earth and the Earth heats the air above, which becomes **unstable** and rises. This creates a band of low pressure in the atmosphere, known as the intertropical convergence zone, the **ITCZ**, which circles the equatorial region of the Earth. The position of the ITCZ is shown in Figure 3. Notice that its position varies throughout the year. This is because of the tilt of the Earth's axis. The northern hemisphere leans towards the Sun in June and July so the ITCZ is slightly north of the Equator. The ITCZ migrates to south of the Equator in December and January when the southern hemisphere leans towards the Sun.



The Sun heats the Earth and the Earth heats the air above, which becomes unstable and rises creating an area of low pressure.

The air circulates back towards the equator in the lower atmosphere creating the trade winds.

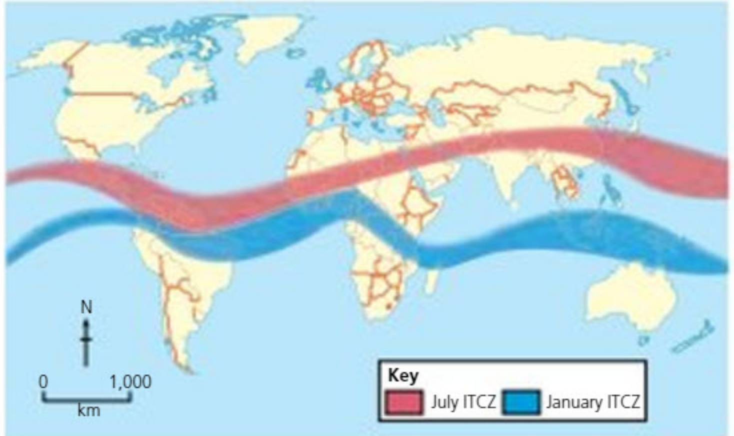
At about 30 °N and 30 °S the air descends creating an area of high pressure. This air is dry. It seldom rains.

The air reaches a boundary layer in the atmosphere called the tropopause which is about 17 km above the equator. The air spreads outwards towards the poles.

◀ **Figure 2** How solar heating at the Equator creates the ITCZ.

Activity

3 a) Using Figure 3, describe the position of the ITCZ:
    i) Over the Pacific Ocean in January and July.
    ii) Over Central America in July.
  b) Compare the location and distribution of cyclones on Figure 1 to the position of the ITCZ in Figure 3. What conclusion do you come to?

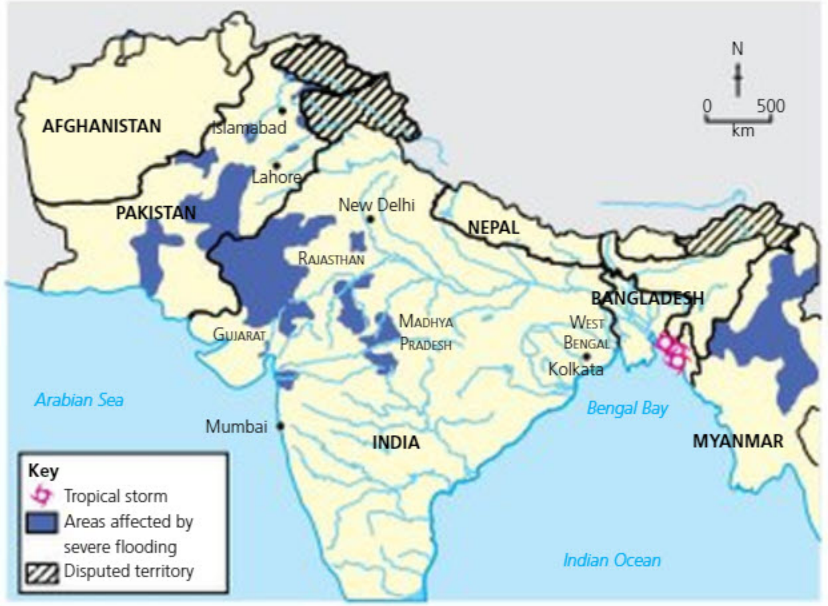


▲ **Figure 3** The location of equatorial and tropical low pressure systems (ITCZ).

How low pressure causes extreme weather

In late July 2015, India and Pakistan were badly affected by **monsoon** rains that caused flash floods and landslides. More than 120 people were drowned in India. It is thought that 116 people died in Pakistan and almost 1 million people had to leave their homes temporarily because of the floods. At the same time, West Bengal, Bangladesh and Myanmar were hit by flooding after a tropical storm caused heavy rainfall. Villagers in West Bengal said, 'We have seen floods, but never anything like this before. This year is the worst.' Why did these extreme weather events take place?

▲ **Figure 4** People struggle to get around after flash floods in Lahore, Pakistan.



Why does South Asia have a monsoon season?

The flash floods of July 2015 were not the first time this region has suffered extreme weather. The monsoon rains occur each year across South Asia. These rains are formed as the ITCZ moves northwards across India during July (see Figure 3 on page 173). Figure 7 shows how the position of the ITCZ creates the perfect conditions for a month during which heavy rain storms can happen on any day. When the rain comes, it often falls on hard, dry-baked earth. The ground cannot soak the rainwater up fast enough so it runs-off, creating a sudden flash flood. In cities the rain falls on impermeable tarmac or concrete and cannot soak away. The storm drains cannot cope so the streets quickly become flooded with a mixture of rain water and sewage from the foul drains.

Activities

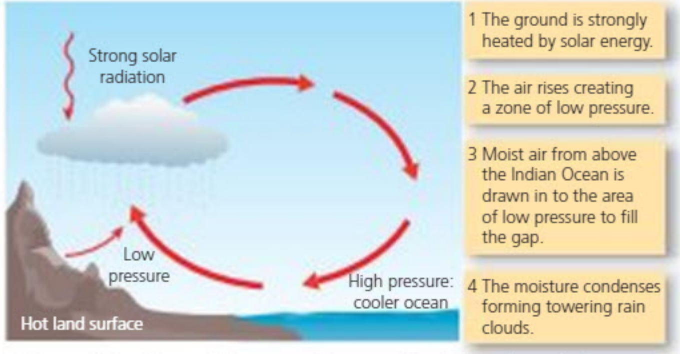
1 Study Figure 4. Apart from drowning, list five ways floods of this sort could affect everyday life or people's health and well-being.

2 Use Figures 4 and 5 to write a brief news report about the floods across South Asia in July 2015. Make sure you describe:
   a) The location of the flooding.
   b) The cause and effects of the flooding.

◀ **Figure 5** Map of South Asia showing areas affected by flooding during July 2015.

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Rainfall (mm)	0	0	1.6	0	0	0	9	0	0	0.1	0.1	42	4	0.1	0	0
Day	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Rainfall (mm)	119	0.1	75	5	2	0.1	2	17	0.1	17	2	0	0	0	1	

▲ **Figure 6** Rainfall (mm) in Lahore for each day of July 2015.



▲ **Figure 7** Circulation of the atmosphere over South Asia during July.

Activities

3 a) Use the data in Figure 6 to draw a suitable graph.
   b) Use your graph to explain the flash floods you can see in Figure 4.

4 Make a copy of Figure 7. Annotate your diagram in appropriate places to show why the ITCZ's position creates such a large quantity of rainfall during the monsoon.

How do cyclones form?

Cyclones, known as hurricanes in America and typhoons in Asia, are more violent than tropical storms. They are seasonal events caused by extreme low pressure when the ITCZ is overhead. The destructive energy of a cyclone is created when warmth from the sea is transferred to the air above. Sea temperatures need to be at 27°C or above for several weeks before a cyclone will form. The warm water heats the air above it, which rises rapidly, creating an area of very low pressure in the atmosphere. This causes towering clouds to form and torrential rain to fall. At sea level, the rising air is replaced by more warm moist air coming in from the outside. As the air moves towards the centre of the low pressure, it spirals upwards into the atmosphere. The spiral effect comes from the rotation of the Earth, a process known as the **Coriolis Effect**.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vanuatu	29.1	29.5	29.5	29.3	28.4	27.7	27.0	26.5	26.6	27.0	27.4	28.2
Trinidad	27.6	27.3	27.3	27.6	28.1	28.2	28.3	29.3	29.4	29.0	28.4	27.9
Hong Kong	19.1	18.9	20.1	22.7	26.8	28.5	29.1	28.6	28.3	26.5	24.3	21.0
Cornwall, UK	10.4	10.0	9.7	10.6	12.0	14.2	16.5	17.1	16.5	14.8	13.2	11.7

▲ **Figure 8** Average sea temperatures for selected locations (°C).

Activity

5 Use Figure 8 to draw two graphs to represent average sea temperatures in Hong Kong and Cornwall. Use your graphs, and Figure 1, to explain why Hong Kong is at risk of cyclones but Cornwall is not.

Enquiry

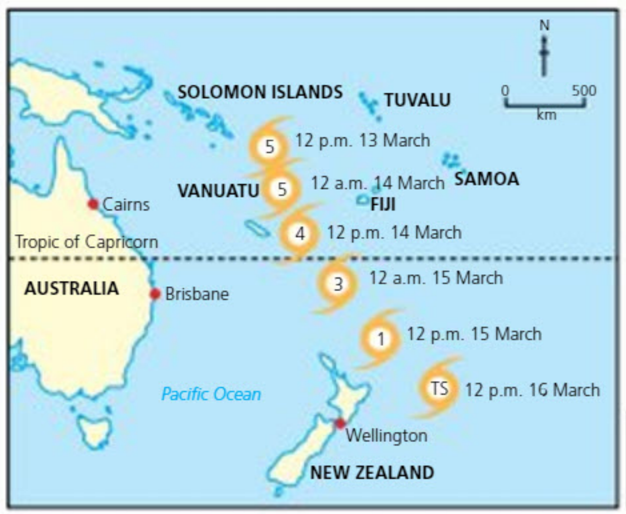
Predict when cyclones are most likely to threaten each of the following islands. Use the information in Figures 1, 3 and 8 to justify your answer:
a) Trinidad
b) Vanuatu.

Cyclone Pam, March 2015

In March 2015, Cyclone Pam tore through the island chain of Vanuatu in the Pacific, causing a trail of destruction. Cyclones are placed in different categories according to the strength of the wind. These categories are described in Figure 10. Pam was a Category 5 cyclone. The cyclone was at full strength as it crossed several islands. Winds were at around 250 km per hour, with some gusts reaching 320 km an hour. Many homes were destroyed and crops flattened by the wind. The cyclone had been forecast and many people took shelter in evacuation centres. Eleven people lost their lives.

Factfile

- Vanuatu is a group of 83 volcanic islands in the Pacific Ocean.
- The population is 272,000.
- GNI is US$3,090, making Vanuatu one of the lower Middle Income Countries.
- The main forms of employment are farming, fishing and tourism.
- Many people rely on rainwater harvested from roofs.
- Australia is Vanuatu's largest donor of aid. It gave A$60.7m (£31.45m) in 2013/4.



▲ **Figure 9** The track of Cyclone Pam.

Activities

1. Describe the track of Cyclone Pam. Use the North arrow and scale line.
2. Identify one social, one economic and one environmental problem faced by islanders.
3. Identify one social, one economic and one environmental problem caused by Cyclone Pam.

Category	Strongest gusts of wind (km/h)	Air pressure at the centre (millibars)	Typical damage
1	Less than 125	>980	Minimal damage to houses, but there is some damage to crops and trees. Some boats may drag their moorings.
2	125–164	965–980	Storm winds cause minor damage to houses but significant damage to road signs, trees and some crops. There is a risk of power failure. Small boats break from their moorings.
3	165–224	945–964	Very destructive winds cause damage to roofs. Many crops and trees are damaged. The risk of power failure is high.
4	225–279	920–944	Very destructive winds cause damage to roofs, walls and windows. Widespread power failures. Debris is blown by the wind, creating risk of injury.
5	More than 280	<920	Extremely destructive winds cause widespread damage to property and vegetation. Severe disruption to infrastructure such as roads, telephone lines and power lines.

▲ **Figure 10** Cyclone categories.

What were the effects of Cyclone Pam?

Villages in Vanuatu rely on two types of water supply:

- Rainwater is collected from streams or from the roofs of buildings and fed into overground tanks.
- Groundwater is collected from shallow wells.

Both types of supply were damaged by Cyclone Pam. The strong winds tore off roofs and blew down the storage tanks. Sea water from the storm surge flooded coastal areas and contaminated fresh water wells. It is estimated that 68 per cent of rainwater-harvesting structures and 70 per cent of wells were damaged.

The destructive winds damaged up to 90 per cent of homes on islands that lay directly in the path of the storm such as Erromango. In all, 90,000 people had their homes damaged. The winds also damaged hospitals and schools, affecting more than 35,000 pupils. The winds destroyed both up to 80 per cent of subsistence crops, such as vegetables, and cash crops such as coffee. Damage to farming was estimated to be US$2.5 million.

▲ **Figure 11** United Nations personnel on board an RAF plane carrying emergency aid to Port Villa, Vanuatu.

How did the world respond to the emergency in Vanuatu?

Australia, Fiji, France, New Zealand, Solomon Islands, Tonga and the United Kingdom all sent emergency aid using military aircraft and personnel. Vanuatu is a very remote group of islands. The steep volcanic slopes mean that there are very few long air-strips and the islands have very few harbours capable of taking large ships. Emergency aid was flown into Port Villa. The government then set up an 'air bridge' using smaller planes and boats to take the aid to where it was most needed.

- 21,000 people received supplies of safe drinking water
- 26,000 repairs made to water supply systems
- 153 temporary schools created
- 67,000 tarpaulin sheets
- 92,500 blankets
- 20 foreign medical teams
- 95,000 people received medical care
- 19,000 children vaccinated against measles

▲ **Figure 12** Emergency aid in numbers, by July 2015.

Activities

4. Explain why the government of Vanuatu would want to tackle each of the following problems urgently:
   a) Repairing water supplies
   b) Providing medical care
   c) Setting up temporary schools.
5. Suggest how countries, such as Australia, might provide effective long-term aid for the people of Vanuatu. Justify your ideas.

Enquiry

Analyse the impacts of extreme weather caused by low pressure. What are the main differences between the monsoon that affected South Asia in 2015 and the Cyclone Pam? Write a short report. Focus on:

a) causes
b) the scale of the event (area and people affected)
c) the duration of the event (length of time)
d) the social and economic impacts.

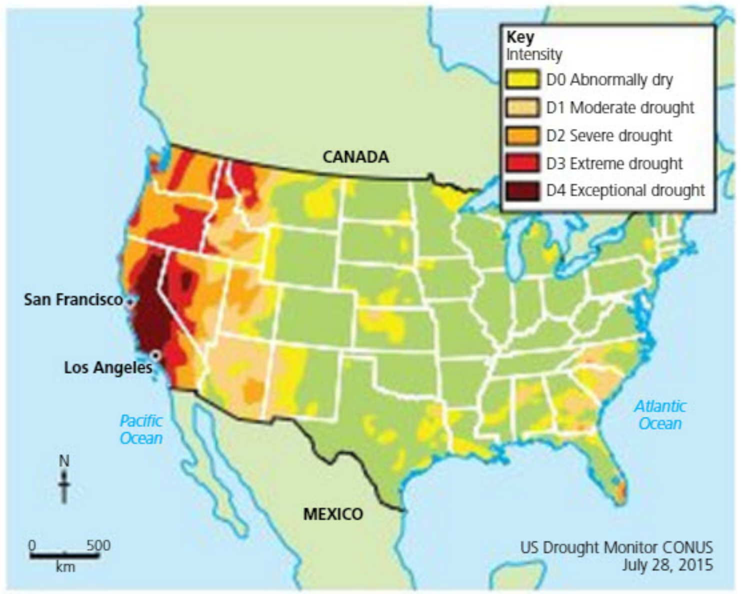
Heat wave and drought in California

In July 2015, wildfires in California hit the news headlines in the UK. In one fire, near Clear Lake, over 3,000 acres of land burnt out of control. People had to be evacuated from their homes. In another wildfire, shown in Figure 17, cars stuck in road works on Interstate 15 had to be abandoned as a wildfire swept across the road. What was causing this extreme weather?

The wildfires were a result of a three year-long drought that affected California between 2012 and 2015. A drought is when significantly less rain falls than usual over a prolonged period of time. During the period 2012–15, the winter rainfall totals in California were much lower than usual and it doesn't normally rain much in the summer months anyway. The result was a drought and dry vegetation that easily burns in the hot summer months.

Activities

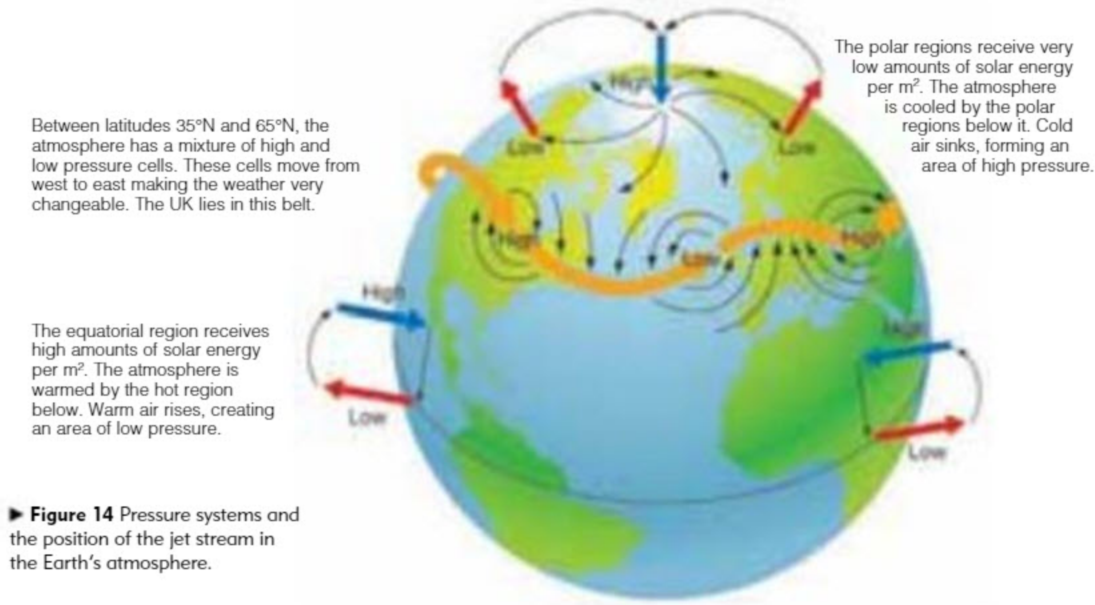
1 Use Figure 13 to describe:
  a) the location of Los Angeles
  b) the distribution of states affected by exceptional drought conditions.
2 Suggest how the drought and wild fires might have affected farmers, consumers, homeowners and firefighters.
3 Use Figure 15 and an atlas.
  a) Forecast the weather in each of the following places. You should be able to comment on the temperature and precipitation.
    i) Los Angeles
    ii) Ottowa
    iii) Mexico City.
  b) The jet stream has a wave-like motion as it swerves to the north and south, as shown in Figure 14. Explain why the winter weather of the USA would be different if the jet stream followed a more normal pattern.



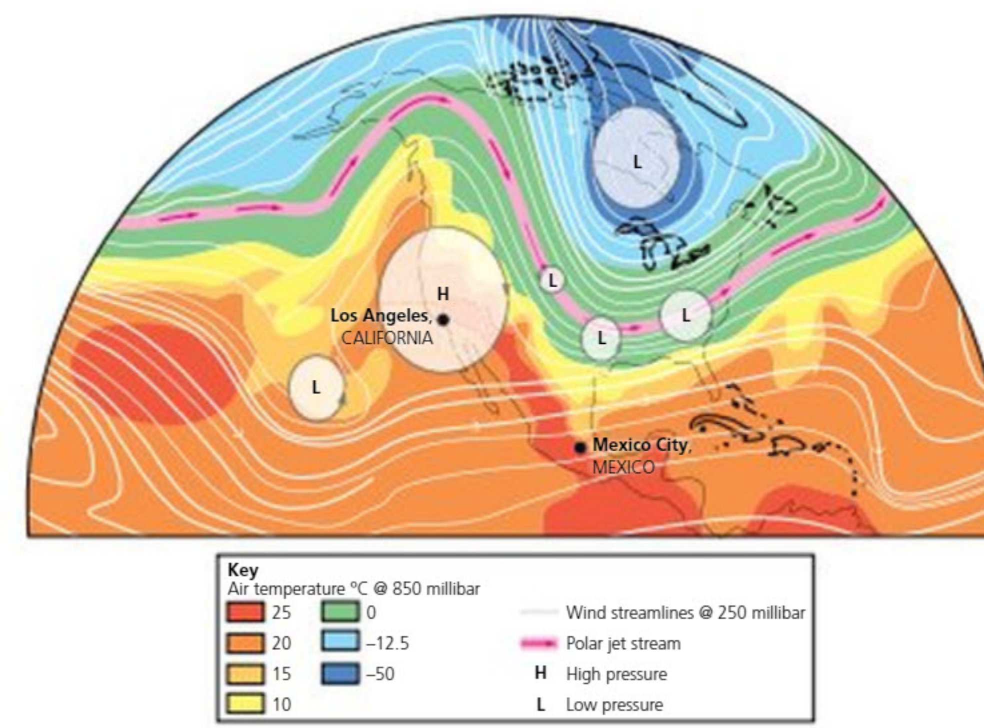
▲ **Figure 13** The extent of the drought across the USA in July 2015.

What caused the drought in California?

The low winter rainfall has been caused by the position of the **jet stream**. The jet stream is a strong ribbon of winds that circle the globe between 9 and 16 km above the surface of the Earth. These winds separate the cold polar air masses to the north from the warmer tropical air masses to the south, as you can see in Figure 14. The jet stream usually curves further south than in Figure 14. It normally pushes rain-bearing low pressure air masses across California during the winter months. However, between 2012 and 2015, it was wrapped around a huge area of high pressure in the north-eastern Pacific. Dry air to the west of California had remained stationary for long periods of time. The United States Weather Service nicknamed this pressure system the 'Reluctant Ridge' of high pressure because of its reluctance to break down or move. Meanwhile, low air pressure and cold air from Canada was dragged down into the central and eastern areas of the USA, as you can see in Figure 15.



► **Figure 14** Pressure systems and the position of the jet stream in the Earth's atmosphere.



▲ **Figure 15** The Reluctant Ridge of high pressure in the eastern Pacific in mid-February 2015.

What have been the effects of the Californian drought?

Short-term impacts are easy to see. The amount of discharge in most rivers of California fell to much lower levels than usual. In August 2015, 44 per cent of rivers had flows that were just 10 per cent of their normal flow. In the summer heat, moisture from the soil is evaporated. Plants become withered and dry.

In these conditions a spark can easily trigger a wildfire. If the weather is windy then the fire can spread very quickly, endangering properties and lives. One way that firefighters use to tackle such a problem is to light deliberate fires between the wildfire and any property. The fire burns up any vegetation and is then put out. In this way, the wildfire has no fuel to burn when it arrives.

Farmers in Central Valley lost $810 m during 2015.

Homeowners were told to stop using water to wash down their driveways, or water gardens. Using a hose to wash cars was banned. Californians caught ignoring water restrictions were shamed on Twitter using the hashtag #DroughtShaming.

Most HEP dams stopped producing electricity.

Cracks appeared in buildings and roads due to subsidence. This happened because water was being pumped out of the ground faster than it was being naturally replaced.

California usually produces nearly half of the fruits and vegetables grown in the USA. Shortages meant that prices rose by 6% in the shops. More food was imported.

There was a 36% increase in wildfires. Property was damaged and wildlife killed. 31,000 acres of oak habitat burned.

The state government paid $687m of its savings to compensate farmers and homeowners who lost earnings or property. This money could have been used for other much needed projects.

Salmon and trout died in the San Joaquin River Delta. An increase in river temperature means the water carries less oxygen for fish.

The state lost 17,100 agricultural jobs due to the drought.

▲ **Figure 16** How has the drought affected people and the environment?

▲ **Figure 17** A wildfire destroyed several vehicles stuck in a traffic jam on Interstate 15, California, in July 2015. No one was injured.

Activities

1 Study the data in Figure 18.
   a) Use the data to draw a series of graphs.
   b) Compare the rainfall of 2014 to both the normal rainfall and the 1976 drought.
   c) Identify one strength and one limitation of this evidence and the way you have chosen to represent it.

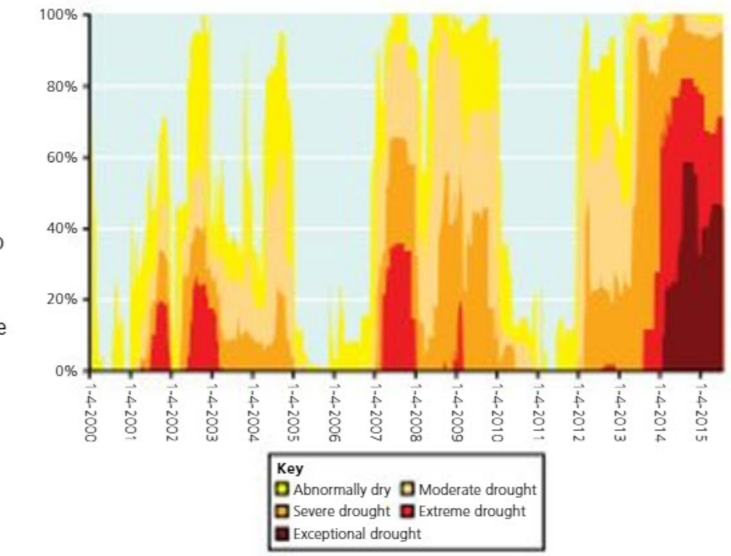
2 Other than the physical cause of the drought, suggest three other factors that may have led to water shortages.

Rainfall: monthly figures in mm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean rainfall	78	95	45	30	18	3	3	12	8	25	40	105
The 1976 drought	37	42	32	22	0	0	0	4	5	12	19	33
The 2014 drought	25	28	30	2	0	0	1	2	0	9	15	22

▲ **Figure 18** San Francisco, like the rest of California, is experiencing record low rainfall.

What are the long-term impacts?

The long-term impacts of drought could be more serious to the economy and way of life in California. The drought means that groundwater is not recharged by rainfall soaking into the ground. So the water table drops as water is abstracted quicker than it is replaced. In the long term, this is unsustainable for water supplies and the important farming businesses that rely on the abstraction of ground water.



▲ **Figure 19** The percentage of California experiencing drought conditions (2000–15).

I had to introduce compulsory water restrictions. Every town and city must show how it will reduce water use by 25% compared to 2013 levels. Agricultural users must provide the State with frequent reports about their medium term plans to reduce water consumption. Those who install toilets, domestic washing machines and showers must only use modern, low-water technologies.

Jerry Brown, Governor of California

We have introduced a mixture of voluntary and compulsory water conservation programmes. Watering gardens, cars and driveways is banned. We will offer subsidies to people who want to change their toilets and washing machines for newer models. We have sent out millions of leaflets offering advice on how to conserve water in the home.

Harlan Kelly, General Manager of the San Francisco Water Utility

California needs to reduce the amount of electricity it gets from Hydro Electric Power. Reservoirs must be used for water supply not electricity supply. For the customer this will mean higher prices as we turn to natural gas in the short term. This will certainly mean adding more greenhouse gases into the atmosphere. In the longer term, Californians will need to get more serious about using solar and wind power.

An energy expert

Californians must realise that this problem will not go away. We must pay more for our water and put money into desalination plants that remove salt from sea water. We must encourage farmers to grow crops that are less thirsty, even if the profits are lower and more food is imported. We must hold back some water supplies to protect delicate ecosystems, to allow nature to have a fair chance of survival.

An environmentalist

▲ **Figure 20** The response to the drought.

Activities

3 Study Figure 16.
   a) Sort the impacts of the drought into social, economic and environmental effects.
   b) Use a diamond ranking technique (see page 108) to rank the impacts of the drought.
   c) Choose the three most serious impacts. Explain why you have chosen each one.

4 How should the people of California respond to the drought in the long term? Write a short report highlighting how the house building, farming and energy industries could respond.

Enquiry

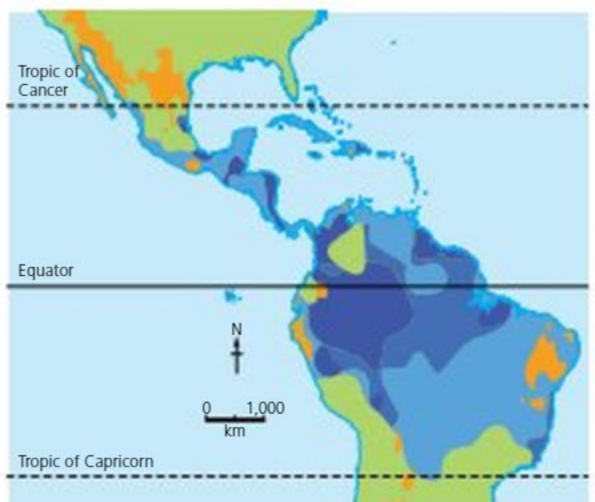
How severe was the 2014–15 Californian drought? Study Figure 19. Use evidence from this graph to describe the severity of the 2015 drought. Consider both the length of the drought and the percentage of California that was affected, compared to previous years.

Chapter 6 Patterns of weather and climate

Features of the tropical climate

Tropical climates are hot and wet. In the equatorial region of the Amazon Basin (within 5° of the Equator) there is between 1,500 mm and 2,000 mm of rainfall a year. London, by comparison, has an average of 593 mm of rainfall each year. The rainfall is created by heat. Large air masses are constantly warmed by the hot ground below. This creates massive zones of low pressure. These air masses are **unstable**, meaning that warm air is rising within them. The unstable air rises and spreads away from the Equator, creating the **tropical rain belt** (or **ITCZ**) that circles the globe. You can see some of the clouds forming in the ICTZ in Figure 3.

There are three main types of wet tropical climate. Two have seasonal patterns to their rainfall. Figure 2 summarises the features of these climates. It also introduces the other main tropical climate type we will explore in this chapter, the hot semi-arid climate.

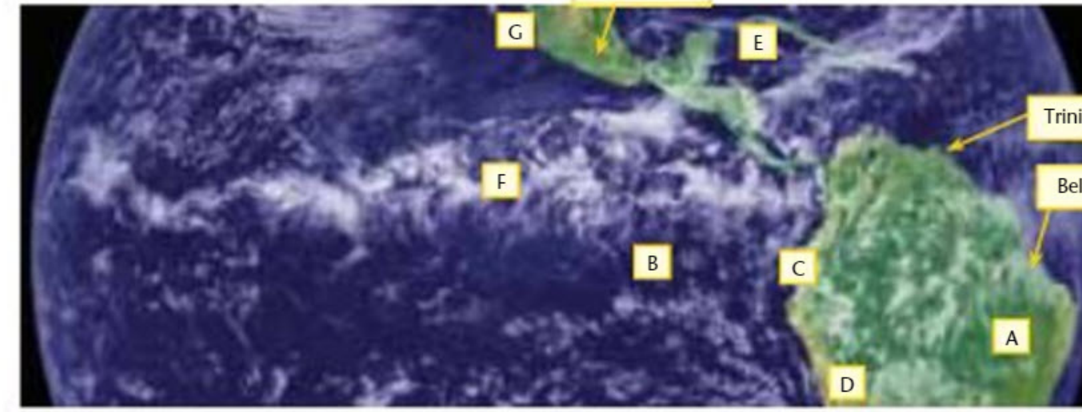


▲ **Figure 2** The distribution of the three main tropical climate types, and the hot semi-arid climate in Central and South America.

- Warm air rises within the unstable air mass
- Tiny water droplets join together
- Atmospheric molecules get further apart
- Water vapour in the air condenses
- The atmosphere is heated by the ground
- Rainclouds form
- The ground is heated strongly at the Equator by the Sun
- Air pressure falls

▲ **Figure 1** Atmospheric processes within the tropical rain belt.

Key	Climate type	Features
	Equatorial (also known as the tropical rainforest climate)	All months have an average precipitation of at least 60 mm, often much higher. There are no seasons. It is hot and wet throughout the year.
	Tropical wet (also known as the tropical monsoon climate)	It is hot in every month with no real seasonal variation in temperature. Precipitation is seasonal, with some months having exceptionally high rainfall totals but other months having less than 60 mm of rainfall.
	Tropical wet and dry (also known as tropical savanna climate)	It is hot in every month but some months are a little cooler than others. There are very distinct wet and dry seasons. During the dry season monthly precipitation totals are below 60 mm. There is usually less total annual rainfall than a tropical wet climate and the dry season is drier and longer.
	Hot semi-arid	This is the most seasonal of the four tropical climates. It is extremely hot in the summer and mild in the winter. There is a short wet season and a long dry season. There is a lower annual precipitation total than in the savanna type of climate.



▲ **Figure 3** A satellite image of the tropical rain belt over the Pacific, Caribbean and Central America.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Belem, Brazil	Average temp °C	26	26	27	27	27	26	26	26	27	27	27	27
	Average rainfall mm	318	358	358	320	259	170	150	112	89	84	66	155
Trinidad	Average temp °C	26	26.5	26	26.5	27	27	26.5	26.5	27	27	27	26
	Average rainfall mm	69	41	46	53	94	193	218	246	193	170	183	125
Mexico City, Mexico	Average temp °C	12	13	16	18	19	18.5	17.5	17.5	17.5	17.5	14	11.5
	Average rainfall mm	13	5	10	20	53	119	170	152	130	51	18	8

▲ **Figure 4** Three contrasting tropical climates (average 1961–90).

Activities

1 Study Figures 2 and 3 and, using an atlas:
  a) Name the countries A, B, C, D and E.
  b) Working in pairs, match the following label to letters F and G:
    - The atmosphere is warmed by the hot region below. Warm air rises, creating clouds and an area of low pressure.
    - Sinking air creates high pressure and cloudless skies.
  c) Explain why the clouds in Figure 3 indicate areas of low pressure.

2 Study Figure 2 and the phrases in Figure 1. Make a flow diagram that shows how large areas of low pressure are formed and how these create the tropical rain belt.

Enquiry

How and why does the tropical climate vary from one place to another?

a) Use the data in Figure 4 to create three tropical climate graphs (see page 185).
b) Use Figure 3 and an atlas to describe the location of each place.
c) Compare the rainfall patterns in all three locations. What type of climate does this indicate for each location?
d) Mexico City is 2,000 m above sea level. How does this fact help to explain the different climate here?

What are the features of the hot semi-arid climate?

Areas of hot semi-arid climate are found on the fringe, or outer edge, of arid areas. You can think of them as a transition zone, or a zone of change, between hot deserts and places with a seasonal tropical wet and dry climate. They are found largely between the Tropics of Cancer and Capricorn.

▲ **Figure 5** The world distribution of hot semi-arid climates.

What is the climate pattern like?

Temperatures vary throughout the year but, compared to the UK, remain high. The hot temperatures are due to the position of the Sun which remains high in the sky across the tropical belt throughout the year (see Figure 3 on page 284–285). The most striking feature of the climate is the low rainfall.

Hot semi-arid climates have low annual precipitation. Precipitation totals are lower than 600 mm per year. Precipitation falls only as rain. Snow never falls in this area except on the highest mountains, such as Kilimanjaro in Tanzania. The rainfall is seasonal. The dry period lasts for several months. Rainfall in the hot semi-arid zone is also unreliable. This means that, in some years, the usual rain storms of the wet season fail. The drought months are the result of stable descending air when air pressure remains high. This can be seen in Figure 2 on page 173. Even in the months when rainfall is higher, much of the water is quickly evaporated due to the relatively high temperatures.

▲ **Figure 6** A thunderstorm over Zinder, Niger.

Activities

1 Use Figure 5 to describe the location and distribution of the hot semi-arid climate zone.
2 Describe the vegetation in Figure 6. Suggest how this ecosystem might be affected by the climate of Zinder.

GEOGRAPHICAL SKILLS

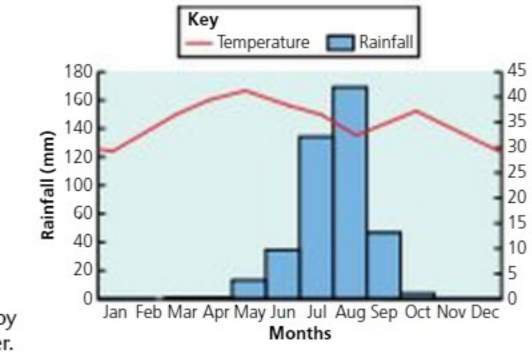
Describing a climate graph

Climate graphs are a form of compound graph because they have at least two parts:

- Bars that represent the precipitation total each month.
- A line that represents average temperatures.

When you are asked to describe a climate graph, there are four features to consider. Study the graph and ask yourself:

1 What is the total annual rainfall? This is calculated by adding all of the values for the rainfall bars together.
2 Are there distinctive wet or dry seasons? If so, when are they, and how long does each last?
3 What is the annual temperature range? This is the difference in temperature between the hottest and coldest times of the year.
4 Does the temperature show a distinctive seasonal pattern? If so, at what time of year are the hot and cold seasons?



▲ **Figure 7** Climate graph to represent the hot semi-arid climate of Zinder, Niger.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average maximum daily temperature °C	6	7	10	13	17	21	23	22	19	14	10	7
Average monthly precipitation (mm)	78	59	61	51	55	56	45	51	63	70	75	79

▲ **Figure 8** Climate data for London, UK (average 1961–90).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average maximum daily temperature °C	36	36	35	34	31	29	28	32	35	38	39	38
Average monthly precipitation (mm)	125	150	60	15	10	0	2	0	1	17	52	92

▲ **Figure 9** Climate data for Daly Waters, Australia (average 1961–90). Daly Waters is in the southern hemisphere.

Activities

3 Use Figure 8 to draw a climate graph for London in the same style as Figure 7.
4 Use Figure 8 to compare the climate of Zinder with London. You should compare:
a) The total annual precipitation
b) If one or both have distinctive wet/dry seasons
c) The annual temperature range
d) If one or both have distinctive hot/cold seasons.

Enquiry

How do places with a hot semi-arid climate in the southern hemisphere compare to places like Zinder which is in the northern hemisphere?

Study Figure 9.

a) Draw a climate graph for Daly Waters in the style of Figure 7.
b) Daly Waters is also in the hot semi-arid climate zone.
(i) Compare the climate data with Zinder. What are the similarities, what are the differences?
(ii) Suggest reasons for the differences.

The temperate maritime climate of the UK

The UK has a temperate climate, that is mild, without extremes of temperature. The climate is **maritime** because it is strongly influenced by air masses and ocean currents crossing the Atlantic Ocean. A feature of the climate is its variability throughout the year. The UK has four distinct seasons.

The main factors that affect the UK's climate are:

- latitude
- the track of the jet stream and its effect on the movement of air masses
- the effect of ocean currents
- altitude and aspect.

London	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature °C	6	7	10	13	17	21	23	22	19	14	10	7
Precipitation (mm)	78	59	61	51	55	56	45	51	63	70	75	79

Oban	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature °C	8	8	8	10	13	14	16	16	15	12	10	8
Precipitation (mm)	195	142	155	84	69	83	105	123	174	189	185	197

▲ **Figure 10** Climate data for London in the south east of England and Oban in the north west of Scotland show how the UK's climate varies across the country.

Effects of aspect and altitude

The northern, central and western parts of the UK have upland landscapes. Upland areas are much colder than lowlands. Temperatures decrease by 1°C for every 100 m in height. **Aspect**, or the direction of a slope, is another factor that affects temperatures as it determines the amount of sun received. South-facing slopes tend to be warmer than north-facing slopes.

Activities

1 Compare the climate of London to that of Oban, making sure that you comment on the seasonality of both graphs.

2 a) Make a sketch of Figure 11.

b) Complete and add the labels to the correct places on your sketch.

Flat valley floor

North-west facing slope

South-east facing slope

... will remain in shadow for most of the day in winter

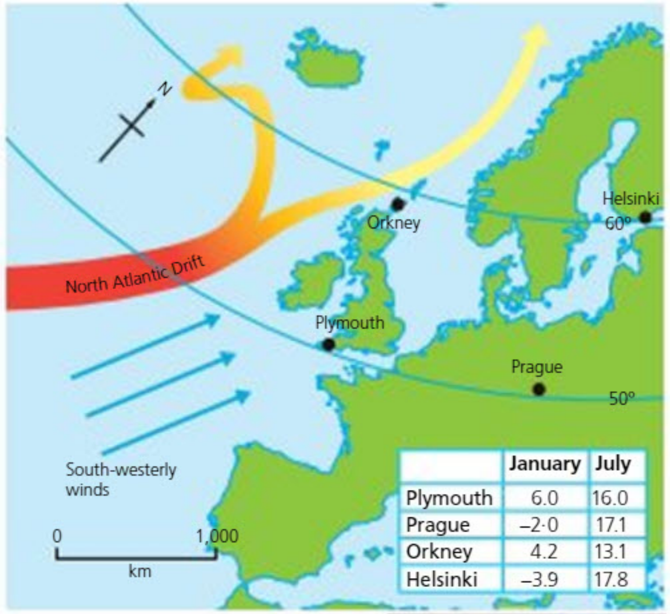
... is warmed by early morning sunshine

... will remain in shadow until the Sun is higher in the sky so frost remains longer in the morning

▲ **Figure 11** A valley in the Lake District shows how aspect can affect temperature.

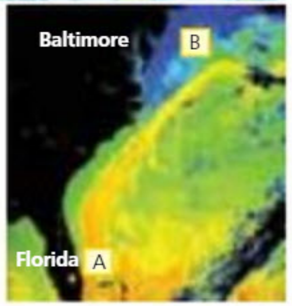
How does the maritime climate affect the UK?

Oceans contain flowing currents of sea water. These **ocean currents** circulate around the globe. They are able to transfer heat from warm latitudes to cooler ones. The Gulf Stream, and its extension the North Atlantic Drift, is one of these currents. It carries warm water from the Gulf of Mexico across the Atlantic, towards Europe. This warm water transfers heat and moisture to the air above it and influences the climate of the UK. It gives the UK a maritime climate which is warmer and wetter than other places at similar latitudes in **continental** parts of Europe.

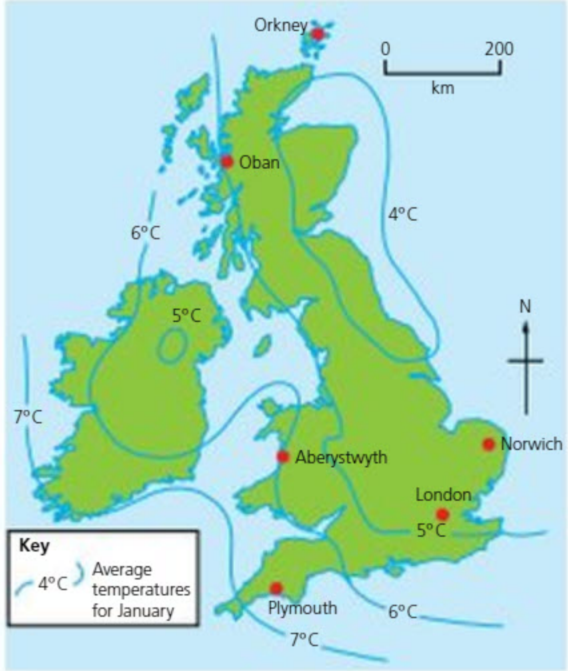


	January	July
Plymouth	6.0	16.0
Prague	–2.0	17.1
Orkney	4.2	13.1
Helsinki	–3.9	17.8

▶ **Figure 12** Comparing temperatures in the maritime climate of the UK to the more continental parts of Europe.



▶ **Figure 14** Satellite image of the Gulf Stream. The orange colours show warm water. Cold water is blue. Land is black.



▲ **Figure 13** Average temperatures for January. Lines of equal temperature are known as isotherms

Activities

3 Compare the temperatures that are at the same line of latitude in Figure 12. Explain why this pattern occurs.

4 a) Use Figure 13 to describe the January temperature in:

i) Aberystwyth

ii) Norwich

iii) Orkney.

b) Which parts of the UK have the lowest January temperatures?

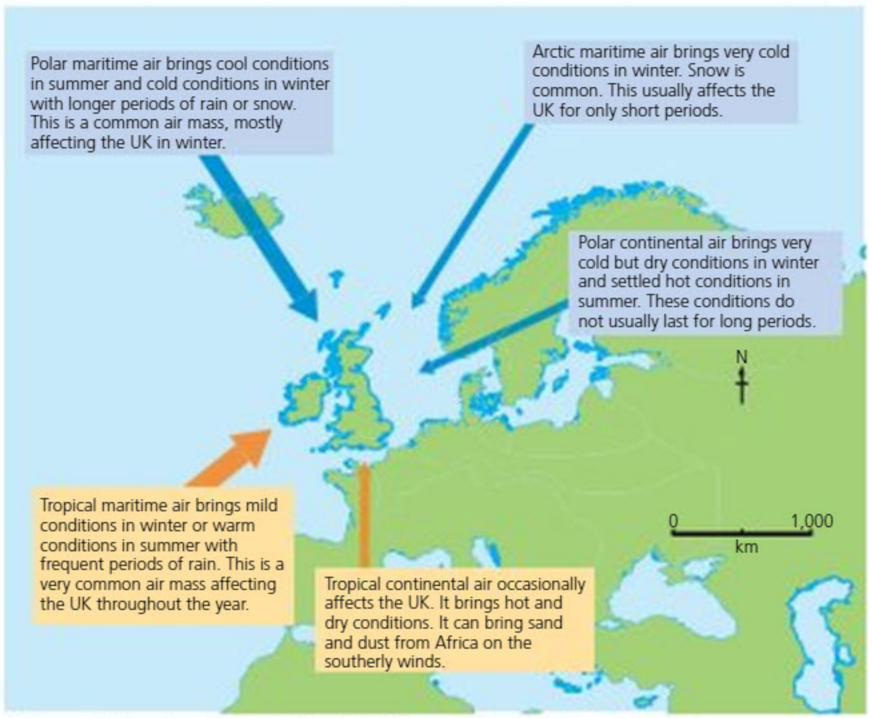
c) Draw a cross-section to represent the temperature change between Plymouth and Orkney.

5 a) Make a sketch of Figure 14. Label what is happening at A and B.

b) Suggest how the ocean current at B will affect the climate of Baltimore.

How do air masses affect the UK?

When **air masses** move towards the UK, they bring with them different kinds of weather. Five air masses affect the UK. These are shown in Figure 15. Usually, the UK receives air masses from the west. In the summer, air masses generally come from the south-west. In the winter, air masses generally come from the north-west. The line where these two air masses meet creates a zone of low air pressure. Warmer air from the south-west moves up over colder air to the north. This line is where depressions can form (see page 190). The three other air masses affect the UK less often, but they are responsible for some of the more extreme weather we receive.



▲ **Figure 15** How do air masses affect the UK?

Enquiry

Can you predict the weather?

Use the Weblink on this page to view the surface pressure chart for the next four days. Use the position of the high and low pressures to predict places across Europe that will have:

a) dry, settled weather
b) wet weather
c) the strongest winds.

www.metoffice.gov.uk/public/weather

Visit this website and click on the icon for surface pressure charts to see the current areas of high and low pressure across the UK.

How does the jet stream affect the UK's weather?

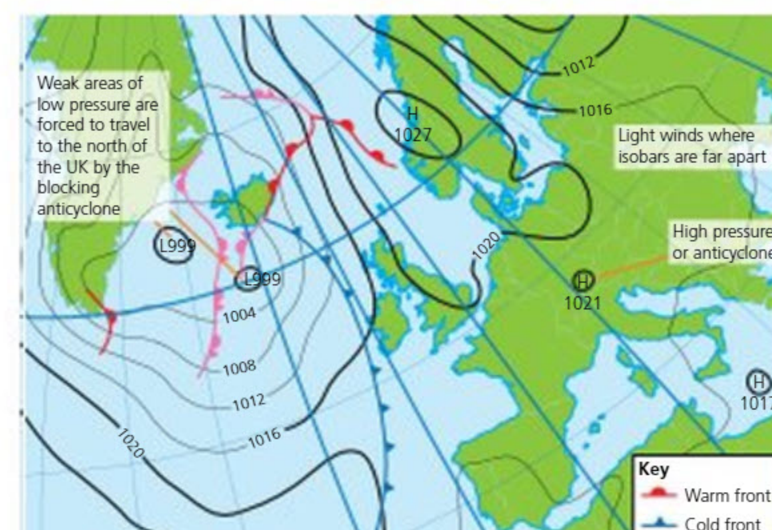
The jet stream (shown on page 179) is a strong ribbon of wind that circles the globe between 9 and 16 km above the surface of the Earth. It crosses over the UK, taking a sinuous course. It separates the cold polar air masses to the north from the warmer tropical air masses to the south.

▲ **Figure 16** Typical paths for the jet stream across the UK.

When the jet stream takes a northerly track to the west of the UK, it tends to drag high pressure over the UK from the south. Areas of high pressure, also known as **anticyclones**, bring periods of dry, settled weather. The track taken by the jet stream tends to shift slightly over time. But if it stays in the same position for several weeks, then the UK will experience a long spell of similar weather. When high pressure becomes fixed over the UK in winter, the weather is sunny and dry but cold, and especially cold at night. During the summer an anticyclone brings hot dry weather. If the jet stream becomes fixed in this position it can cause problems such as heatwaves or drought. The UK's worst drought in recent years was in 2003 when an anticyclone stayed over western Europe for several weeks.

Activities

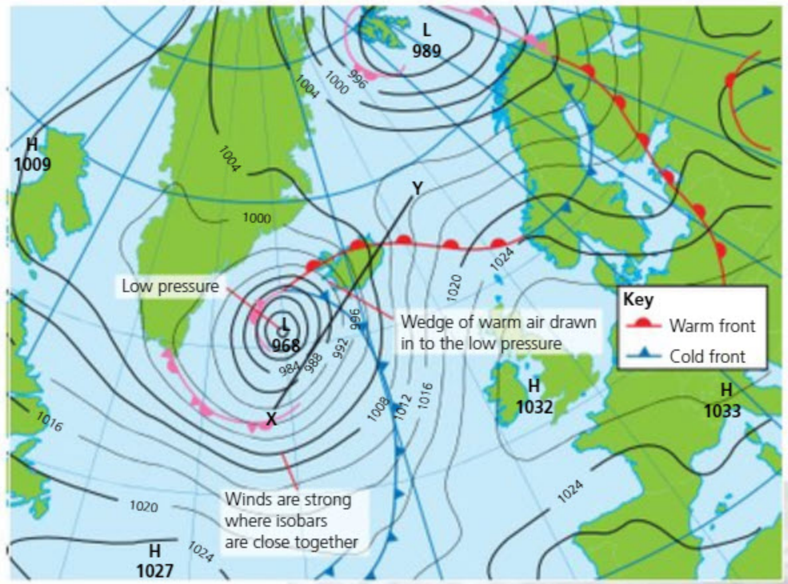
1 Use Figures 15 and 16 to explain:
   a) Why the more northerly route (track 1) of the jet stream will bring settled weather.
   b) Why the more southerly route (track 3) of the jet stream will bring unsettled weather.
2 Use Figure 17 and an atlas to describe:
   a) The location of the three zones of high pressure.
   b) The cold front.



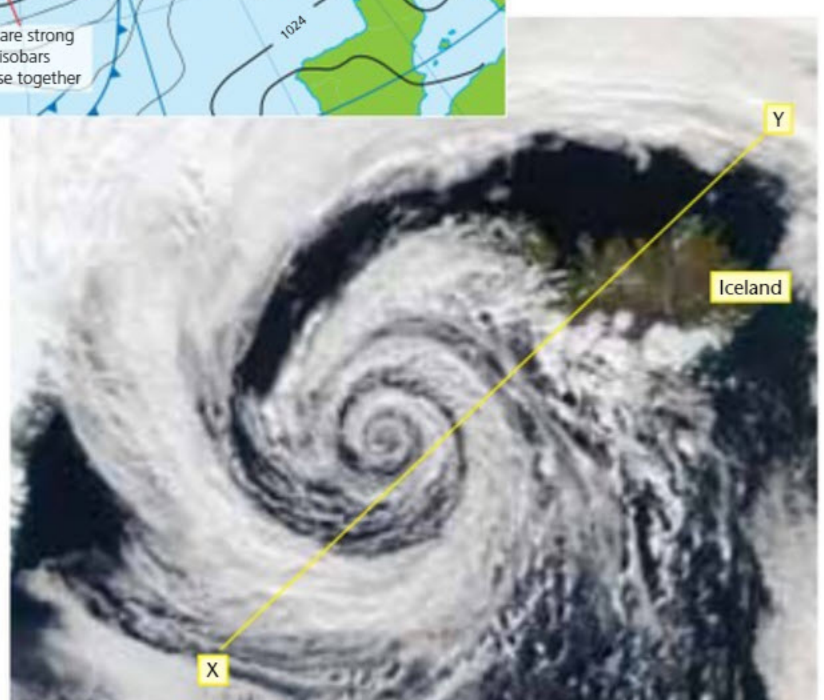
◄ **Figure 17** A weather map showing an anticyclone in August 2003.

The effects of low pressure (or depressions)

Regions of low pressure in the atmosphere are formed when air lifts off the Earth's surface. It is common for several cells of low pressure, also known as **depressions**, to form in the North Atlantic at any one time. They then track eastwards towards Europe, bringing changeable weather characterised by wind, cloud and rain. Depressions are more likely to be deeper (have lower pressure) in the winter months. These weather systems can bring damaging gusts of wind and large waves onto the coast, as well as heavy rain like the storms that battered the UK in the winter of 2013–14. However, low pressure in the summer months is quite common: depressions during July 2012 caused flooding.

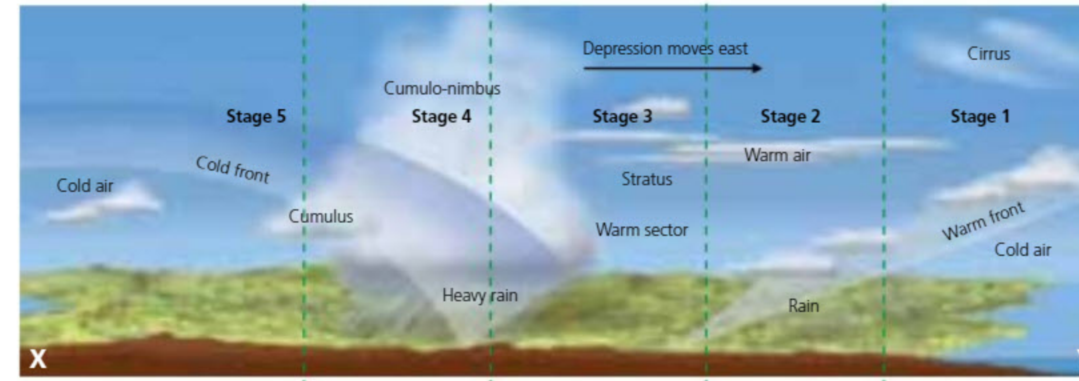


◀ **Figure 18** Weather map showing a deep area of low pressure in the North Atlantic (4 September 2003). A cross-section through the atmosphere along the line X–Y is shown in Figure 20.



▶ **Figure 19** A satellite image of the same area of low pressure off Iceland (4 September 2003).

Inside the depression there is a battle between huge masses of warmer and colder air. These air masses revolve slowly around each other in an anti-clockwise direction (in the northern hemisphere) as the whole system tracks eastward. As the warmer air rises and rotates, its moisture condenses, forming huge banks of cloud. Seen from above, these curving banks of cloud give the depression a characteristic shape.



	Stage 5	Stage 4	Stage 3	Stage 2	Stage 1
Air mass	Cold	Cold			
Temperature °C		7	11	6	5
Wind strength		Very strong	Strong		
Wind direction	SSW	S	SSE	SE	E
Cloud / rain		Thick, low cloud and heavy rain	Some high cloud and clear skies No rain		

▲ **Figure 20** Weather that would have been associated with the easterly progress of the depression shown in Figures 18 and 19.

Feature	Cyclones or depressions	Anticyclones
Air pressure		High, usually above 1,020 mb (millibars)
Air movement		Sinking
Wind strength		Light
Wind circulation		Clockwise
Typical winter weather		Cold and dry. Clear skies in the daytime. Frost at night.
Typical summer weather		Sunny and warm

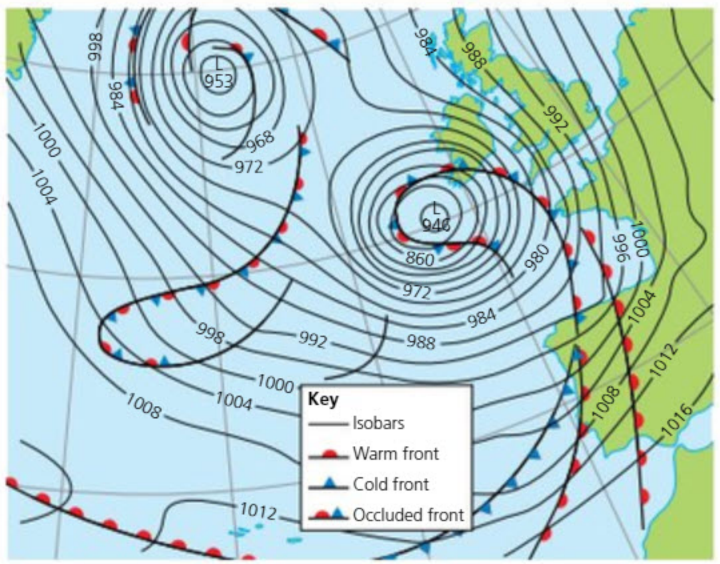
▲ **Figure 21** Comparing cyclones and anticyclones.

Activities

1 Use an atlas and Figures 18 and 19. Describe the location of the areas of high and low pressure.
2 a) Make a copy of the table in Figure 20. Use the evidence in Figures 18 and 19 to complete the missing sections.
  b) Imagine you are a weather forecaster working in north-east Iceland. Prepare a local weather forecast for the next few hours.
3 Make a large copy of Figure 21 and use the information on these pages to complete the blank spaces.

The winter storms of 2014

Between December 2013 and February 2014, the UK suffered its stormiest period for 20 years. Storms, created by extreme low pressure, battered the North Sea coastline during December 2013 (see pages 146–7). The coasts of Devon and Cornwall were badly damaged by a combination of fierce winds and huge waves. Much of Somerset, which had already been affected by flood water from earlier storms, received a further soaking. South-westerly winds reached speeds of 146 kmph on the exposed coast of Devon. Rainfall figures were well over twice the monthly average, with a high of 210 mm in Somerset.



◀ **Figure 22** The weather map for 4th February 2014.

◀ **Figure 23** The coastal rail line at Dawlish was destroyed by the winter storms of 2014.

Activities

1 Study Figure 22.
   a) Describe the location of the area of low pressure.
   b) What do the isolines on this map tell you about the strength and direction of the winds?
2 Write a weather forecast for the southern half of the UK on 5 February 2014. Use Figure 19 to help you interpret Figure 22.

The short-term effects of the winter storms of 2014

Social impacts	Economic impacts	Environmental impacts
Hundreds of people were still in temporary accommodation for months after the flood levels went down. This disrupted family and school life.	Network Rail estimated that the cost of repairing the severed rail line near Dawlish was £35 million.	Conservationists have reported that 600 guillemots, puffins, razorbills and other birds have been killed in the storm.
The dirty secret of flooding is sewage. Homes and possessions were left with a coating of mud and raw sewage. Disease is a threat. Many homes are faced with needing new electrics and re-plastering.	The tourist industry was badly hit. The value of lost visitor days in January and February was thought to be £8m. Forward bookings went down by 20%. Spring and Easter are normally peak periods.	An ancient formation known as Pom Pom Rock has been destroyed by ferocious weather off Portland. The rock could not withstand the high winds and stormy seas.
During the floods, it was the most vulnerable groups who were at serious risk. The very young, the very old, the unwell, and people with disabilities found it difficult to move to higher floors as the water levels started to rise.	Some farmers lost as much as 95% of their land under water for many weeks. Livestock farmers had to evacuate animals. Instead of grazing the fields, sheep and cattle were fed with reserve stocks of animal feed.	Where embankments line rivers, floodwater that overtops the banks gets trapped for long periods of time. This lying water can drown all the worms and insects that live in the soil. These are vital food for birds like waders.

▲ **Figure 24** The short-term effects of the winter storms of 2014 in the Somerset Levels.

I think that concrete walls lining our river banks and coastlines are no longer the solution. A "back to nature" approach is needed to return water systems to the natural, slow systems they once were. Fields can be used as temporary ponds, and vegetation can soak up the water.

Academic researching flood protection in the UK

A huge amount of rain fell on the Somerset Levels, far greater than the river channel could ever cope with. We should simply stop building in flood prone areas.

Scientist at the Meteorological Office

Despite the thousands of homes being flooded during this record breaking winter, about one million homes and businesses have been protected by the defences that held out.

Officer at the Environment Agency

Attention needs to shift towards individual households being prepared for extreme weather. Measures can be simple from inflatable toilet bungs to stop sewage overflows, to slot-in door protectors. We can rewire electrical circuits nearer the ceiling. We can even build homes on stilts if they are in a flood prone area.

Government Minister

The government must reverse its spending cuts which target flood defence schemes. It is not cost effective to cut schemes that aim to reduce the impact of wild weather and then go on to make large compensation payments to those affected.

Local Councillor

▲ **Figure 25** Attitudes to the extreme weather of 2014.

Activity

3 Select one of each of the social, economic and environmental effects of the winter storms. Explain why you think your chosen effects are the most serious of the impacts shown.

Enquiry

What do you think is the most sustainable response to the threat of similar extreme weather events in the future?

a) Discuss the viewpoints in Figure 25.
b) Use these ideas, and your own, to suggest how the UK should respond to severe winter storms in the future.
c) Justify your answer.

Chapter 7 Climate change

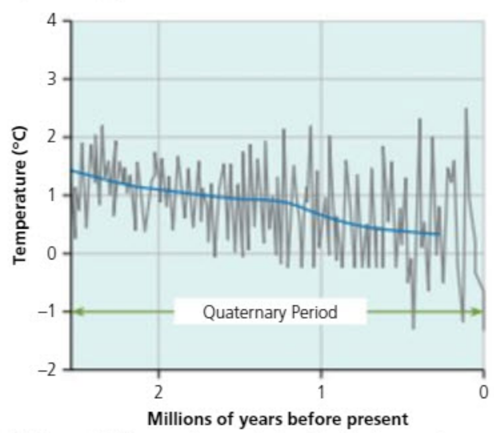
How has climate changed during the Quaternary period?

The Quaternary, sometimes called the Pleistocene, is the most recent period of geological time. It is a period of Earth's history that has been dominated by cold climates and ice shaping the land. At the beginning of the Quaternary, the polar ice sheets were far bigger than they are today, as you can see in Figure 1. Throughout the 2.6 million years of the Quaternary, the climate has changed constantly. There have been periods, known as **glacials**, when the polar ice has reached much further south, covering large parts of the earth. At other times, known as **inter-glacials**, the polar ice retreated. Scientists have evidence of 60 different cycles of ice advance and retreat.

▲ **Figure 1** The extent of the ice during a colder period of the Quaternary period.

Are temperatures rising or falling?

With all the talk about global warming, Figure 2 may come as a bit of a surprise! The blue line shows the general trend of a cooling climate over the last 5 million years. The black lines show fluctuations around the general trend. Temperatures at the beginning of the Quaternary were much colder than they had been in the previous geological time period, known as the Tertiary. Since the Quaternary began, you can see that cooling has continued but that fluctuations have been much wilder. Evidence shows that the last 400,000 years have been a particularly unstable period, with very significant changes in temperature between glacial and inter-glacial periods. The ice sheets retreated about 10,000 years ago and the Earth is currently experiencing an inter-glacial period. However, the ice has not disappeared. Technically, we are living in an ice age!



▲ **Figure 2** Climate change during the Tertiary and Quaternary.

Activities

1 Study Figure 1.
  a) Describe the amount and distribution of the ice sheets.
  b) Study the Mediterranean region carefully. Suggest why the Mediterranean Sea appears to be smaller than it is today.

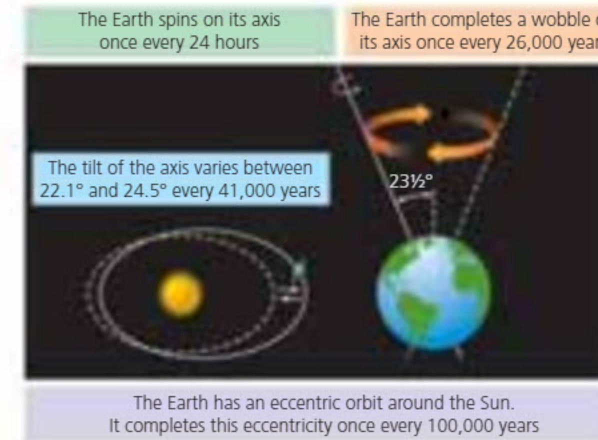
2 Why does the surface temperature of the Earth change when the tilt of the Earth varies due to the natural 'wobble' and due to an eccentric orbit?

3 How does the information on pages 194–5 explain why some people remain sceptical about the threat from global warming?

What are the natural causes of climate change?

There is much debate about the cause of the change from glacial periods to inter-glacial periods. The most commonly accepted theory is based on the work of a scientist called Milankovitch. He suggests that the warmer and cooler periods are caused by a combination of two things:

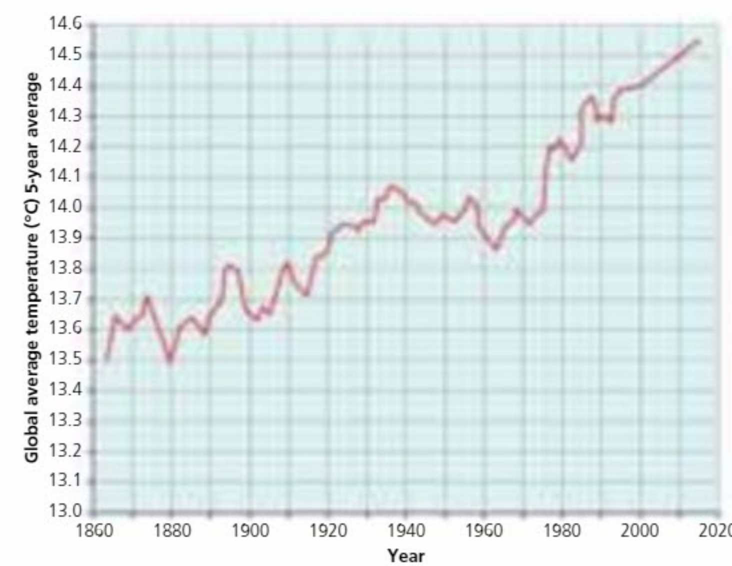
- The natural wobble of the earth as it moves around the Sun. This affects the tilt of the Earth and the amount of energy it receives from the Sun.
- The fact that the Earth does not have a circular orbit around the Sun. The orbit is eccentric. It is sometimes closer to the Sun, sometimes it is further away.



▲ **Figure 3** Why does the Earth's climate fluctuate?

So why worry?

In the last 150 years, records of world temperature change have become more accurate. Figure 4 shows changes in the average global temperature since 1860. Those who are sceptical about climate change argue that the increase in temperature is just part of the normal cycle of an inter-glacial period. Those who say the world needs to worry about climate change point to the fact that the change over time is now very fast. Indeed, since 1960, the rate of increase has been even greater.



▲ **Figure 4** The increase in average global temperature since 1860.

Activity

4 Study Figure 4. How far does this graph suggest that the sceptics may be wrong to dismiss the threat of global warming? Use figures from the graph to support your answer.

Enquiry

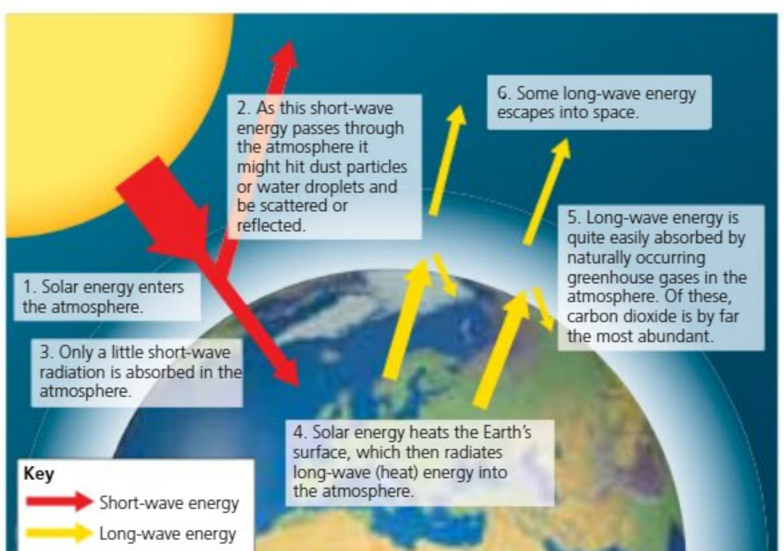
To what extent are we still living in an ice age? Use an atlas or the internet to compare the amount and distribution of permanent ice today with that shown in Figure 1.

▲ **Figure 5** Wildfires in San Marcos, California (May 2014). 13,000 people had to be evacuated.

What is the greenhouse effect?

The greenhouse effect is a natural process of our atmosphere. Without it, the average surface temperature of the Earth would be –17° Celsius rather than the 15° Celsius we currently experience. At these temperatures, life would not have evolved on Earth in its present form and we probably wouldn't exist!

The greenhouse effect, shown in Figure 6, means that Earth's atmosphere acts like an insulating blanket. Light (short wave) and heat (long wave) energy from the Sun passes through the atmosphere quite easily. The Sun's energy heats the Earth and it radiates its own energy back into the atmosphere. The long-wave heat energy coming from the Earth is quite easily absorbed by naturally occurring gases in the atmosphere. These are known as **greenhouse gases**. They include carbon dioxide (CO_2), methane (CH_4) and water vapour (H_2O). Carbon dioxide is the fourth most common gas in the atmosphere. It occurs naturally in the atmosphere as a product of respiration from all living things. So carbon dioxide has existed in the atmosphere for as long as there has been life on Earth. Methane and water vapour have been in the atmosphere for even longer, so the greenhouse effect has been affecting our climate for thousands of millions of years.



▲ **Figure 6** The greenhouse effect.

Activity

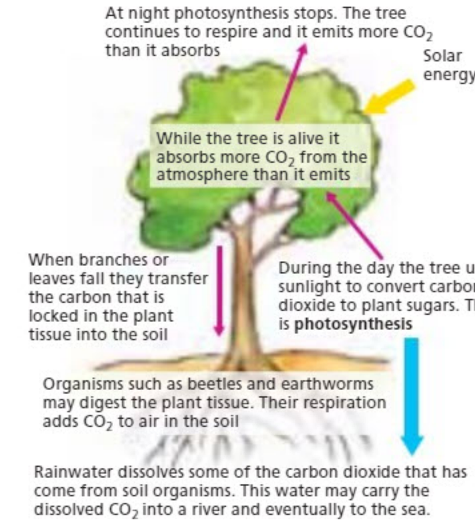
1 Use Figure 6 to explain the greenhouse effect. Make sure that you use technical terms such as long-wave and short-wave energy in your answer.

How have people's actions affected the greenhouse effect?

Carbon is one of the most common elements in the environment. It is present in:

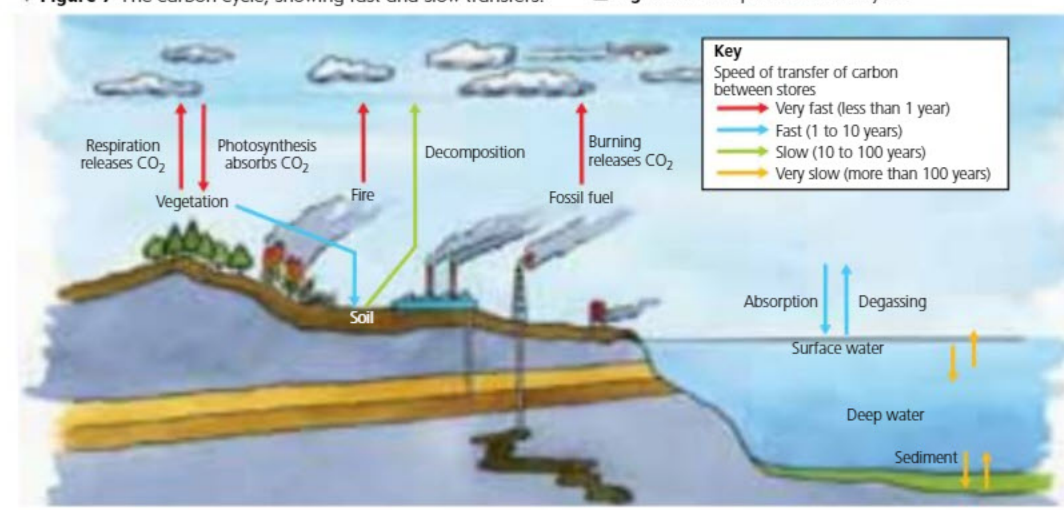
- all organic substances, i.e. all living things
- simple compounds such as CO_2, which exists as a gas in the atmosphere and is dissolved in the oceans
- complex compounds, for example, hydrocarbons found in fossil fuels such as oil, coal and gas.

Carbon is able to transfer from one part of the environment to another through a series of biological processes, such as respiration, and chemical processes such as solution. These transfers take place between parts of the environment that release carbon, known as sources, and parts of the environment that absorb the carbon over long periods of time, known as **carbon sinks**. The transfer between sources and sinks is shown in the carbon cycle diagrams, Figures 7 and 8.



▲ **Figure 8** A simplified carbon cycle.

▼ **Figure 7** The carbon cycle, showing fast and slow transfers.



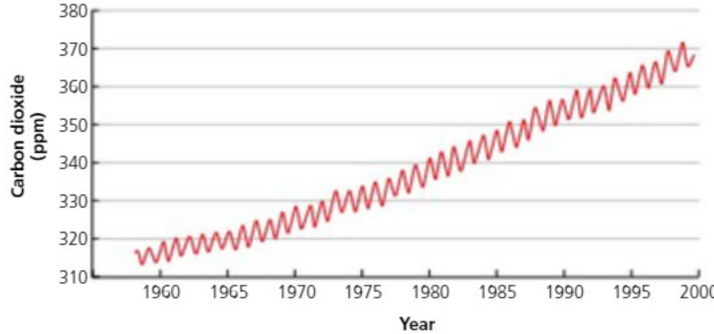
Activities

2 Study Figures 7 and 8.
  a) Describe the human actions that release CO_2 into the atmosphere.
  b) Explain the processes that allow forests to act as a carbon sink.
  c) Give two reasons why the burning of tropical rainforests will increase the amount of CO_2 in the atmosphere.

3 Use Figure 7.
  a) Describe the difference in the speed of transfer of carbon in the natural part of the cycle compared with the part of the cycle affected by human action.
  b) Explain what difference this makes to the amount of carbon stored in the atmosphere compared with the long-lasting carbon sinks. Explain why this is alarming.

How conclusive is the evidence for climate change?

In 1958 a team of scientists began to take regular measurements of carbon dioxide concentrations from the atmosphere. They realised that local levels of CO_2 could be higher if the sampling took place close to industry or traffic congestion, so they decided to conduct their tests on Mauna Loa, Hawaii. They thought that this would give them readings that would represent average CO_2 levels in the atmosphere. The sampling has been conducted regularly ever since and the graph, known as the Keeling Curve, is shown in Figure 9.

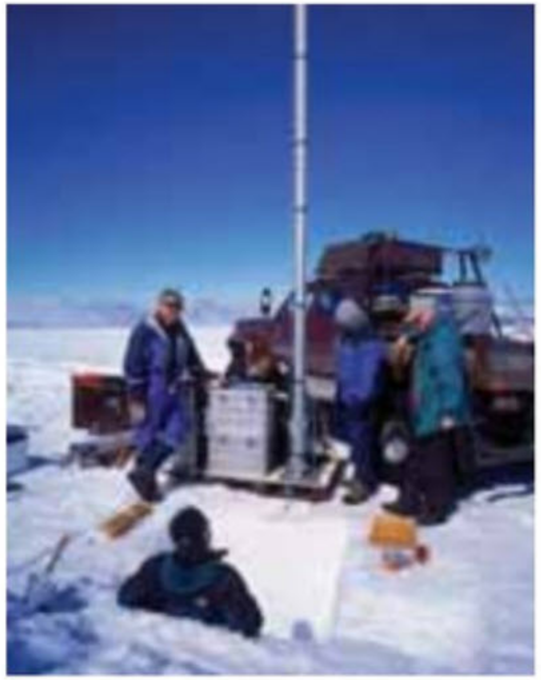


▲ **Figure 9** The Keeling Curve shows the rise of carbon dioxide in the atmosphere since monitoring began in 1958 (ppm = parts per million).

Evidence from the ice cores

We have already seen that scientific evidence from Hawaii proves that carbon dioxide levels have been rising steadily since 1958. However, can we be certain that this isn't part of a natural cycle? Perhaps carbon dioxide levels vary over long periods of time and the recent rise is part of one of those cycles.

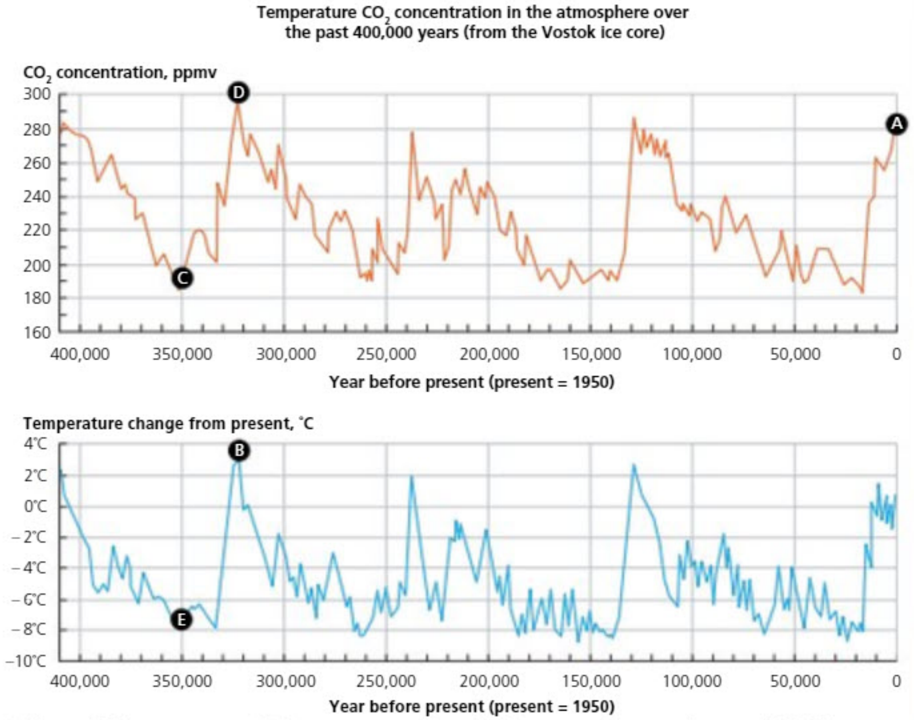
Scientists working in both Greenland and Antarctica have been investigating information trapped in the ice to uncover evidence of past climate change. The snowfall from each winter is covered over and compressed by the following winter's snowfall. Each layer of snow contains chemical evidence about the temperature of the climate. Each layer also contains trapped gases from the atmosphere that the snow fell through. Gradually the layers turn to ice. Over thousands of years these layers have built up and are now thousands of metres thick. By drilling down into the ice, scientists can extract older and older ice cores. Chemical analysis of these ice layers and the gases they contain reveal a record of the climate over the last 420,000 years. This evidence suggests that the climate has indeed gone through natural cycles of colder and warmer periods known as glacials and inter-glacials. They also show that levels of carbon dioxide in the atmosphere have also gone up and down as part of a natural cycle.



▲ **Figure 10** Scientists taking ice core samples from the ice sheet in Iceland.

Activity

1 a) Describe and explain the trend of the Keeling Curve.
  b) Explain why the scientists chose Hawaii as a good place to collect their samples.



▲ **Figure 11** Temperature and CO_2 concentration (ppm) in the atmosphere over the past 420,000 years.

Carbon dioxide concentrations reached a maximum of 300 ppm in the warmest periods

Carbon dioxide concentrations dropped to 180 ppm during the coldest periods

Narrow peaks in the temperature record represent short warm episodes (interglacials)

Broad dips in temperature represent glacial periods

Carbon dioxide concentrations were at about 280 ppm in 1950

Activities

2 Use Figure 11.
  a) Match the five statements to the correct place on the graph shown by the letters A, B, C, D and E.
  b) Use the graph to copy and complete the following statement:
  The graph shows natural cycles of .... periods and .... periods. Average temperatures were higher than present on *three/four/five* occasions. These are known as .... periods. The current inter-glacial period appears to have lasted much *longer than/shorter than* previous periods.

3 Use your understanding of the greenhouse effect to explain why reduced levels of carbon dioxide in the atmosphere might be linked to cooler periods of climate.

4 Compare Figure 11 with Figure 9.
  a) How many times in the last 420,000 years have CO_2 levels been as high as in 2000?
  b) Based on the ice core data, do you think that the Keeling Curve fits into a similar natural cycle of carbon dioxide concentrations? Explain your answer fully.

Enquiry

How conclusive do you find the evidence for:
a) natural cycles of climate change over the last 420,000 years?
b) an unusual rise in carbon dioxide levels since 1958?

How is global warming affecting climate and ecosystems?

We have seen that some extreme weather events are being attributed to global warming. The theory is that pollution is causing heat to be trapped in our atmosphere. The extra heat energy may be causing:

- more violent storms such as Cyclone Pam that hit Vanuatu in 2015 (pages 176–7)
- more heatwaves, like the one in California in 2013–2015 (pages 178–81).

In addition, global warming is likely to affect global patterns of climate. Desert regions may become drier. The wet tropical regions which contain our rainforests may also receive less annual rainfall. That's why the media often refers to global warming as climate change. One region where there is evidence of climate change is the Arctic.

How is climate change affecting wildlife in the Arctic?

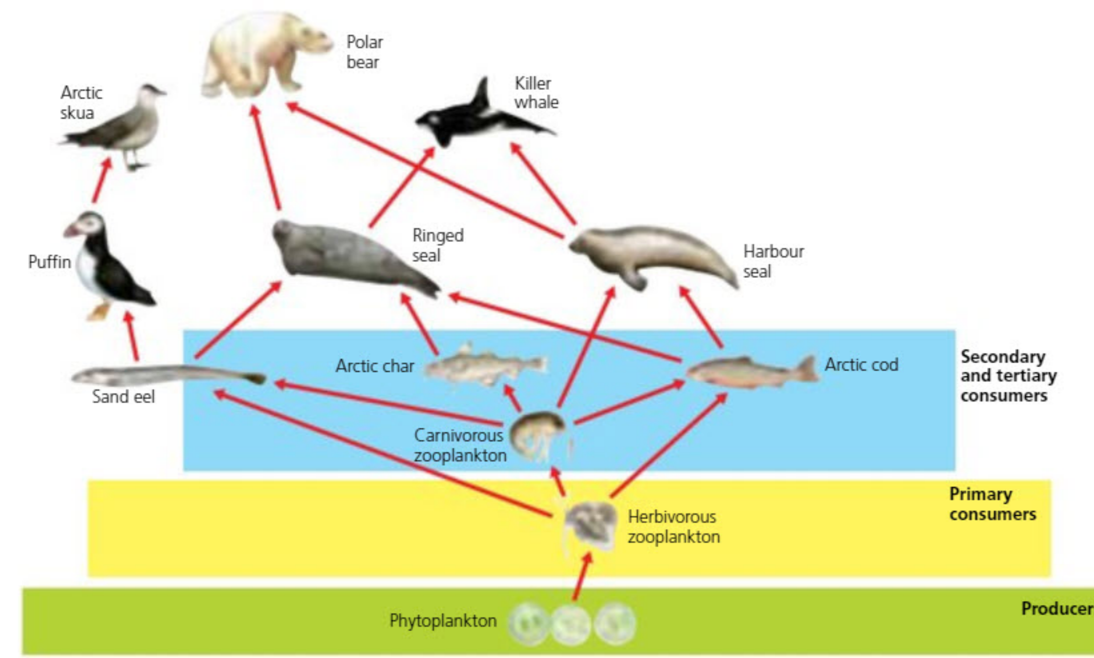
The polar bear is the world's largest land predator. There are about 20,000 polar bears living in the wild, but their numbers are falling. There are several possible reasons. One is chemical pollution. Bears are at the top of the Arctic food chain and can accumulate poisons in their bodies that they have taken in from the animals they have eaten. However, climate change is increasingly seen as the main reason for the decline in numbers.

There are 1,200 polar bears living in the region of Hudson Bay, Canada. This population of polar bears has been monitored by the Canadian Wildlife Service (CWS) for more than 40 years. Their results show that earlier thawing of sea ice in Hudson Bay is threatening the survival of polar bears.

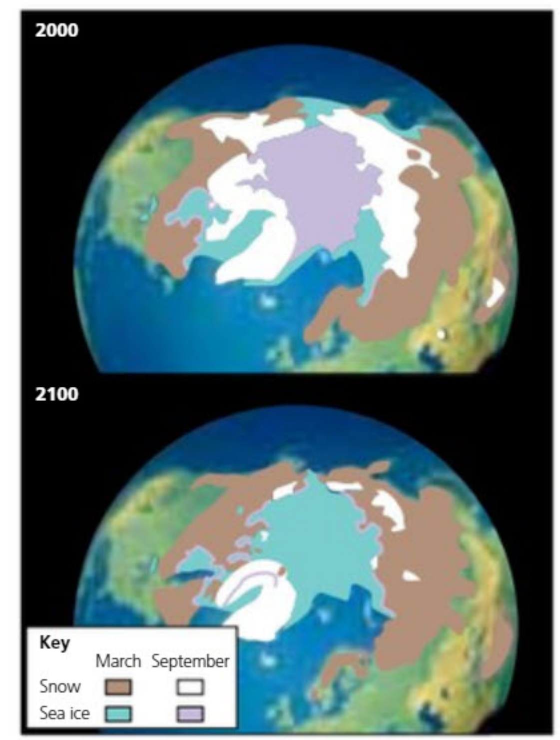
Adult polar bears need the sea ice to remain frozen for a few weeks in the late spring so they can hunt for seals on the ice. Once the ice breaks up and melts, the seals become much harder to catch. CWS studies show that the ice now melts three weeks earlier than it did when studies began in the early 1970s. For each week that the thaw comes early, the bears have less chance to feed, and come on shore 10 kg lighter. Consequently, some polar bears do not have enough fat reserves to survive the summer months when food is harder to catch. The consequences of further climate change are worrying:

- More young bears and pups will starve over the longer summer.
- Females will be less fertile.
- Hungry bears are more likely to forage for food in towns where they come into conflict with people.

▲ **Figure 12** Distribution of polar bears and the location of Hudson Bay.



▲ **Figure 13** The Arctic food web.



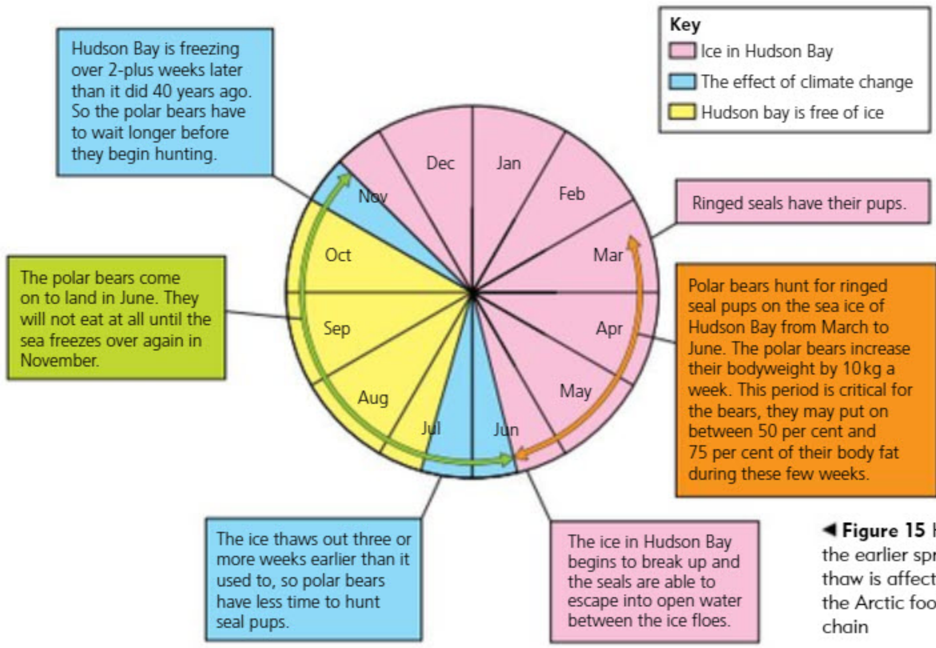
◀ **Figure 14** The extent of sea ice in 2000 compared with the predicted extent in 2100.

Activities

1. Study Figure 12.
   a) Describe the location of Hudson Bay.
   b) Describe the distribution of polar bears.
2. a) Use Figure 13 to draw a food chain which includes the polar bear.
   b) Explain what will happen to this food web if the polar bears are unable to catch enough ringed seals to survive the summer.
3. Look at Figures 12 and 14.
   a) Compare the distribution of polar bears to the sea ice in March 2000.
   b) Describe what is predicted to happen to the sea ice in March 2100.
   c) Compare the distribution of September sea ice in 2000 to 2100.

How do warmer temperatures affect the Arctic food chain?

We have seen that, as the Arctic warms, the sea ice breaks up and melts a little earlier in spring. This makes it harder for polar bears to catch seals. Figure 18 shows the average date at which the sea ice broke up in different parts of Hudson Bay.



◀ **Figure 15** How the earlier spring thaw is affecting the Arctic food chain

▲ **Figure 16** Polar bear, with two cubs, hunting a seal on the sea ice.

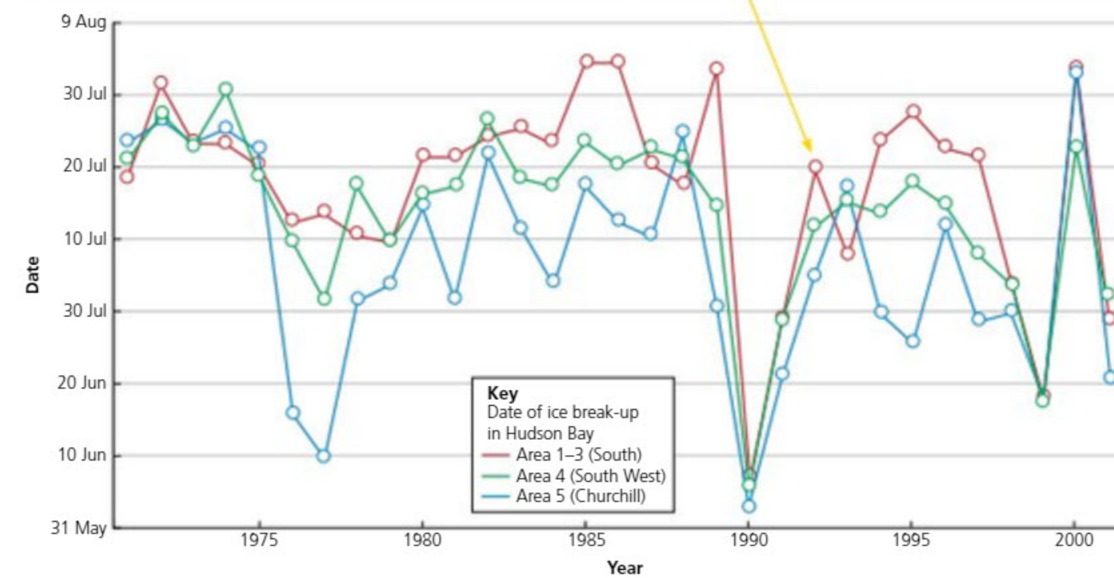
The potential for fairly significant rises in temperature in Arctic regions seems to be quite high. And should that happen, especially over a time scale of decades, the possibility of marine mammals being able to adapt rapidly enough is very low.

▲ **Figure 17** The opinion of Dr Malcolm Ramsey, Professor of Biology at the University of Saskatchewan in Canada.

How do volcanic eruptions affect climate?

Large volcanic eruptions can eject dust and sulphur dioxide (SO_2) into the lower stratosphere – a layer in the atmosphere that is 15–25 km above the Earth. At this altitude, the jet stream is able to carry the volcanic material in a belt right around the globe. The mixture of dust and SO_2 form an **aerosol** – tiny droplets that scatter sunlight back into space. This can have the effect of reducing the amount of solar energy that reaches the Earth's surface, so average temperatures can be reduced slightly for a year or more.

The eruption of Mount Pinatubo in 1991 sent so much dust into the atmosphere that for the next year or so there was a temporary cooling of the whole planet by around 1°C. In 1992, when the polar bears came off the ice in July, they were heavier and more of their cubs survived than in the previous year.



▲ **Figure 18** The average date of ice break-up in Hudson Bay.

Activities

1 Study Figure 18.
   a) What was the average date of the thaw between 1971 and 1975?
   b) What was the average date of the thaw in 1999 and 2001?
   c) Which of the two populations of polar bears will be more threatened by an earlier thaw? Justify your choice.

2 a) Use Figure 15 to help explain why polar bears are unable to adapt to climate change.
   b) Does it matter that polar bears might be threatened with extinction in the next few decades? Justify your point of view.

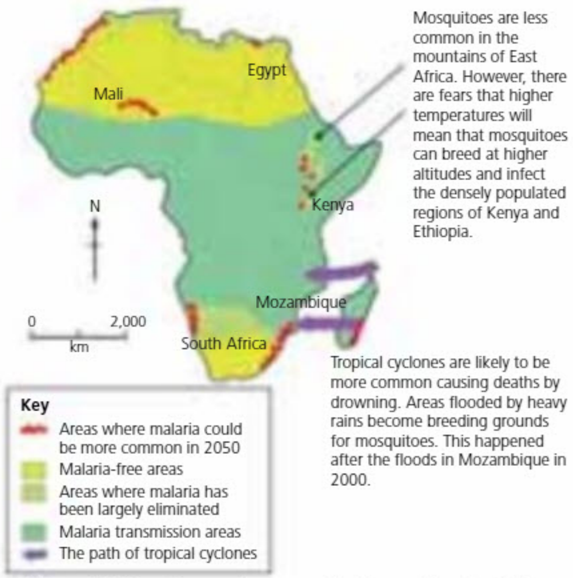
Enquiry

Why do changes in climate affect the polar bear population?

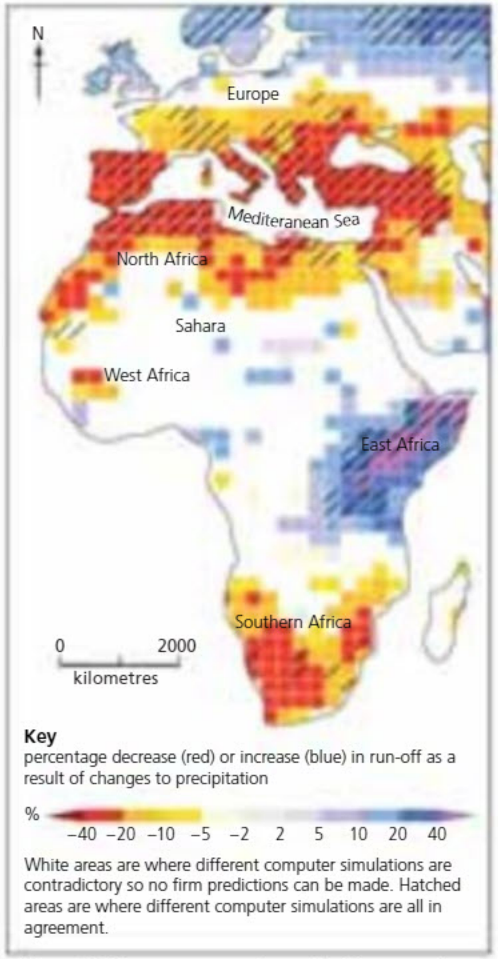
a) Describe the date of the thaw in the years between 1990 and 1993.
b) Explain why this happened and the effect it had on the bears.
c) How does this evidence support the view that climate change can have a direct effect on polar bear populations?
d) Draw a flow chart to show how climate change is affecting the polar bears.

How might climate change affect water supply and health in Africa?

Climate change is likely to have serious impacts on people and environments in Africa. More frequent extreme weather events, increased temperatures and more irregular patterns of rainfall will have effects on crop production. These, in turn, could damage some economies and cause food shortages. It is also likely that the mosquitoes that carry malaria will move into new regions and the number of people at risk of infection will increase. Perhaps the largest concern is that the number of people who suffer **water stress** (i.e. do not have access to enough fresh water) will increase. There are currently 1.7 billion people worldwide who suffer water stress. Most of these are in Africa. As the population grows and the climate changes, it is expected that this number will rise to 5 billion by 2025.



▲ **Figure 19** How climate change could affect malaria by 2050.



▲ **Figure 20** Future patterns of run-off in Europe and Africa in 2090–99 (compared with 1990–99).

Activities

1. Use Figure 20 to describe the distribution of countries which are expected to have:
   a) much less run-off
   b) much more run-off.
2. a) Explain how increased run-off might have positive and negative effects for people.
   b) Suggest why African countries might find it harder to cope with changes to run-off than European countries.

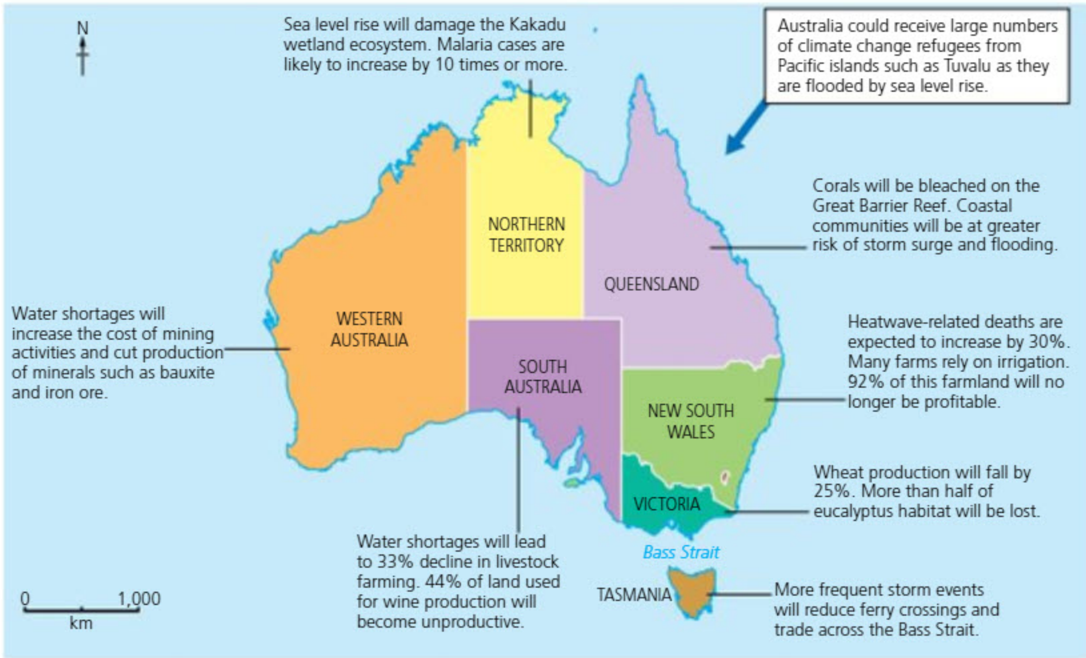
Enquiry

How is the risk of malaria likely to change?

a) Use Figure 19 to describe the zone of Africa which is currently at risk from malaria.
b) Describe how and why this zone is likely to change by 2050.

How might climate change affect Australia?

The Australian Bureau of Meteorology has predicted that Australia is likely to experience an increase in average annual temperature of 1.3˚C by 2030 (compared with average temperatures recorded between 1986 and 2005). They predict more extreme droughts and less rainfall for southern regions of this vast country. They warn that average temperatures could rise by more than 5˚C by 2090 if little global effort is made to cut the amount of greenhouse gases entering the atmosphere.



▲ **Figure 21** The predicted impacts of climate change on Australian states by 2100.

Activity

3. Use Figure 21. Select three impacts and explain how climate change may cause these issues.

Enquiry

How serious is the threat of climate change in Australia?

a) Select five impacts of climate change in Australia and place them in rank order. The top-ranked one should be the most problematic or have the most serious impact.
b) Justify your ranking.
c) Suggest who should be responsible for trying to fix the most serious of these problems.

▲ **Figure 22** The Kakadu wetlands will be damaged by sea water.

How might climate change affect where people live?

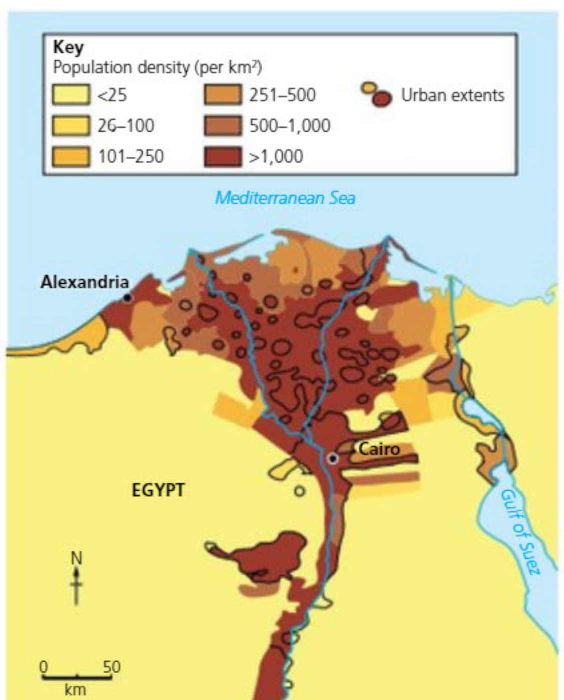
The International Organization for Migration suggests that climate change will displace 200 million people by 2050. Rising sea levels, drought, food and water insecurity and increased health risks are the main reasons. Egypt is one country that could be affected.

Egypt is a desert country. It has a population of 85 million. Most urban areas and farmland are squashed into just 15 per cent of the nation's landmass – mainly along the length of the River Nile and in the Nile Delta. Climate change will create a number of challenges for Egypt:

- Rising temperatures and less frequent rain will increase the current problems of water stress. This will affect the urban poor and it will mean that farmers will have to find new efficient techniques to irrigate crops.
- Water-borne diseases and malaria will become more common. There is also likely to be a huge increase in parasitic diseases, skin cancer, eye cataracts, respiratory ailments and heat stroke
- Sea level rise may erode and flood the Nile Delta, displacing as many as 8 million people.

Alexandria, in the Nile Delta, is Egypt's second largest city. This Mediterranean port handles 80 per cent of Egypt's imports and exports. The wealth of the city attracts migrants. Natural population increase adds to pressure on space. Houses and flats are often built without proper planning permission or building regulation. In fact, it is estimated that 50 per cent of Alexandria's population live in informal housing. The urban poor are perhaps at greater risk of climate change than others because they:

- Have few savings so cannot afford to lose their jobs or their homes.
- Often rely on boreholes that are polluted by human waste so are at risk of water-borne disease or they have to buy water from street vendors at great cost.
- Often live in locations that are dangerous to human health. For example, near to stagnant water where mosquitoes that carry malaria breed.
- Live in badly built multi-storey buildings that are at risk of collapse during earthquakes.



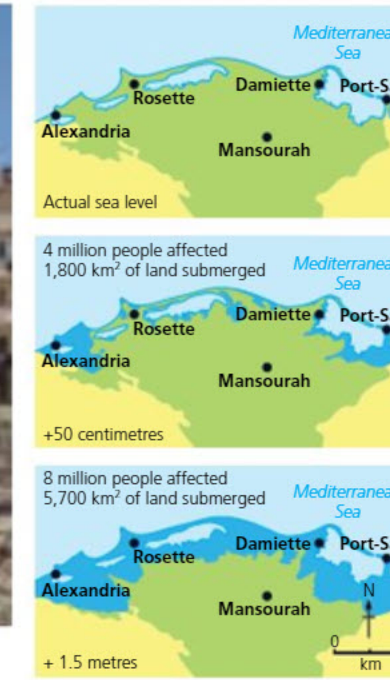
Year	Population
1950	1.04
1960	1.50
1970	1.99
1980	2.52
1990	3.06
2000	3.55
2010	4.33
2020	5.23
2030	6.31

▲ **Figure 24** The population of Alexandria (millions). Figures after 2010 are predictions.

◄ **Figure 23** Population density of the Nile Delta.

Alexandria is built on Egypt's Low Elevation Coastal Zone (LECZ) (see page 168) so is vulnerable to permanent flooding if sea levels rise. If this happens, Egypt will find it difficult to re-house the huge number of environmental refugees. Presumably, many people who currently live in informal housing in Alexandria will move into the poorest, most overcrowded districts of Cairo.

▲ **Figure 25** Illegally built flats in Alexandria, Egypt.



▲ **Figure 26** Predicted changes to Egypt's coast-line as the sea level rises
Source: The Sea elevation model has been calculated by Otto Simonett (UNEP/GRID, Arenday and Nairobi) at the beginning of the 1990s.

Activities

1 Describe the location of Alexandria.

2 a) Use Figure 24 to draw a line graph of population growth.
b) Describe the trend of your graph.
c) If this trend continues, what might be the population of Alexandria in 2040?

3 a) Outline three different problems that will be created for the people of Egypt by climate change.
b) Explain why the urban poor are most at risk. Give two different reasons.

4 Describe the possible loss of land in the Nile Delta. How big is the potential environmental refugee problem?

5 a) Use Figure 23 to describe the distribution and density of Egypt's population.
b) Why is this a significant problem for the Egyptian government if sea levels rise as predicted?

Enquiry

'Solving the problems caused by climate change refugees is the responsibility of all nations.' How far do you agree with this statement? Justify your answer.

How might climate change affect tourism?

For many countries, the income gained from tourism is the most important source of revenue. It pays for health services, schools and infrastructure projects like sewers and roads. Millions are employed in the tourist industry across the world. Climate is a key factor in the development of tourism, so the industry is vulnerable to the effects of climate change. This is especially true at:

- beach destinations such as in the Caribbean and Mediterranean;
- mountain tourist resorts or winter sports locations, such as in the Alps.

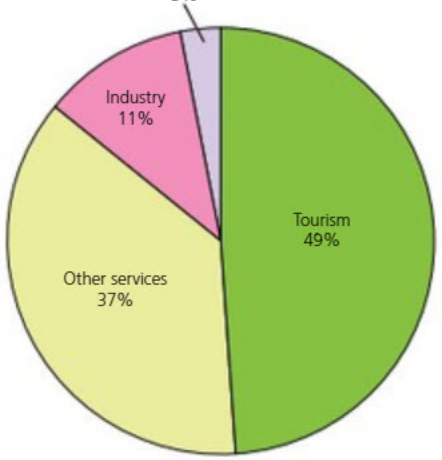
Very small changes to snow conditions in the Alps could severely damage the tourist industry.

On the other hand, warmer temperatures in Northern France might encourage French tourists to take a **staycation** rather than travel to the tropics in search of sun and sand.

How might climate change affect tourism in the Bahamas?

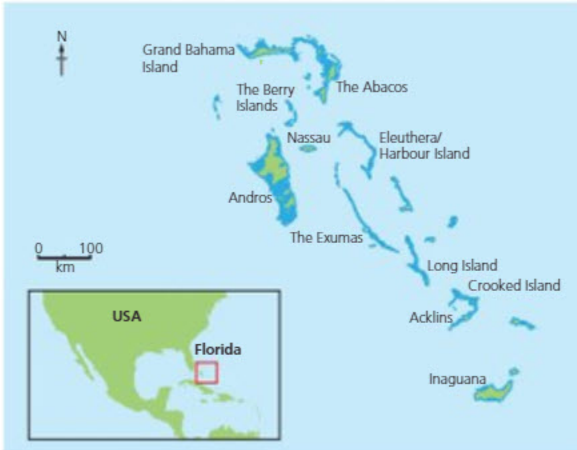
Tourism is vital to the economy of the Bahamas. In 2015, the income from tourism accounted for 40 per cent of gross domestic product (GDP) and earned the islands $1.3 billion in foreign exchange. It is estimated that half of the government's spending on health, education, sanitation, roads and airports comes from tourism. Climate change threatens to change the tourist industry for ever. The Bahamas is one of 58 Small Island Developing States (SIDS – see page 169) and is particularly vulnerable to the effects of climate change. These include:

- loss of beaches to erosion and inundation through sea level rise
- damage to freshwater aquifers due to salt water intrusion
- increasing stress on coastal ecosystems, particularly coral reefs, due to bleaching and sea temperature rise
- damage to infrastructure from increased frequency and intensity of tropical storms.



▲ **Figure 27** Labour-force in the Bahamas, by occupation (percentage figures).

▲ **Figure 28** A beach resort in the Bahamas.



◀ **Figure 29** The islands of the Bahamas.

Short-term solutions	Difficulties to overcome
Building sea walls to reduce the problems of beach erosion through sea level rise and storm surges.	Sea walls are costly to build and maintain. They are visually unattractive and it is impossible to protect every island.
Invest in desalination plants and educate people and businesses about water conservation to make up for the loss of freshwater in aquifers.	Desalination plants are expensive. Rainfall totals may fall so water conservation is unlikely to be effective enough to meet demands.
Improve existing hurricane prediction and alert systems and construct more hurricane-proof buildings.	Hurricane-proof buildings are costly. They will not necessarily prevent damage by the strongest hurricanes.

▲ **Figure 30** Short-term solutions for the Bahama government to consider.

Activities

1. Describe the location of the Bahamas.
2. a) Explain why the economy of the Bahamas is more vulnerable to climate change than France, even though more tourists visit France.
   b) Identify six geographical factors that make the tourist industry in the Bahamas particularly vulnerable to climate change.
3. Discuss how far the Bahamian government should go in introducing short-term measures to reduce the immediate threat of climate change.

Enquiry

'The Small Island Developing States (SIDS) are more vulnerable to climate change than other, larger countries.' To what extent do you think this statement is true? Justify your decision.

▲ **Figure 31** Perry Christie, Prime Minister of the Bahamas, speaking in 2015 at the Paris International Climate Summit.

Attitudes to a low-carbon future in the UK

A low-carbon future could be achieved by combining three approaches:

- Using new technologies to reduce our dependence on fossil fuels for energy and transport.
- Better energy conservation and efficiency. This means changing our lifestyles so that each of us plays a part in reducing carbon emissions. For example, individuals can reduce energy consumption by insulating their homes, using low-energy appliances, using more public transport and taking fewer flights.
- Finding ways to remove carbon dioxide from the atmosphere and storing it in long-term sinks such as forests or in rocks underground.

Each of these approaches to the low-carbon future has advantages and disadvantages, and some may prove more popular than others. Figure 32 examines some different points of view on these low-carbon solutions.

▼ **Figure 32** Different attitudes towards a low-carbon future.

Energy conservation and efficiency

My husband has a low-paid job and I work part time. We don't have much money. I'm worried we don't have enough money to pay for the heating on this winter. The TV news calls this fuel poverty. Our house was built in the 1930s and it doesn't have much insulation. I know that it would be good to insulate the roof. It would cost a bit less to heat the house and eventually the savings I make would pay for the work. But, you see, I really have no money to spare. The insulation will just have to wait.

Young family

Liberal Democrat politician

Everyone should do their bit to help save energy. Simple things like insulating the roof and only boiling as much water as you need every time you use the kettle. We estimate that the CO_2 emissions from electrical items left on standby in the UK is the same as 1.4 million long-haul flights. That's the same as everyone in Glasgow flying to New York and back! And the number of TVs is growing fast. We think that by 2020 there will be 74 million TVs in the UK, that's more TVs than people!

Carbon capture and storage

We could capture carbon dioxide emissions from coal- and gas-fired power stations. The gas could then be turned to a liquid, pumped down into the ground and stored in sedimentary rocks. In fact, North Sea oil rigs that currently pump oil out of the ground could pump the CO_2 into the rocks when the oil has run out. Those rocks would make a perfect long-term carbon sink.

The process is not difficult but would be quite expensive to set up. Each person in the UK makes about 10 tonnes of CO_2 each year by their use of energy. We estimate that the cost for capture and storage of CO_2 in North Sea rocks is about £20 per tonne. So it will cost about £200 per person each year. Would people want to pay?

The government will have to find a way to make the power companies start to do this. The electricity generators have to capture the CO_2 and then transport it to a disposal site. The oil exploration companies will need to pay for the CO_2 to be stored deep underground. The government could threaten to tax these companies more unless they begin to capture and store the carbon.

Scientist

Nuclear power or renewables?

Some argue that nuclear power is a solution to climate change because it has no carbon emissions. But here at Friends of the Earth we oppose the building of any new nuclear power stations in the UK. We believe that nuclear power is dangerous for a number of reasons. Firstly, there is a security issue and power stations could be targets for terrorists. Secondly, there is the hazardous radioactive waste that will need careful management for generations. Finally, nuclear waste can be converted to be used in weapons.

We are in favour of green energy which is energy from renewables such as wind and solar. These technologies are a safer, cheaper and cleaner solution to the problem of climate change.

Spokesperson for Friends of the Earth

Biofuels

Industry spokesperson

There are a number of crops that produce oil that can be processed to make fuel for either cars or aircraft. The growth of these biofuels could reduce poverty in developing countries by creating jobs and wealth for farmers. At the same time people in the developed nations can continue to use their cars and take flights without the fear of oil shortages.

Biofuel crops are causing poverty and hunger in some developing countries. Farmers are being encouraged to grow biofuels instead of food so that we can drive our cars without feeling guilty about carbon emissions. But here at Oxfam we believe that in 2007 and 2008 this has been a factor in the rising cost of food. Using the World Bank's figures we reckon that rising food prices have pushed 100 million people worldwide below the poverty line.

Since April 2008, all petrol and diesel in Britain has had to include 2.5 per cent from biofuels. The European Union considered raising that target to 10 per cent by 2020. However it is now concerned that this could push food prices even higher.

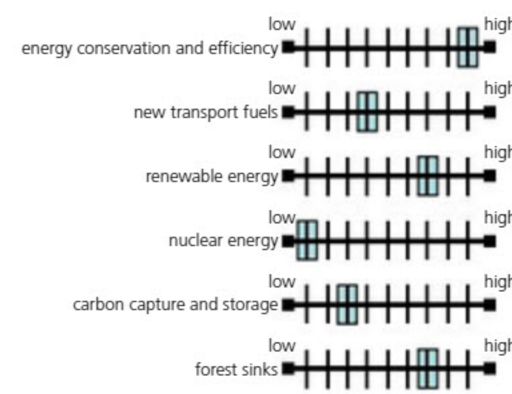
Spokesperson for Oxfam

Forest sinks

Planting trees seems like a really a good solution to climate change. They soak up carbon from the atmosphere and store it. However, here at Greenpeace we don't think that planting trees is enough. People have got to actually reduce their carbon emissions in order to tackle climate change. So planting a tree to offset your emissions is just not good enough.

We have been raising awareness of some companies who plant trees to offset their carbon emissions. For example, there is a Japanese power company who wanted to offset their carbon emissions by planting trees. So they bought some land in Tasmania, Australia. They cut down the natural forest that was growing here so they could plant 3,000 hectares of fast growing eucalyptus trees to soak up the carbon. How crazy is that!

Spokesperson for Greenpeace



▲ **Figure 33** Which carbon future would you support?

Activities

1. Discuss the points of view shown in Figure 32. Outline some advantages and disadvantages of:
   a) energy efficiency and conservation
   b) biofuels
   c) nuclear power.
2. Explain why some environmentalists argue that planting forests is not a good enough option.
3. Working in pairs, study Figure 33.
   a) Imagine each slider represents the amount of effort and investment that could be made in the six possible solutions to climate change. Agree with your partner how each slider should be placed in your ideal low-carbon future. Be prepared to justify your decision.
   b) Team up with another pair. Each pair must give a short presentation to describe and justify their low-carbon future. Can you persuade the other pair to change their minds?

How can we create an alternative, low-carbon future?

Since 1990 representatives of governments from around the world have met periodically to discuss the issue of climate change. The Kyoto Protocol (1997) is an international agreement which commits countries to targets to reduce greenhouse gas emissions. The latest version of this agreement is the Doha Amendment to the Kyoto Protocol (2012). The Doha Amendment aims to limit global temperature increases to below 2°C. Countries that have signed this agreement, including the UK, are committed to it until 2020.

The Kyoto Protocol recognises that industrial countries like the USA, UK and Germany have been largely responsible for greenhouse gas emissions in the past and should make the biggest efforts to reduce emissions. There is an expectation that Newly Industrialised Countries (NICs) such as India and China will begin to reduce emissions once industrial growth in their economies has helped to reduce levels of poverty.

So how are the EU countries trying to reduce greenhouse gas emissions? Members of the EU have signed agreements to:

- Invest in renewable energy production using wind, solar and hydro-electricity.
- Source at least 10 per cent of their transport fuel from biofuel. Biofuel is the kind of fuel that is made from natural plant oils. It is considered to be **carbon-neutral** because these quick-growing crops absorb as much carbon from the atmosphere while they are growing as they give off when they are burnt as fuel.

◀ **Figure 35** The new solar furnace which provides electricity for the city of Seville, Spain.

Activity

1 a) Explain why biofuels are considered to be carbon-neutral.
b) Suggest one disadvantage of growing biofuels.

Enquiry

How quickly should the international community reduce its greenhouse gas emissions?

a) Discuss Figure 34. Which model do you think the international community should be aiming for? Justify your decision
b) At what point do you think India and China should start reducing their emissions?

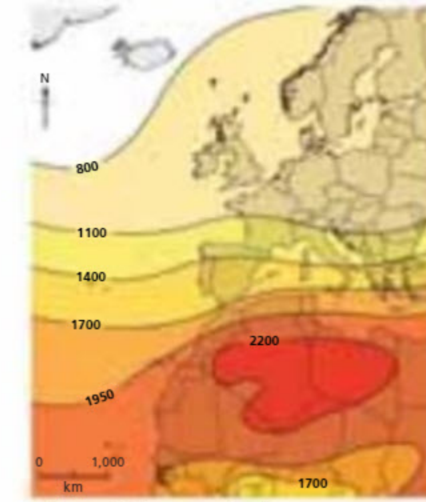
Model	Peak CO_2 level (ppm)	Year peak CO_2 is reached (year)	Change in CO_2 emissions in 2050 compared with 2000 (per cent)	Global average temperature increase compared with pre-industrial age (Celsius)	Global average sea level rise due to expansion of sea water but not taking ice melting into account (metres)
1	350–400	2000–2015	−85 to −50	2.0–2.4	0.4–1.4
2	400–440	2000–2020	−60 to −30	2.4–2.8	0.5–1.7
3	440–485	2010–2030	−30 to +5	2.8–3.2	0.6–1.9
4	485–570	2020–2060	+10 to +60	3.2–4.0	0.6–2.4
5	570–660	2050–2080	+25 to +85	4.0–4.9	0.8–2.9
6	660–790	2060–2090	+90 to +140	4.9–6.1	1.0–3.7

▲ **Figure 34** Computer models from the Intergovernmental Panel on Climate Change (IPCC), a highly respected group of climate scientists. Their computer models show that temperatures will rise even if we are able to control CO_2 concentrations below 400 ppm in the next five or so years. Model 1 would require the biggest and quickest cuts in CO_2 emissions, while model 6 allows countries to make smaller, slower cuts.

Can new renewable technologies help us achieve a low-carbon future?

Figure 35 may be a glimpse of a future, low-carbon Europe. A field of 600 steel mirrors reflect solar energy. They direct a beam of light and heat to the top of a 40 m tower where the energy is focused on to water pipes. The heat turns the water to steam which then turns a turbine to generate electricity. The whole system is computer controlled so that each mirror tilts at exactly the right angle. At the moment this **solar furnace** produces enough energy for 6,000 homes, but the plant is being extended and will eventually provide power for the whole of the city of Seville, Spain.

In the future it would be possible to build more solar furnaces in the Sahara desert and bring the electricity into Europe through a new 'super-grid' of cables. Scientists believe that all of Europe's electricity could be generated from just 0.3 per cent of the sunlight that falls on the Sahara. The cost of the super-grid alone would be around €45 billion. This would certainly reduce Europe's carbon emissions dramatically, but critics point out that Africa should also benefit from some of this clean energy.



▲ **Figure 36** Patterns of solar energy across Europe and Africa (kilowatts/m^2/year).

Activities

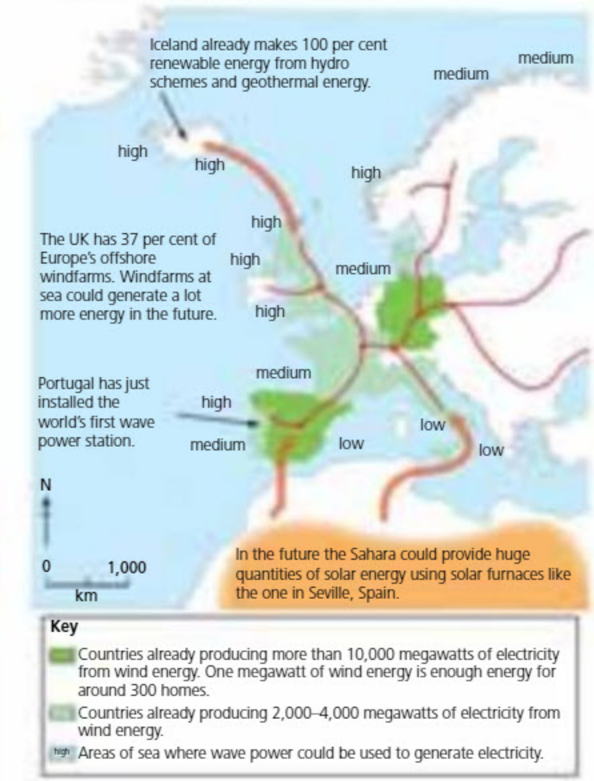
2 Use Figure 36 to describe the distribution of countries that have:
a) between 1,100 and 1,400 kilowatts/m^2/year
b) more than 2,200 kilowatts/m^2/year.

3 Use Figure 37 to describe the distribution of:
a) countries currently producing more than 2,000 megawatts of wind energy a year
b) countries that could use their seas to make high levels of wave power.

Enquiry

How should renewable energy be made in Europe?

Research and then make a poster about renewable energy in Europe. Focus on wind, wave and solar. Include facts and figures about how much renewable energy is made in at least one European country.



▲ **Figure 37** In the future an international grid of power cables could link the countries of Europe and North Africa so that renewable energy made in the Sahara could be fed into your home.

How can individuals and government reduce the risk of climate change?

The UK Government has an international role in combatting climate change. It is a signatory of the Doha Amendment (which is described on page 212) and the Paris Agreement (2015). The outcome of the Paris Agreement was a long-term aim to keep global warming to well below 2°C compared to pre-industrial levels. The UK Government also works at a national scale. It provides targets for local government and works with industry to reduce greenhouse gas emissions by:

- investing in low-carbon energy sources;
- improving fuel standards in cars;
- increasing energy efficiency in new buildings.

Councils must publish a policy statement on climate change by law.

Activity

1 Study Figure 38.
  a) Explain why ideas 5 and 7 will help Bristol meet its climate change target.
  b) Make a diamond nine diagram (like the one on page 108) and place the strategies from Figure 38 in the diagram, putting those that you think are essential at the top of the diagram.
  c) Justify your choice of the top three strategies.

Figure 38 describes some of the ways in which Bristol City Council is trying to meet its own climate change targets.

	What will they do?	Why it helps
1	Warmer homes. £105 million will be spent fitting external wall insulation to homes (including blocks of flats).	£3.5 million could be saved each year on heating bills. Possible 5 per cent reduction in the amount of gas used. 17,900 tonnes of CO_2 saved each year.
2	Install district heating (or heat networks). These will duct spare heat between the university, the hospital and buildings in the city centre.	Heating buildings and hot water use are two of the main reasons for CO_2 emissions in large cities. District heating uses energy efficient boilers.
3	Lead by example. Improve the energy efficiency of council offices, the museum, library and two schools.	£500,000 energy saving and 2,000 tonnes of CO_2 saved each year.
4	High energy performance. Install efficient boilers in all new council buildings, including schools, care homes and council housing.	It is cheaper in the long term to install energy efficient technologies when buildings are new rather than trying to modify older buildings.
5	Solar photovoltaic programme. Two solar farms were constructed in 2014 at a cost of £35.9 million.	
6	Metro-bus scheme. Build 6 km of new roads, 18 km of new bus lanes and purchase 50 new hybrid vehicles.	Shift passengers from car to bus will reduce congestion and CO_2 emissions from commuter traffic.
7	Sustainable transport. Invest in 10 km of cycle lanes and promote cycling and walking for people aged 8–80.	
8	Land use planning. Locating new homes to reduce the need for commuting and allow the use of district heating.	Future proof new housing developments by making them sustainable.
9	Improve mass transit. Spend £90 million improving suburban train services.	Improve air quality and transport safety. Reduce congestion and CO_2 emissions.

▲ **Figure 38** How Bristol City Council hopes to meet its targets to reduce CO_2 emissions.

GEOGRAPHICAL SKILLS

Collecting qualitative data

Some geographical data is easily **quantified** – meaning that it is easy to measure and record an actual number. Examples include pedestrian counts or the number of vacant shops in a high street. Other useful data is difficult to quantify; other people's opinions, for example, on their views about leading a low-carbon lifestyle. This is **qualitative data** and it can be collected in a number of ways:

- in a lengthy interview
- using a questionnaire
- with a quick survey such as a Likert scale.

If you are designing a questionnaire it is a good idea to have examples of both closed and open questions. Closed questions have set answers which you can tick.

For example: How do you get to school?

Walk [ ]   Cycle [ ]   Bus [ ]   Car [ ]

An open question is where people can give their own unstructured answer, e.g. How do you think the school could reduce its GHG emissions?

A **Likert scale** is where people are asked to use a scale when responding to a question.

Activities

1 Show one way you would represent each of the data sets from the survey. Justify your choice.
2 What conclusions can you draw from the responses given?
3 Suggest two other questions you could ask to investigate individual attitudes to climate change.
4 Explain why data representation and data analysis are easier if closed rather than open questions are asked in questionnaires.
5 Suggest an open question that you might ask. Explain why this open question would reveal useful information about how individuals feel about climate change.

Only offshore wind farms should be developed in future			
1	2	3	4
Agree	Slightly agree	Slightly disagree	Disagree

▲ **Figure 39** An example of a Likert scale.

Question, with responses measured on a Likert scale of 1–10 (1 = not at all seriously and 10 = very seriously)	Mean score
How seriously do you regard the threat of climate change?	7.5
How effective do you think that individuals can be in reducing the threat of climate change?	4.5

▲ **Figure 40** An example of a climate change enquiry.

A group of geography students were interested in investigating how people of different ages are responding to climate change. They set an enquiry question:

Are younger people more willing to change their lifestyles than older people?

As part of their enquiry, they used a Likert Survey with 100 people. They also asked the respondents to tick up to five things that they already do (as individuals) to help reduce the threat of climate change. The results are shown below.

Possible actions that individuals can take	Number of responses
Use low-energy bulbs	82
Choose energy-efficient goods	57
Improve insulation for the home	53
Recycle all plastics, glass, etc.	89
Lower the thermostat settings on the heating	23
Walk or cycle to avoid using the car	2
Use public transport	17
Buy locally produced food	11

▲ **Figure 41** Possible actions that individuals can take.

THEME 2

Chapter 8 Problem-solving exercise: How should the Red River be managed?

Introducing the Red River, southern USA

The Red River drainage basin is the second largest in southern USA. The Red River is heavily used and managed for a variety of purposes. In the **upper course** of the river, there is often not enough water and drought is an issue. In the **lower course**, flooding often impacts on human activity. In this chapter you will study the contrasting demands placed on the Red River and consider the priorities for its long-term management.

▲ **Figure 1** The Red River in drought, Texas.

▲ **Figure 2** The Red River in flood at Shreveport, Louisiana.

▲ **Figure 3** The drainage basin of the Red River.

Activity

1 Use Figure 3 to describe the course of the Red River.

How does climate affect the nature of the Red River drainage basin?

In its upper course, the Red River flows through high open grasslands and rough terrain known as the Great Plains. The cold semi-arid climate makes much of this region dry, with long periods of drought. As a result, river flow is intermittent. However, thunderstorms and tornadoes are common between April and August, leading to torrential downpours and flash flooding. Erosion levels can be very high during these storms, leading to large amounts of sediment being deposited in the river. This can severely reduce water quality, leading to silting up of the river channel.

In its middle and lower course, the Red River flows through mixed grasslands and forests and eventually through marshes and swamps, where the humid subtropical climate is warmer and wetter. Here the river meanders across its flood plain in a 300 m wide channel. When the river is in flood, it can widen to 2 km. The river is deep enough for shipping, but navigation is difficult. This is because of regular flooding that erodes banks, deposits sediment in the river and shifts the shape of the channel.

Cold semi-arid	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp high (°C)	10.3	12.3	16.9	21.7	26.4	30.9	33	31.9	28.1	22.2	15.6	9.8
Temp low (°C)	-4.8	-3.1	0.7	5.3	11	16.1	18.4	17.9	13.6	7.1	0.3	-4.4
Precipitation (mm)	18	14	35	36	58	80	72	74	49	42	20	18

▲ **Figure 4** Climate data for Amarillo, Texas in the upper course of the Red River (average 1961–90).

Humid subtropical	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp high (°C)	14.1	16.4	20.8	24.9	28.8	32.3	34.1	34.5	31.2	25.7	19.7	14.7
Temp low (°C)	2.3	4.3	7.9	12	17.1	20.8	22.6	22.3	18.7	12.6	7.3	3.2
Precipitation (mm)	107	121	105	106	125	137	93	69	80	126	115	121

▲ **Figure 5** Climate data for Shreveport, Louisiana, in the lower course of the Red River (average 1961–90).

Enquiry

Research five major world rivers and complete a copy of the table below.

River	Continent	Basin area (km^2)	Length (km)	Mean discharge at mouth (cumecs)
Red River	North America	169,900	2,190	1,600
Rhine				
Nile				
Thames				
Yangtze				
Murray–Darling				

Compare the Red River to each of the other world rivers. Use sentence connectives such as *'whereas'*, and comparative words such as *'bigger'* and *'most'* in your response.

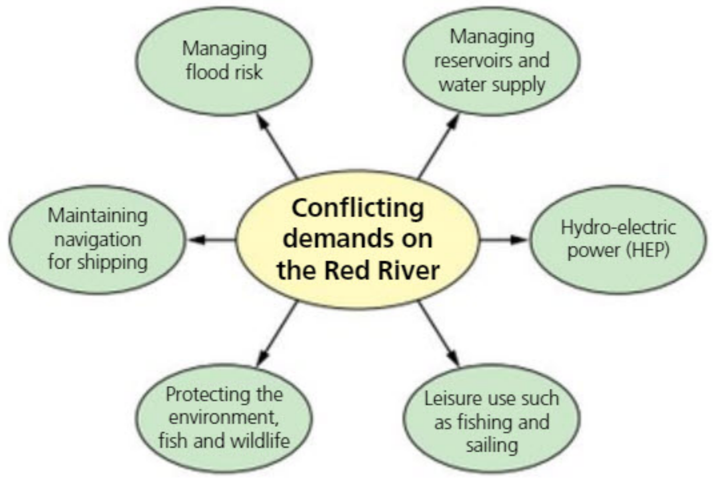
Activity

2 Study the data in Figures 4 and 5.
 a) Draw climate graphs for Amarillo and Shreveport.
 b) Describe four differences between cold semi-arid and humid subtropical climates.

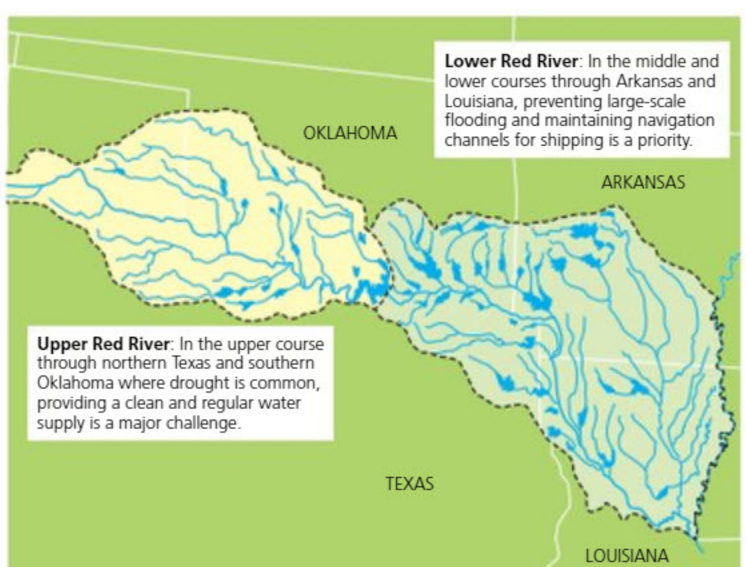
Who manages the Red River?

The US Army Corps of Engineers (USACE) is responsible for managing all water resources in the USA. In the Red River Basin, USACE works closely with many regional and local organisations such as Texas Water Development Board, Red River Valley Association and Red River Water Commission to put water management strategies in place.

The neighbouring states of Arkansas, Louisiana, Oklahoma and Texas all use water from the Red River Basin. Under an agreement called the Red River Compact, these four states have agreed to work together to share the Red River water resources and to resolve any disagreements that may arise between them.



► **Figure 6** The work of the US Army Corps of Engineers (USACE).



▲ **Figure 7** Major issues in the Red River drainage basin.

Activities

1 Use Figure 6 to identify two roles of USACE that may conflict with one another.

2 Study Figure 7.
   a) Explain why it is useful to divide the Red River drainage basin into Upper and Lower sections.
   b) Working in groups of four, use information from this page and your own research to discuss why the Red River Compact is needed. Select a spokesperson to feedback your conclusions to the rest of your class.

Enquiry

How important is USACE to the USA?

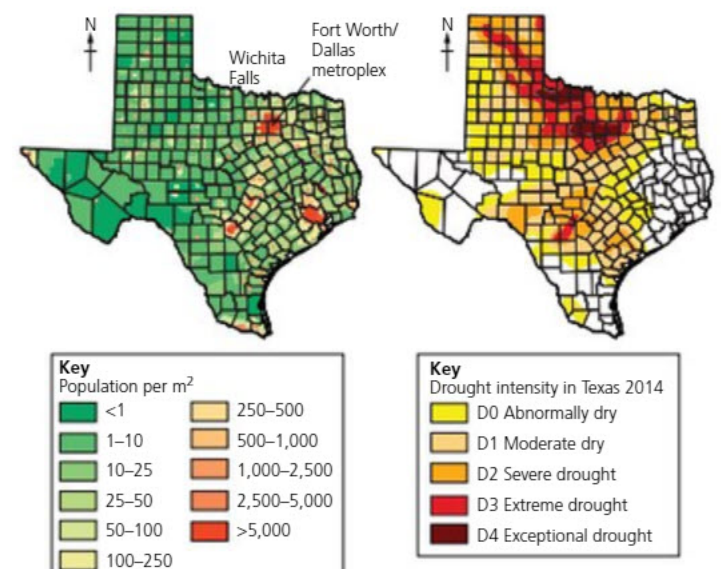
Use the internet to find out more about the river management work of USACE.

How is the Upper Red River managed?

The population of the USA is predicted to grow rapidly from 320 million in 2015 to 440 million people in the year 2050. Much of this growth will happen in cities in arid regions with limited water supplies. For example, the population of Fort Worth/Dallas in northern Texas is expected to rise from 7 million to 12 million by 2050. In a way, building dams on the Red River and its tributaries has encouraged urban growth in this arid region. For example, Lake Texoma, which is a reservoir formed by the Denison Dam, provides hydroelectricity (HEP), flood control, and water storage. This has encouraged people to move into the area to live and work. This and the other dams on the Red River also provide fantastic leisure opportunities such as boating, camping and hiking. As the population continues to grow, the demand for water supply and electricity will increase – will there be enough water in the future?

◄ **Figure 8** Lake Texoma is at the heart of a National Park that attracts over 6 million visitors each year.

Each reservoir has a Drought Management Plan, but despite this, water levels are very low. Climate scientists warn that intense short-term droughts may be more common in this region as the climate changes, so experts are concerned that there will not be enough water to meet demand and to drive the turbines for hydro-electric power. In addition, the dams trap sediment being transported downriver, making the reservoirs shallower and not able to store as much water as they should. The sediment also makes the water salty which needs to be treated before it can be used.



▲ **Figure 9** Population density and drought intensity in Texas (2014).

Activity

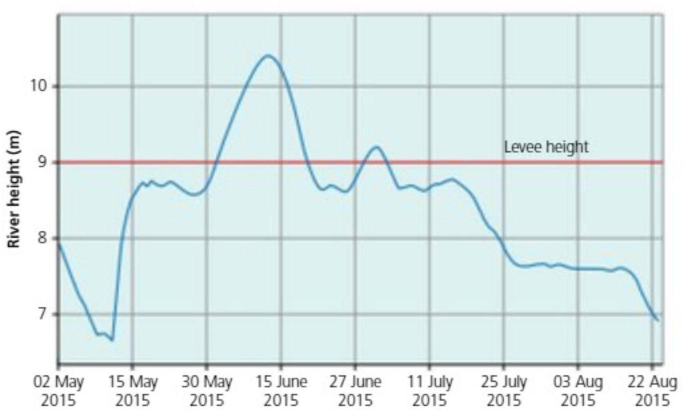
3 a) Use the information in Figure 9 to compare similarities and differences in population distribution and drought intensity in Texas.
   b) Suggest what may happen to towns such as Wichita Falls and the surrounding countryside if short, intense droughts become more common.

How is the Lower Red River managed?

Over the course of late spring 2015, severe thunderstorms caused heavy rainfall across the Red River Basin, filling the Red River and its reservoirs. As the rainfall continued, the Red River eventually burst its banks and flooded large parts of the river basin in Arkansas and Louisiana. At Shreveport–Bossier City, river levels reached record heights, inundating hundreds of homes, businesses, roads and surrounding farmland. A state of emergency was declared and the J. Bennett Johnston Waterway was closed to shipping.

However, according to some experts, the 2015 flood was not as damaging as it could have been because of the system of levees, flood control dams and spillways that had been put in place following previous flooding in 1945, 1957 and 1990.

◀ **Figure 10** Using sandbags to keep the floodwaters out at Shreveport, June 2015.



▲ **Figure 11** River levels (metres) at Shreveport, May to August 2015.

Activities

1 Study Figure 10. Describe the possible impacts of this type of flooding on:
   a) homeowners
   b) commuters
   c) elderly residents.
2 Study Figure 11. Describe the differences in river levels from May to August 2015.
3 Using your own knowledge of how water moves through a drainage basin, suggest reasons for differences in river levels during the Red River 2015 floods.

Challenges and options for the future

Managing the Red River and its valuable water resources can only become more difficult as conflicting demands for water increase and the climate changes. Study Figures 12 and 13 before considering how this drainage basin may need to be managed in the future.

Desalinisation: Chloride control programmes provide millions more litres of drinking water.

Groundwater is used for farming but can be treated for human usage.

Water reuse and recycling: Effluent could be treated and mixed with lake water to provide up to 35 million litres of drinking water per day.

More reservoirs have been built to provide extra water storage capacity.

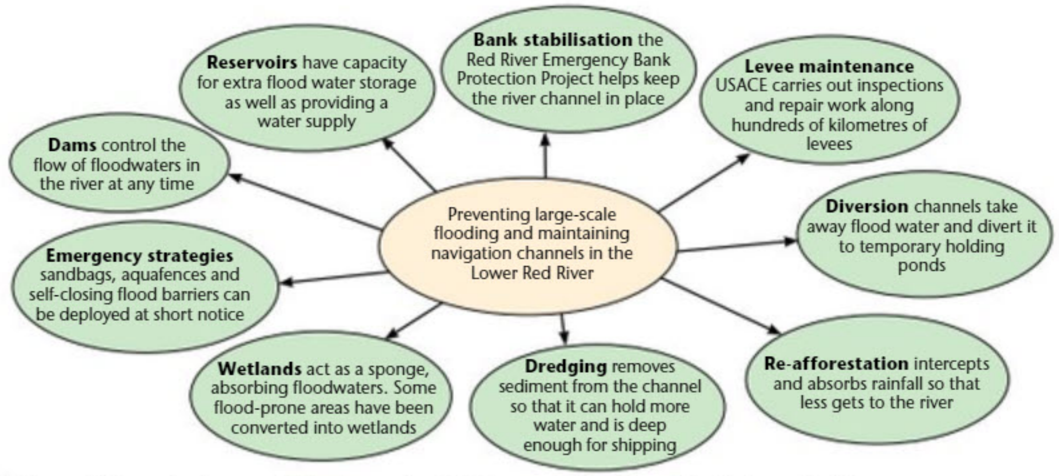
Water-transfer from rivers and reservoirs outside of the Red River Basin along large pipes.

Wetlands are being built to store water and encourage wildlife in the river basin.

Non-conventional methods: Weather modification and evaporation suppression are being considered.

Water restriction: Wichita Falls City reduced consumption from 132 million litres per day to 41 million litres per day.

▲ **Figure 12** Strategies to provide a safe and reliable water supply in the Upper Red River.



▲ **Figure 13** Preventing large-scale flooding and maintaining navigation channels in the Lower Red River.

Activities

1 Study Figure 12. With a partner, discuss each of the strategies. Which of these strategies might:
   a) provide short-term solutions?
   b) provide long-term solutions to the problems?
2 Explain your reasons.
3 Study Figure 13.
   a) In groups, discuss the advantages and disadvantages of each strategy, using criteria such as cost, scale, environmental impact.
   b) Carry out a diamond nine ranking activity (described on page 108), ranking the most effective strategy at the top of the diamond and the least effective strategy at the bottom of the diamond.
   c) Present your diamond nine to the rest of your class, justifying your ordering of the strategies. Do they agree?

Enquiry

How successful are 'non-conventional' strategies such as weather modification and evaporation suppression?

Research these non-conventional strategies. Evaluate the usefulness of these strategies in helping reducing drought in the Red River Basin.

What are the priorities for the longer-term management of the Red River?

Managing rivers such as the Red River is complex, with many competing demands and viewpoints, as outlined in Figure 14 below.

We need more water for our growing population. We have built more reservoirs and water treatment plants so that we can use more river water, groundwater and recycled effluent. We want to take more water from the Red River basin as well as creating wetlands as water stores. This whole programme will cost around $13 billion.

Texas Water Company representative

Six million people use Lake Texoma for recreation each year, bringing in money to the local economy. We are worried about droughts and floods restricting boating and fishing activities on the lake. Drought will also make the water saltier and kill fish - our business will suffer.

Lake Texoma Tourist Business representative

We receive $70 million per year from power generated by Denison Dam and other dams on the Red River. Much of this money is re-invested into managing the river. It is important that we have enough water in our reservoirs to generate this energy supply – otherwise we may not be able to pay for other flood and drought control projects.

United States Army Corps of Engineers

As the climate becomes drier, there will be less water stored in reservoirs. We need to look for alternatives to water energy such as wind power, which is much cheaper to produce. The high open grasslands in the upper Red River basin are ideal for this because of the strong, steady winds that blow all year round.

Energy Conservationist

We have dramatically reduced levee erosion through bank stabilisation schemes. Unless $19 million is spent every year continuing these schemes then the river will wash away all our good work, breaking through the levees and flooding the land behind. It would cost many more millions to repair the levees and clear up after the floods.

River scientist

Dams and levees make flooding worse as they trap sediment in the channel, making it shallower and pushing water levels higher. We need to remove dams and levees and let the Red River flood naturally. The money saved could be spent on creating wetlands and restoring grasslands which will reduce the amount of water and eroded sediment getting to the river in the first place.

Environmentalist

▲ **Figure 14** Different viewpoints on managing the Red River.

Your decision

Your class has been asked to advise the US Government on water management in the Red River.

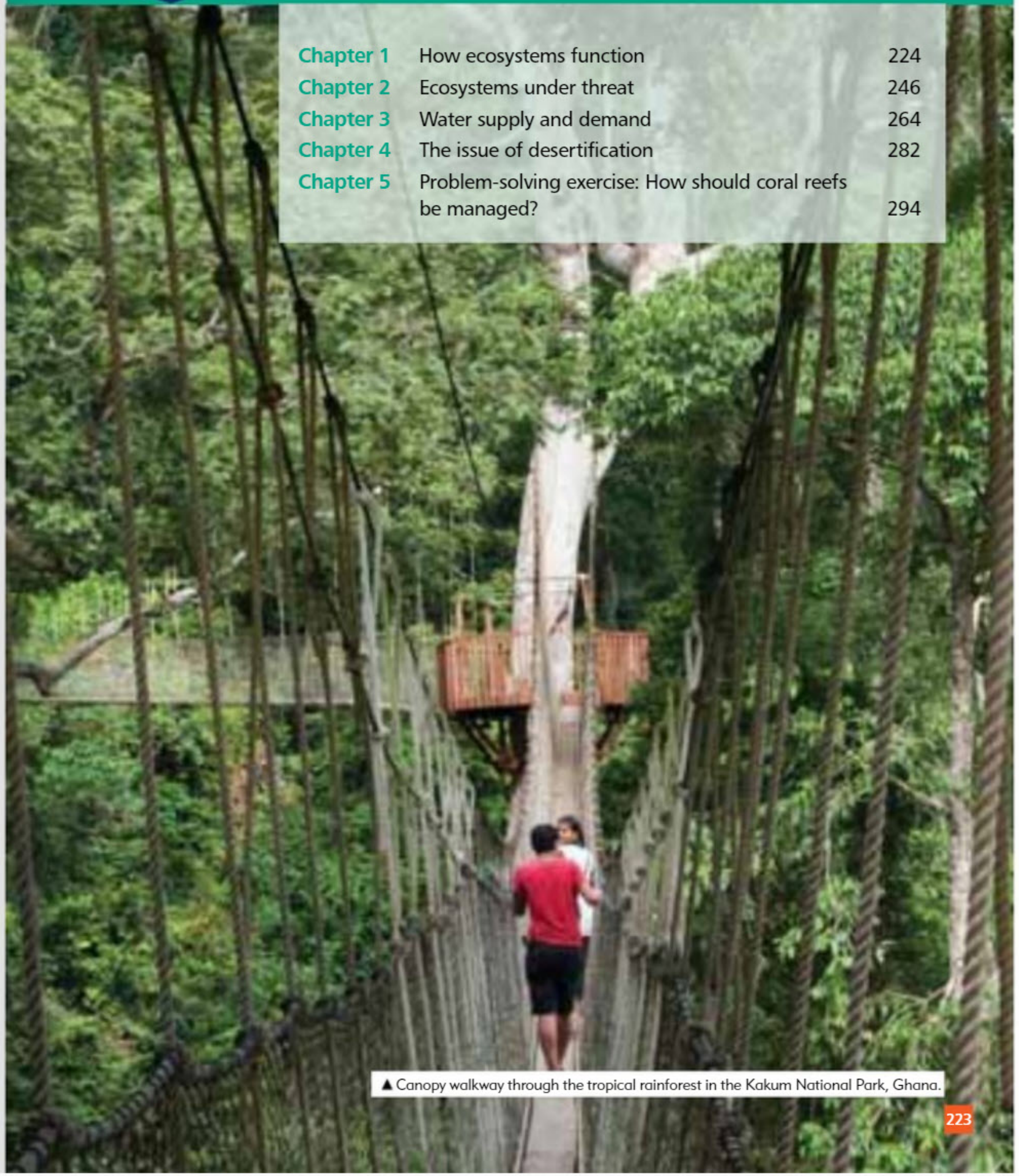
1 Use the information in this chapter and the viewpoints in Figure 15 to hold a class debate on whether the US Government should prioritise drought management in the Upper Red River OR flood control in the Lower Red River. In your debate you should ensure that the viewpoints of all stakeholders are taken into account.

2 Following the class debate, present a report in which you:

a) justify your chosen option, taking into account its advantages and disadvantages;

b) explain why you rejected the other option.

THEME 3 ENVIRONMENTAL CHALLENGES



▲ Canopy walkway through the tropical rainforest in the Kakum National Park, Ghana.