9 UK landscapes

9.1 The UK's relief and landscapes

On this spread you will find out about the relief and landscapes found in the UK

What is relief?

Relief is a term used by geographers to describe the physical features of the landscape. This includes:

- height above sea level
- steepness of slopes
- shapes of landscape features.

The relief of an area is determined mainly by its *geology* – the rocks that form the landscape. Tough, resistant rocks such as granite and slate form some of the UK's most dramatic mountain ranges such as those in Arran, Scotland (photo **A**). Weaker rocks such as clays and limestone often form low-lying plains and gently rolling landscapes (photo **B**).

A *Dramatic mountains in Arran, Scotland*

The UK's landscapes

A landscape is an area whose character is the result of the action and interaction of natural and human factors. In the UK a wide variety of rock types are responsible for creating our varied landscapes. Map **C** is from an atlas and shows the relief of the UK. The key uses different colours to show land heights and sea depths.

B *The Cotswold Hills*

The UK's river systems

You can see on map **C** that the UK has a very extensive river system. Most rivers have their source in the mountain ranges or hills and flow to the sea (can you see any that don't?).

ACTIVITIES

Use map **C** to answer Activities 1–3.

1. a What is the name and height of the highest mountain in the UK? In what mountain range is it located?
   b What is the name and height of the highest mountain in Wales?
   c Describe the relief of your home area or that of your school.
   d Compare the location and relief of Arran and the Cotswold Hills (photos **A** and **B**).
   e What is special about the relief of the Fens in eastern England?
2. Describe the pattern of upland areas in the UK.
3. a Describe the course of the River Severn from its source to its mouth.
   b Locate the river that is closest to your home or school. Describe its course.
4. As a class complete a wall display of photos from around the UK showing the different landscapes and river systems. If possible, locate each photo on a large map of the UK.
5. Alphabet Run! Can you find an upland area, mountain or river for each letter of the alphabet?

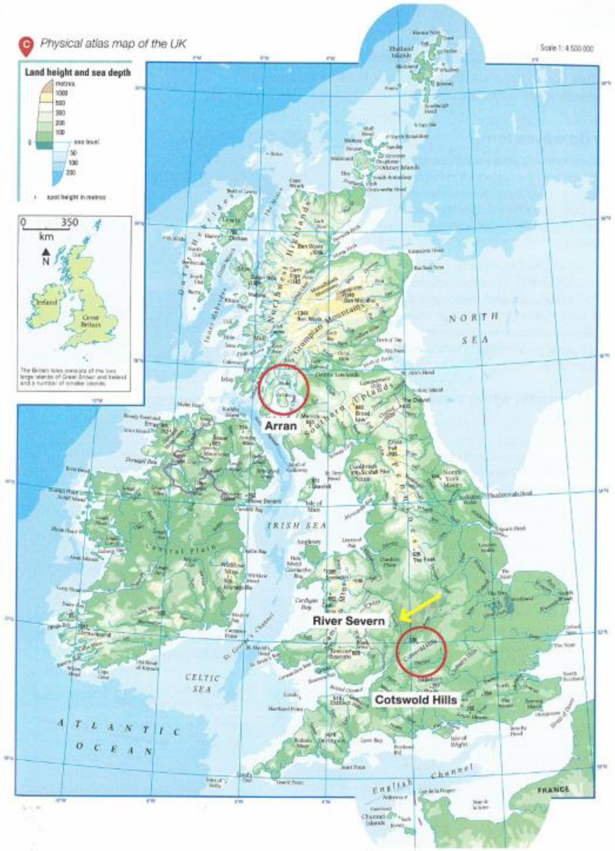
Stretch yourself

Use the spot heights and the height values in the key for map **C** to try drawing a cross-section sketch across the UK. For example, from Snowdon in North Wales to the Norfolk Broads in East Anglia; or from Snowdon to Romney Marsh in Kent, to include include the Cotswolds (photo **B**). Take time to choose an appropriate vertical scale.

Practice question

Explain how different types of rock determine the UK's landscapes. *(4 marks)*

C *Physical atlas map of the UK*



10 Coastal landscapes

10.1 Wave types and their characteristics

On this spread you will find out about the formation and characteristics of waves

How do waves form?

Waves are formed by the wind blowing over the sea. Friction with the surface of the water causes ripples to form and these develop into waves. The distance the wind blows across the water is called the *fetch*. The longer the *fetch*, the more powerful the wave.

Waves can also be formed more dramatically when earthquakes or volcanic eruptions shake the seabed. These waves are called *tsunami*. In March 2011 a wall of water up to 40m high crashed into the Japanese coast north of Tokyo destroying several coastal settlements and killing over 20000 people (photo **B**).

A Surfing at Newquay, Cornwall

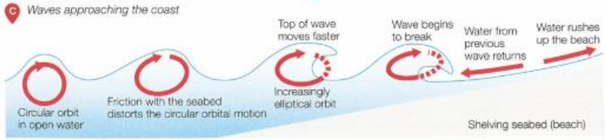
What happens when waves reach the coast?

In the open sea, despite the wavy surface, there is little horizontal movement of water. Only when the waves approach the shore is there forward movement of water as waves break and surge up the beach (diagram **C**).

The seabed interrupts the circular movement of the water. As the water becomes shallower, the circular motion becomes more elliptical. This causes the crest of the wave to rise up and eventually to collapse onto the beach. The water that rushes up the beach is called the *swash*. The water that flows back towards the sea is called the backwash.

B *Tsunami waves hit the coast of Japan*

C *Waves approaching the coast*



Wave types

It is possible to identify two types of wave at the coast.

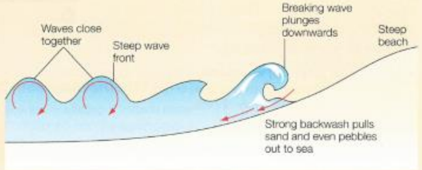
Constructive waves

These are low waves that surge up the beach and 'spill' with a powerful swash (diagram **D**). They carry and deposit large amounts of sand and pebbles and 'construct' the beach making it more extensive. Surfers prefer constructive waves because they give longer rides (photo **A**)! These waves are formed by storms often hundreds of kilometres away.

D *Constructive waves*

Destructive waves

These are formed by local storms close to the coast, and they can 'destroy' the beach – hence their name. They are closely spaced and often interfere with each other producing a chaotic swirling mass of water. They become high and steep before plunging down onto the beach (diagram **E**). There is little forward motion (swash) when a destructive wave breaks but a powerful backwash. This explains the removal of sand and pebbles and the gradual destruction of the beach.



E *Destructive waves*

ACTIVITIES

1 **a** Copy diagram **C** and draw an arrow to show the direction of the waves.
b Add the labels *swash* and *backwash* in the correct places.
c What causes the waves to rise up and break on the beach?
d When waves break on a sandy or pebbly beach the amount of backwash is often less than the amount of swash. Why do you think this is?
e Larger pebbles are found at the top of the beach with smaller ones near the bottom. Use your answer to **d** to suggest reasons why.

2 Why do surfers prefer constructive waves to destructive waves?

3 Outline the characteristics of constructive and destructive waves. Complete a copy of the table below.

Wave characteristic	Constructive wave	Destructive wave
Wave height		
Wave length		
Type of wave break (spilling or plunging)		
Strength of swash		
Strength of backwash		
Net beach sediment (gain or loss)		

Stretch yourself

Carry out some research about the tsunami waves that struck Japan in March 2011.

- Why were the waves so high and so powerful?
- What were the impacts on people and human activities?
- What effect did the waves have on the physical geography of the coast of Japan?

Practice question

Compare the characteristics of constructive and destructive waves. *(4 marks)*

Rivers and coasts pages

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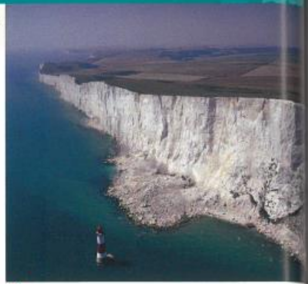
Mr E Stevenson

10.2 Weathering and mass movement

On this spread you will find out about processes of weathering and mass movement at the coast



A Rockfall at Beachy Head, Sussex

Rockfall at Beachy Head, 2001

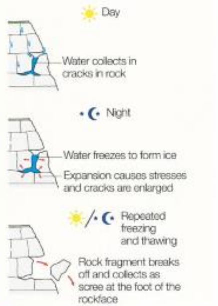
Photo **A** shows a dramatic rockfall that happened at Beachy Head in East Sussex. During the wet winter of 2000 the chalk rock became saturated with water. The water froze during the winter. In April 2001 this caused a rockfall – a huge slab of chalk broke away and collapsed into the sea. Processes like this combine with the action of the waves to shape the coastline.

What causes cliffs to collapse?

Cliffs collapse because of different types of weathering. This is the weakening or decay of rocks in their original place on, or close to, the ground surface. It is mostly caused by weather factors such as rainfall and changes in temperature.

There are three types of weathering:

- **Mechanical (physical) weathering** – the disintegration (break-up) of rocks. Where this happens, piles of rock fragments called *scree* can be found at the foot of cliffs.
- **Chemical weathering** – caused by chemical changes. Rainwater, which is slightly acidic, very slowly dissolves certain types of rocks and minerals.
- *Biological weathering* – due to the actions of flora and fauna. Plant roots grow in cracks in the rocks. Animals such as rabbits burrow into weak rocks such as sands.



B The process of freeze-thaw weathering

C Landslip at Holbeck Hall, Scarborough

Weathering process	Description
Freeze-thaw (mechanical)	Look at diagram **B**. • Water collects in cracks or holes (pores) in the rock. • At night this water freezes and expands and makes cracks in the rock bigger. • When the temperature rises and the ice thaws, water will seep deeper into the rock. • After repeated freezing and thawing, fragments of rock may break off and fall to the foot of the cliff (scree).
Salt weathering (mechanical)	• Seawater contains salt. When the water evaporates it leaves behind salt crystals. • In cracks and holes these salt crystals grow and expand. • This puts pressure on the rocks and flakes may eventually break off.
Carbonation (chemical)	• Rainwater absorbs CO_2 from the air and becomes slightly acidic. • Contact with alkaline rocks such as chalk and limestone produces a chemical reaction causing the rocks to slowly dissolve.

What are the processes of mass movement?

Mass movement is the downward movement or **sliding** of material under the influence of gravity. In 1993, 60m of cliff slipped onto the beach near Scarborough in North Yorkshire taking with it part of the Holbeck Hall Hotel (photo **C**). The hotel was left on the cliff edge and had to be demolished.

Diagram **D** describes some of the common types of mass movement found at the coast. Both mass movement and weathering provide an input of material to the coastal system. Much of this material is carried away by waves and deposited further along the coast.

D *Types of mass movement at the coast*

ACTIVITIES

1 a Draw a simple sketch of the coastline in photo **A**. Label the rockfall, the chalk cliffs and the rocky beach.
  b Do you think freeze-thaw is active here?
  c What is scree? Label this feature on your sketch.
  d How might rockfalls be a hazard to people?

2 Make a copy of diagram **B** and add detailed annotations to describe the process of freeze- thaw weathering.

3 Describe the process of mass movement in photo **C** and suggest the causes.

Stretch yourself

Investigate the Beachy Head rockfall in 2001.

- Which weathering and mass movement processes were responsible?
- What impact did the rockfalls have on the shape of the coast?
- Find out how and why the Belle Tout lighthouse had to be moved.

Practice question

Describe the effects of weathering and mass movement on a cliffed coastline. *(6 marks)*

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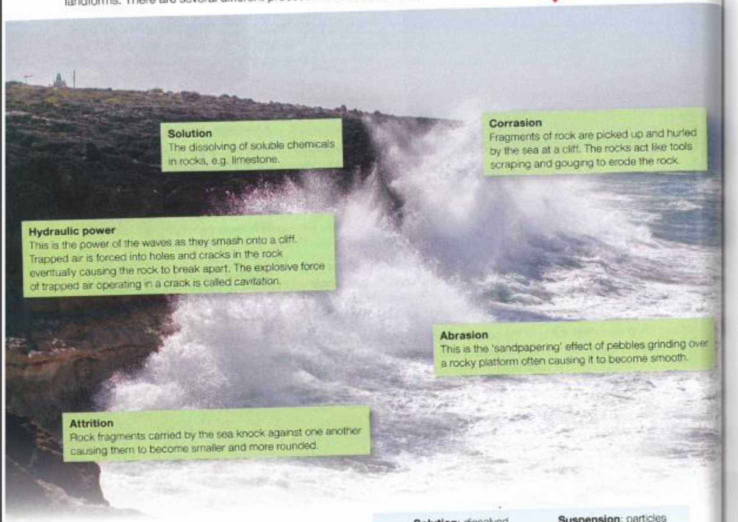
0.3 Coastal erosion processes

On this spread you will find out about the processes of erosion and deposition

Coastal erosion

Erosion involves the removal of material and the shaping of landforms. There are several different processes of coastal erosion.

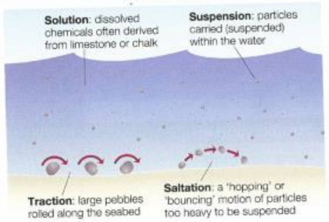


A Processes of erosion

Coastal transportation

Sediment of different sizes can be transported in four different ways. (diagram **B**):

- **solution**
- **suspension**
- **saltation**
- **traction**.

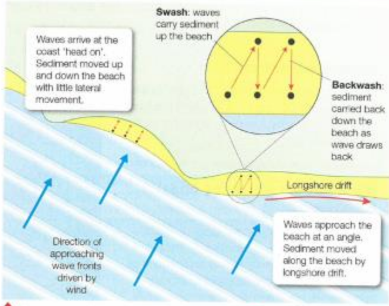


B Types of coastal transportation

Longshore drift

The movement of sediment on a beach depends on the direction that waves approach the coast (diagram **C**). Where waves approach 'head on', sediment is simply moved up and down the beach. But if waves approach at an angle, sediment will be moved *along* the beach in a 'zigzag' pattern. This is called **longshore drift**.

Longshore drift is responsible for a number of important coastal landforms including beaches and spits (pages 100–1).

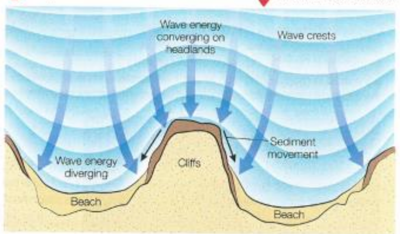


C Longshore drift

Coastal deposition

Coastal **deposition** takes place in areas where the flow of water slows down. Waves lose energy in sheltered bays and where water is protected by spits or bars (see page 101). Here sediment can no longer be carried or moved and is therefore deposited. This explains why beaches are found in bays, where the energy of the waves is reduced. This is called *wave refraction* (diagram **D**).

Mudflats and saltmarshes are often found in sheltered estuaries behind spits where there is very little flow of water.



D Coastal wave refraction

ACTIVITIES

1. a Draw an annotated diagram similar to **B** to show the processes of *erosion*. Show a wave breaking against the foot of a cliff.
   b Add detailed labels to describe the *five* processes of erosion.
2. a What is meant by the term 'longshore drift' (diagram **C**)?
   b Why does this only occur on some beaches?
   c Draw a diagram to show the process of longshore drift. Add labels to describe what is happening.
   d Imagine you are doing a fieldwork investigation for evidence of longshore drift along a stretch of coast. What evidence would you look for and why?

Stretch yourself

Find out more about the coastal locations where deposition occurs.

- Focus on a stretch of coastline near to your school or one that you have visited.
- Use maps and satellite images to zoom in on locations where deposition has happened. Describe the material that has been deposited and suggest reasons why.

Practice question

What factors affect the processes operating along a stretch of coastline? *(6 marks)*

Coastal erosion landforms

On this spread you will find out about the characteristics and formation of coastal landforms

What is a landform?

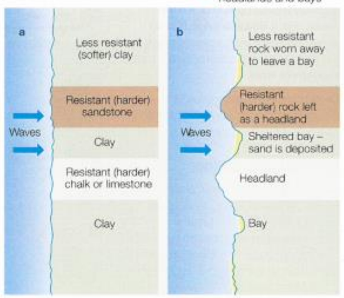
You will come across the term 'landform' all the time in physical geography. A landform is a feature of the landscape that has been formed or sculpted by processes of:

- erosion
- transportation
- deposition.

What factors influence coastal landforms?

Some rocks are tougher and more resistant than others. Rocks such as granite, limestone and chalk form impressive cliffs and headlands because they are more resistant to erosion. Softer rocks, clays and sands are more easily eroded to form bays or low-lying stretches of coastline.

Geological structure includes the way that layers of rocks are folded or tilted. This can be an important factor in the shape of cliffs. **Faults** are cracks in rocks. Enormous tectonic pressures can cause rocks to 'snap' rather than fold (bend) and movement (or *displacement*) happens on either side of the fault. Faults form lines of weakness in rocks, easily carved out by the sea.



A *The formation of headlands and bays*

Headlands and bays

Different types of rock at the coastline will be eroded at different rates. Weaker bands of rock (such as clay) erode more easily to form *bays*. As the bays are sheltered, deposition takes place and a sandy beach forms (diagram **A**).

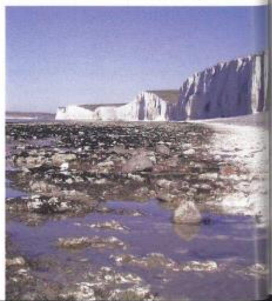
The tougher, more resistant bands of rock (such as limestone or sandstone) are eroded much more slowly. They stick out into the sea to form **headlands**. Erosion dominates in these high-energy environments, which explains why there are no beaches. Most *erosional* landforms are found at headlands.

Cliffs and wave-cut platforms

When waves break against a **cliff**, erosion close to the high tide line will wear away the cliff to form a wave-cut notch. Over a long period of time – usually hundreds of years – the notch will get deeper and deeper, undercutting the cliff. Eventually the overlying cliff can no longer support its own weight and it collapses.

Through a continual sequence of wave-cut notch formation and cliff collapse, the cliff will gradually retreat. In its place will be a gently sloping rocky platform called a **wave-cut platform** (photo **B**). A wave-cut platform is typically quite smooth due to the process of abrasion. However, in some places it may be scarred with rock pools.

B *Wave-cut platform and beach near Beachy Head*



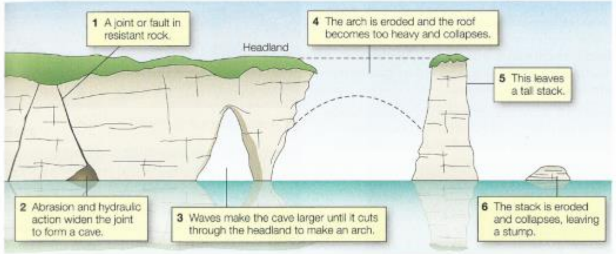
Caves, arches and stacks

Lines of weakness in a headland, such as *faults*, are particularly vulnerable to erosion. The energy of the waves wears away the rock along a line of weakness to form a **cave** (diagram **C**). Over time, erosion may lead to two back-to-back caves breaking through a headland to form an **arch**. Gradually the arch is enlarged by erosion at the base and by weathering processes (such as freeze-thaw) acting on the roof. Eventually the roof will be worn away and collapse to form an isolated pillar of rock known as a **stack**.

Remember!

- A cliff, a river meander or a delta *are* all landforms.
- A process such as longshore drift is *not* a landform.
- A geological feature such as a joint in a rock outcrop is *not* a landform.

If you are in any doubt, check with your teacher!



C *How caves, arches and stacks are formed*

A chalk arch, Bwa Gwyn, Anglesey

Bwa Gwyn (Photo **D**) is an impressive arch formed by erosion in an outcrop of white quartzitic rock on the Anglesey coastline. In the past, Bwa Gwyn was quarried for china clay. Today you can still see the grindstone used to extract the clay on the top of the rocks. It is a stunning climb across the rocks, but it can be dangerous because of unstable cliffs.

D *Bwa Gwyn arch, Anglesey*

Stretch yourself

Find an example of a coastline with headlands and bays. This could be a stretch of coastline near to where you live or one that you have visited.

- Search for a map or satellite photo and add labels to describe the main features.
- Find out about the different types of rock.

Practice question

Use one distinctive coastal landform to illustrate the erosive power of the sea. *(6 marks)*

ACTIVITIES

1. Draw a sequence of diagrams to show the formation of headlands and bays. To test your understanding, draw your coast facing a different direction to diagram **A**.
2. Draw a sequence of labelled diagrams to show how a cliff is undercut by the sea and then collapses to form a wave-cut platform. Use your labels to explain the processes and landforms.
3. Use a sequence of diagrams to explain the formation of a stack (diagram **C**).

10.5 Coastal deposition landforms

On this spread you will find out about the characteristics and formation of coastal deposition landforms

Beaches

Beaches are deposits of sand and shingle (pebbles) at the coast. Sandy beaches are mainly found in sheltered bays (photo **A**). The waves entering the bay are *constructive* waves (see page 93). They have a strong swash and build up the beach.

Not all beaches are made of sand. Much of the south coast of England has pebble beaches. These high-energy environments wash away the finer sand and leave behind the larger pebbles. These come from nearby eroded cliffs or are deposited onshore from vast accumulations out to sea.

Diagram **B** shows the profile of a typical sandy beach. Notice the clear ridges called *berms*. One of these marks the high tide line where seaweed and rubbish get washed up onto the beach.

Sand dunes

At the back of the beach in photo **A**, sand deposited on the beach has been blown inland by onshore winds to form *dunes*. Diagram **C** shows how dunes change in form and appearance the further inland.

Embryo dunes form around deposited obstacles such as pieces of wood or rocks.

↓

These develop and become stabilised by vegetation to form *fore dunes* and tall *yellow dunes*. Marram grass is adapted to the windy, exposed conditions and has long roots to find water. These roots help bind the sand together and stabilise the dunes.

↓

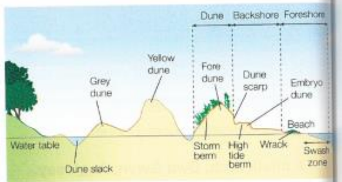
In time, rotting vegetation adds organic matter to the sand making it more fertile. A much greater range of plants colonise these 'back' dunes.

↓

Wind can form depressions in the sand called *dune slacks*, in which ponds may form.

C Development of sand dunes

A A sandy beach at Studland Bay, Dorset



B Cross section through beach and sand dunes

D Hurst Castle Spit, Hampshire

Spits

A **spit** is a long, narrow finger of sand or shingle jutting out into the sea from the land (photo **D**).

Spits form on coasts where there is significant longshore drift. If the coastline changes orientation and bends sharply, sediment is then deposited out to sea (diagram **E**). As it builds up, it starts to form an extension from the land. This process continues with the spit gradually growing further out into the sea. Strong winds or tidal currents can cause the end of the spit to become curved to form a feature called a *recurved end* (photo **D**). There may be a number of recurved ends marking previous positions of the spit.

In the sheltered water behind the spit, deposits of mud have built up. An extensive saltmarsh has formed as vegetation has started to grow in the emerging muddy islands. Saltmarshes are extremely important wildlife habitats and over-wintering grounds for migrating birds.

Bars

Longshore drift may cause a spit to grow right across a bay, trapping a freshwater lake (or *lagoon*) behind it. This feature is called a **bar** (photo **F**).

An offshore bar forms further out to sea. Waves approaching a gently sloping coast deposit sediment due to friction with the seabed. The build-up of sediment offshore causes waves to break at some distance from the coast.

In the UK some offshore bars have been driven onshore by rising sea levels following ice melt at the end of the last glacial period some 8000 years ago. This type of feature is called a *barrier beach*. Chesil Beach in Dorset is one of the best examples of this feature in the UK.

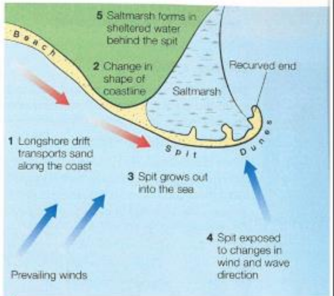
ACTIVITIES

1 Describe the processes responsible for the formation of the beach and the sand dunes in photo **A**.
2 Draw a sketch of Hurst Castle Spit. Add labels to describe the characteristic features and the processes responsible for the spit's formation.
3 Describe the characteristics and possible formation of the bar in photo **F**.

Stretch yourself

Investigate the characteristics and formation of sand dunes.

- Why do they only form in certain places on the coast?
- Research 'sand dune succession' to find out the sequence of events in the formation of sand dunes.
- What are the characteristics of marram grass and why does it thrive on sand dunes?



E The formation of a spit

F Bar at Slapton Ley, Devon

Practice question

How do the processes of deposition lead to the formation of distinctive landforms?
(6 marks)

10.6 Coastal landforms at Swanage (1)

10.6 Coastal landforms at Swanage (1)

On this spread you will find out about coastal erosion and deposition landforms at Swanage, Dorset

Example

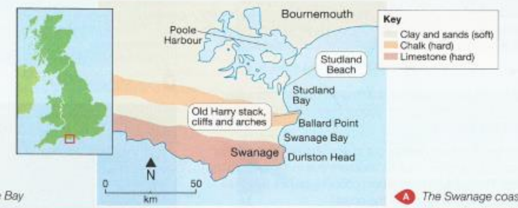
Where is Swanage?

Swanage is a seaside town in Dorset on the south coast of England. It is located in a sheltered bay and has a broad sandy beach (photo **B**). This is a classic stretch of coastline with many impressive landforms of coastal erosion and deposition.

Different rock types and geological structure are important in the formation of this coastline. The rocks have been folded and tilted so that bands of different rock types reach the coast. Headlands and bays form where there are alternating bands of more resistant (harder) and less resistant (softer) rocks (map **A**).

Did you know?

The coast around Swanage is part of what is known as the Jurassic Coast. The 154 km stretch of coast in East Devon and Dorset was made a World Heritage Site in 2001 because of its geological importance. Jurassic is the name of the geological period when the rocks on the coast were formed – 145 to 200 million years ago!



A *The Swanage coast, Dorset*

B *Swanage Bay*

This indented coastline is called a *discordant coastline*. On the south coast there is only one type of rock – limestone. This forms a relatively straight section of coast and is called a *concordant coastline*.

To the north of Swanage is Poole Harbour, one of the UK's largest natural harbours. A great deal of deposition has taken place in this large sheltered bay. You can see two spits at the mouth of the harbour, one on the south side and one on the north.

At Studland there are lagoons, saltmarshes and sand dunes. This area is well known for its wildlife. Photo **C** shows part of the beach and sand dunes at Studland.

C *The beach and sand dunes at Studland*

ACTIVITIES

1 a What rock forms the headland at Durlston Head (map **A**)?
  b What type of rock forms Swanage Bay?
  c Explain why headlands and bays have formed along this stretch of coastline.
2 a Explain why sediment that has been deposited on the beach in photo **B** (see diagram **D** on page 97).
  b Why has a beach formed in Swanage Bay?
  c Why do you think the beach is popular with visitors?
  d What is the evidence in this photo that the tide is going out?
3 a Suggest reasons why sand dunes have formed at the back of the beach in photo **C**.
  b What is the name of the grass growing on the sand dunes?
  c How does this grass help to stabilise the dunes?
  d Describe the characteristics of the barbecue area. Why do you think a specific area has been provided for this purpose?

Stretch yourself

Carry out some further research about Studland.

- What are the main habitats found here?
- Why is it an important area for wildlife?
- Why is it a popular place for visitors?
- Find out how the area is being managed to minimise the harmful effects of visitors.

Practice question

Using evidence from the photos, evaluate any potential conflict between the different uses of the Dorset coast near Swanage and Studland. *(6 marks)*

Coastal landforms at Swanage (2)

On this spread you will use map and photo evidence to study landforms of coastal erosion and deposition at Swanage, Dorset

Example

Using the OS map extract and photo

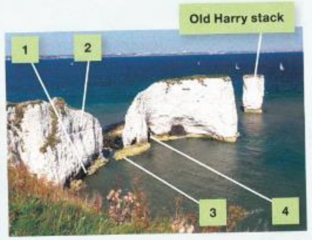
Map **A** is a 1:50000 extract from an OS map of the Swanage coast. Look back to diagram **A** on page 102 to see how the different rock types form the headlands and bays.

Locate the chalk headland Ballard Point on the map, to the north of Swanage Bay. Photo **B** is an aerial photo of this stretch of coastline. Notice the impressive white chalk cliffs and the many isolated stacks. In the far distance is a well-known local landform, an isolated stack called Old Harry. Photo **C** is a close-up view of Old Harry.

Did you know?

Old Harry had a wife ... a stack that stood side by side on the chalk seam that stretched out from Swanage Bay. But, the sea gradually eroded this second stack until her eventual collapse in 1896. Old Harry's wife is now known as a stump.

B *Aerial view of the coastline between Ballard Point and the Foreland*



C *The Foreland and Old Harry*

ACTIVITIES

1 Study map **A** and photo **B**.
- **a** The Foreland, Peveril Point and Durlston Head are all examples of what coastal landform?
- **b** In what grid square is the Foreland?
- **c** In what direction is the photo looking?
- **d** On the map, what local name is given to the stacks shown in the photo?
- **e** Describe the characteristics of the chalk cliffs in the photo.
- **f** Give the six-figure grid reference of Old Harry.

2
- **a** Locate Swanage Bay on the map. Approximately how wide is the bay from Ballard Point to Peveril Point?
- **b** What map evidence is there that deposition is occurring in Swanage Bay?
- **c** How does this deposition help to explain the growth of Swanage as a tourist resort?

Practice question

Use evidence from the OS map of the Swanage coast to suggest how the area's human use has been affected by its physical geography. *(4 marks)*

A *1:50000 OS map extract of Swanage coast*

ACTIVITIES

3 Study map **A** and photo **C**.
- **a** What are the landforms labelled 1–3 on photo **C**?
- **b** Was the photo taken at high tide or low tide? Explain your answer.
- **c** What additional evidence would you need to confirm that landform 4 is an arch?
- **d** Design an information board to be located on The Foreland to explain the formation of Old Harry.
  - Draw a series of annotated diagrams to describe its formation. Refer to the processes of erosion in your annotations.
  - Remember that your information board is aimed at the general public so make sure it is clear and attractive.

4 Locate Studland Bay and Studland Heath on map **A**.
- **a** Give the four-figure grid reference for Studland Heath.
- **b** What is the meaning of the blue bird symbol at 033850?
- **c** Describe the different types of natural environment in this area.
- **d** Why is this area popular with visitors?
- **e** Why do you think Studland needs to be managed?

10.8 Managing coasts – hard engineering

On this spread you will find out how hard engineering can protect coastlines from the effects of physical processes

Why do coasts need to be managed?

Coasts need to be managed to maintain a balance between the forces of nature and the demands of people. People living or working at the coast need to be protected from erosion and flooding. With sea levels expected to rise in the future, coastal defences will become ever more expensive. In some case the increasing costs may outweigh the benefits and coastlines may be left undefended.

What are the coastal management options?

There are three different management strategies for defending the coast.

Hard engineering – using artificial structures such as sea walls to control natural processes

Soft engineering – less intrusive, more environmentally-friendly methods that work with natural processes to protect the coast

Managed retreat – this increasingly popular option enables the controlled retreat of the coastline, often involving allowing the sea to flood over low-lying land

Hard engineering

For centuries people have used hard engineering structures to try to control the actions of the sea and protect property and land. Sea walls, groynes, rock armour and gabions are the most common hard engineering structures used in coastal management.

Sea wall

Description: Concrete or rock barrier against the sea, placed at the foot of cliffs or at the top of a beach. Has a curved face to reflect the waves back into the sea.

Cost: £5000–£10 000 per metre

Advantages:
- Effective at stopping the sea.
- Often has a walkway or promenade for people to walk along.

Disadvantages:
- Can look obtrusive and unnatural.
- Very expensive and high maintenance costs.

A *Sea wall at Dawlish, Devon*

Groynes

Description: Timber or rock structures built out to sea from the coast. They trap sediment being moved by longshore drift and enlarge the beach. The wider beach acts as a buffer to reduce wave damage.

Cost: Timber groynes £150 000 each (at every 200 m)

Advantages:
- Create a wider beach, which can be popular with tourists.
- Provide useful structures for people interested in fishing.
- Not too expensive.

Disadvantages:
- By interrupting longshore drift they starve beaches further along the coast, often leading to increased rates of erosion elsewhere. The problem is therefore shifted rather than solved.
- Groynes are unnatural and rock groynes in particular can be unattractive.

B *Groynes at Eastbourne, Sussex*

Nowadays hard engineering approaches are less commonly used because they:

- are expensive and involve high maintenance costs
- interfere with natural coastal processes and can cause destructive knock-on effects elsewhere – for example, by altering wave patterns erosion can occur further along the coast, leading to new problems such as cliff collapse
- look unnatural.

Maths skills

A local council wishes to defend a 1 km stretch of coastline. Calculate comparative costs for each of the following:

- sea wall
- rock armour
- groynes
- gabions.

Rock armour

Description: Piles of large boulders dumped at the foot of a cliff. The rocks force waves to break, absorbing their energy and protecting the cliffs. The rocks are usually brought by barge to the coast.

Cost: £200 000 per 100 m

Advantages:
- Relatively cheap and easy to maintain.
- Can provide interest to the coast.
- Often used for fishing.

Disadvantages:
- Rocks are usually from other parts of the coastline or even from abroad.
- Can be expensive to transport.
- Do not fit in with the local geology.
- Can be very obtrusive.

C *Rock armour at Walton on the Naze, Essex*

Gabions

Description: Wire cages filled with rocks that can be built up to support a cliff or provide a buffer against the sea.

Cost: Up to £50 000 per 100 m

Advantages:
- Cheap to produce and flexible in the final design.
- Can improve drainage of cliffs.
- Will eventually become vegetated and merge into the landscape.

Disadvantages:
- For a while they look very unattractive.
- Cages only last 5–10 years before they rust.

D *Gabions at Thorpeness, Suffolk*

ACTIVITIES

1 a Why is a sea wall an example of hard engineering?
  b What is the purpose of a sea wall?
  c What are the advantages and disadvantages of a sea wall?
2 Draw a simple diagram to explain how groynes cause a beach to become wider.
3 What are the arguments for and against using gabions as a form of coastal defence?

Stretch yourself

Find out about other options for hard engineering. Consider the following:

- revetments
- offshore breakwaters
- artificial headlands.

What is the cost of construction? Outline the advantages and disadvantages.

Practice question

What are the advantages and disadvantages of hard engineering at the coast? *(6 marks)*

10.9 Managing coasts – soft engineering

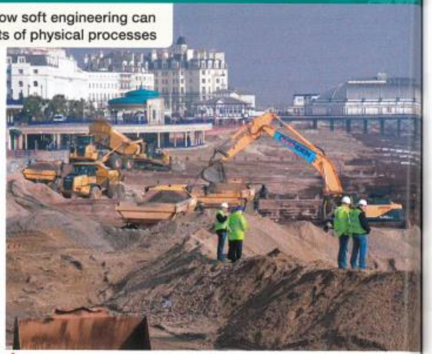
On this spread you will find out how soft engineering can protect coastlines from the effects of physical processes

How does soft engineering protect the coast?

Photo **A** shows **beach nourishment**, one of the most widely used forms of soft engineering. Sand, or in this case shingle, is dredged offshore and transported to the coast by barge. The shingle is then dumped onto the beach and shaped by bulldozers. This is called **reprofiling**. The higher and wider beach now provides greater protection to valuable land and property and creates a natural amenity for tourism and recreation.

Soft engineering approaches such as beach nourishment try to work with natural coastal processes. Photo **B** shows marram grass being replanted to help stabilise sand dunes. This is called **dune regeneration**.

Soft engineering schemes tend to be cheaper than hard engineering although they may require more maintenance. Every few years beaches will need more sand or shingle and sand dunes may need replanting to replace grass that has died or been trampled. However, these schemes are generally more sustainable and are often the preferred option for coastal management today.



A *Beach nourishment at Eastbourne, East Sussex*

B *Sand dune regeneration at Calgary Bay, Mull, Scotland*

Beach nourishment

Description: The addition of sand or shingle to an existing beach to make it higher or wider. The sediment is usually obtained offshore locally so that it blends in with the existing beach material. It is usually transported onshore by barge.

Cost: Up to £500 000 per 100 m

Advantages:
- Relatively cheap and easy to maintain.
- Blends in with existing beach.
- Increases tourist potential by creating a bigger beach.

Disadvantages:
- Needs constant maintenance unless structures are built to retain the beach.

Dune regeneration

Description: Sand dunes are effective buffers to the sea but are easily damaged and destroyed by trampling. Marram grass can be planted to stabilise dunes and help them to develop. Fences can be used to keep people off newly-planted areas.

Cost: Cost: £200–£2000 per 100 m

Advantages:
- Maintains a natural coastal environment that is popular with people and wildlife.
- Relatively cheap.

Disadvantages:
- Time-consuming to plant the marram grass and fence areas off.
- People don't always respond well to being prohibited from accessing planted areas.
- Can be damaged by storms

C *Dune regeneration at Chichester, West Sussex*

Dune fencing

Description: Fences are constructed on a sandy beach along the seaward face of existing dunes to encourage new dune formation. These new dunes help to protect the existing dunes.

Cost: £400–£2000 per 100 m.

Advantages:
- Minimal impact on natural systems.
- Can control public access to protect other ecosystems.

Disadvantages:
- Can be unsightly especially if fences become broken.
- Regular maintenance needed especially after storms.

D *Dune fencing at Formby, Merseyside*

ACTIVITIES

1 a Describe what is happening in photo **A**.
  b Why do you think beach nourishment has been chosen to help defend the coastline at Eastbourne?
  c What other forms of coastal defence have been installed here and what is their purpose?
  d What are the disadvantages of beach nourishment?
2 a Why do you think the area of sand dunes in photo **B** needs to be restored?
  b Apart from planting marram grass, what other forms of management will be needed to restore these dunes?
3 Why do you think there is a wide price range for each of the forms of soft engineering?
4 Suggest why *either* hard engineering *or* soft engineering is the best option for defending the coast.

Stretch yourself

Find out more about sand dune regeneration.
- Try to find an example of sand dunes that have had to be regenerated (restored).
- What caused the problems and what solutions have been adopted?
- What are the challenges and opportunities for the future?

Practice question

Identify the differences between hard and soft engineering coastal management strategies.
(4 marks)

10.10 Managing coasts – managed retreat

On this spread you will find out how managed retreat can protect coastlines from the effects of physical processes

Managed retreat

Managed retreat is a deliberate policy of allowing the sea to flood or erode an area of relatively low-value land. It is a form of soft engineering as it allows natural processes to take place and does not intervene in the way that hard engineering does.

In the long term, allowing managed retreat is a more sustainable option than spending large sums of money trying to protect the coast with sea walls or groynes. As sea levels continue to rise, managed retreat seems likely to become an increasingly popular choice for managing the coastline.

A The breach of the sea defences at Medmerry

Medmerry Managed Retreat, near Chichester, West Sussex

Aerial photo **B** shows a stretch of coastline on the south coast of England near Chichester. This flat, low-lying coast is mainly used for farming and caravan parks. For many years the land was protected by a low sea wall but this is now in need of repair. Building a new sea wall to protect the area against future sea-level rise was a very expensive option.

Given the relatively low value of the land, it was decided to allow the sea to breach the current sea defences (photo **A**) and flood some of the farmland that was previously protected. You can see in the photo how this has happened .

The Medmerry scheme cost £28 million and the controlled breaching of the old sea defences took place in November 2013. In the future, this scheme will:

- create a large natural saltmarsh to form a natural buffer to the sea
- help to protect the surrounding farmland and caravan parks from flooding
- establish a valuable wildlife habitat and encourage visitors to the area.

You can see on photo **B** that embankments have been constructed inland to give protection to farmland, roads and settlements. This alteration of the coastline is called *coastal realignment*.

B Managed retreat at Medmerry, West Sussex

Coastal monitoring and adaptation

Much of the coastline of the UK does not require expensive intervention in the form of coastal defences. Land may be low-value farmland, forest or moorland. In many cases these coastal zones can be left alone – this is sometimes called the 'Do Nothing' approach. People living or working in these areas have to adapt by relocating further inland. This might involve moving mobile homes on a holiday park, a path, a fence or a hole on a golf course (photo **C**).

Scientists conduct monitoring of these stretches of coastline. This helps to reduce the possibilities of conflict between managing the coast and the needs and views of local people whose lives are affected. This monitoring involves studying marine processes, mass movement and human activity to ensure safety and to make sure this approach remains the most appropriate. If conditions change, for example the risk of flooding increases and threatens property, then a new approach might be adopted.

Another view

Some experts argue that plans for managed retreat strategies may not take into account the impact on coastal communities. There may be longer-term effects on coastal trade, tourism, infrastructure and businesses, as well as rehousing costs.

C Manage or adapt?

ACTIVITIES

1 Why is managed retreat a sustainable option for coastal management?

2 a Describe the relief of the area shown in photo **B**.
  b What are the main land uses at X and Y?
  c What is the purpose of the feature at Z?
  d What are the advantages and disadvantages of this scheme?

3 Do you think the stretch of coast in photo **C** should be protected or should people adapt to the natural changes taking place? Justify your answer.

Practice question

Examine why a system of managed retreat may not be a feasible option in some parts of the coast. *(6 marks)*

Stretch yourself

Carry out your own research to find another example of managed retreat.

- What were the pre-existing forms of coastal defence and why has managed retreat now been adopted?
- Assess the advantages and disadvantages of your chosen scheme.
- What are the challenges for the future?

10.11 Coastal management at Lyme Regis

On this spread you will find out about the coastal management schemes at Lyme Regis in Dorset

Example

Lyme Regis is a small coastal town on the south coast of England. It lies at the heart of the World Heritage Site known as the Jurassic Coast. This is one of the most spectacular stretches of coastline in the UK and famous for its fossils. The town is a popular tourist destination. In summer, the population of the town swells from 4000 to 15000!

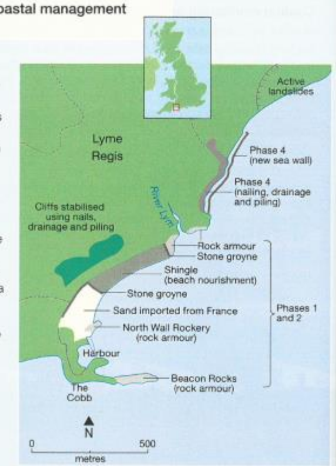
What are the issues at Lyme Regis?

Much of the town has been built on unstable cliffs. The coastline is eroding more rapidly than any in Europe due to the powerful waves from the south west. Many properties have been destroyed or damaged, and there has been considerable erosion of the foreshore. The sea walls have been breached many times.

How has the coastline been managed?

The Lyme Regis Environmental Improvement Scheme was set up by West Dorset District Council in the early 1990s. Its aims were to provide long-term coastal protection and reduce the threat of landslips. Engineering works were completed in 2015.

To reduce conflicts between different interest groups, such as property owners, fishermen and environmentalists, there were consultation meetings and the public were kept informed before and during the construction work.



A Coastal management at Lyme Regis

Phase 1 Date: 1990s (completed 1995)

- New sea wall and promenade constructed to the east of the mouth of the River Lim.
- In the winter of 2003–2004 a £1.4 million emergency project was completed to stabilise the cliffs. Hundreds of large nails were used to hold the rocks together as well as improving drainage and re-profiling the slope of the beach.

Phase 2 Date: 2005–2007

Extensive improvements made to the sea front costing £22 million. These included:

- construction of new sea walls and promenades
- creation of a wide sand and shingle beach to absorb wave energy and increase use of the shore; shingle dredged from the English Channel and sand imported from France
- extension of rock armour at The Cobb (map **A**) and the eastern end of the sea front, to absorb wave energy and help retain the new beach.

Phase 3 Not undertaken.

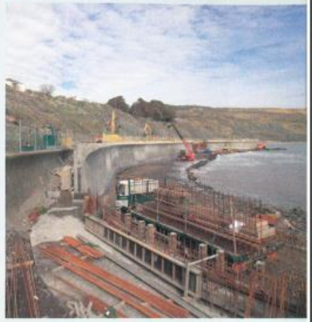
The initial plan to help prevent landslips and coastal erosion to the west of The Cobb were shelved. It was decided to leave this stretch of coast alone as the costs outweighed the benefits.

Phase 4 Date: 2013–2015

This final phase focused on the coast east of the town (photo **B**). It cost £20 million and involved:

- constructing a new 390m sea wall in front of the existing wall (photo **C**) to provide additional protection
- extensive nailing, piling and drainage to provide cliff stabilisation to protect 480 homes.

B The Jurassic Coast east of Lyme Regis in 2013 before Phase 4 began



C Phase 4 coastal defence works at Lyme Regis

How successful has the management scheme been?

Positive outcomes ✓	Negative outcomes ✗
• The new beaches have increased visitor numbers and seafront businesses are thriving. • The new defences have stood up to recent stormy winters. • The harbour is now better protected, benefiting boat owners and fishermen.	• Increased visitor numbers have led to conflicts with local people who think traffic congestion and litter have increased. • Some people think the new defences have spoilt the natural coastal landscape. • The new sea wall may interfere with coastal processes and affect neighbouring stretches of coastline, causing conflicts elsewhere. • Stabilising cliffs will prevent landslips that may reveal important fossils – a potential conflict.

ACTIVITIES

1. Complete a table listing the different types of hard and soft engineering used at Lyme Regis (map **A**).
2. Photo **C** shows Phase 4 of the coastal defence work at Lyme Regis.
   a. Describe what is happening in the photo.
   b. What material has been used to construct the sea wall?
   c. Suggest some of the issues associated with carrying out this new defence work.
3. Suggest why both hard and soft engineering have been used to protect the coast at Lyme Regis.
4. How has the management of the coast at Lyme Regis reduced possible conflicts between different groups of people?

Stretch yourself

Investigate the management measures at Lyme Regis. You will find plenty of photos and maps online with 'before and after' images and information about the different measures implemented. Consider how successful these measures have been since 2015.

Practice question

To what extent can the coastal management at Lyme Regis be considered a success? *(6 marks)*

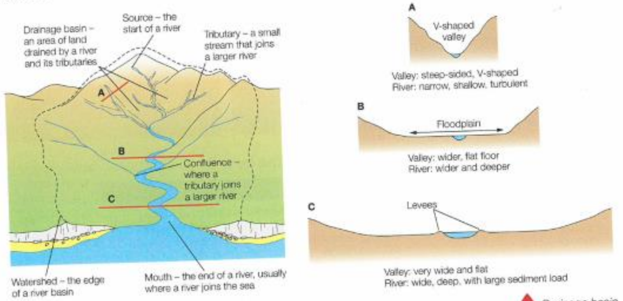
11 River landscapes

11.1 Changes in rivers and their valleys

On this spread you will find out how rivers and their valleys change with distance downstream

What is a drainage basin?

Diagram **A** shows a typical *drainage basin*, an area of land drained by a river and its tributaries. Make sure you are familiar with the key terms on this diagram, as you will need to remember them.

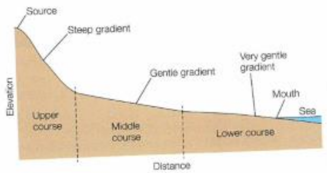


A Drainage basin

How does the long profile of a river change downstream?

Imagine that you were on a raft floating down the river in diagram **A**.

- In the mountains your speed (velocity) would vary considerably. Where the water is shallow and turbulent there is friction with the bed and banks, slowing the rate of flow. But if you encounter rapids, where the channel narrows and the river becomes deeper, you would move much faster!
- Further downstream, the river's channel is much deeper due to the tributaries bringing additional water. Now less water is in contact with the bed and banks and the velocity increases, even though the gradient is less steep than in the mountains. You would now be floating faster!



B The long profile of a river

If you plotted your journey as a line graph it would look like diagram **B**. This is called the long profile of a river. Notice that the river has a steep gradient in its upper course and a much gentler gradient in its lower course. This concave shape is an ideal profile. In most cases, a river's long profile will vary because, for example, of the river crossing bands of tough and weak rock. A waterfall, for example, creates a step in the long profile of a river.

C *The River Tees in County Durham*

How does the cross profile of a river and its valley change downstream?

A **cross profile** is an imaginary 'slice' across a river channel and its valley at a particular point. Diagram **A** shows the cross profile of both a river and its valley downstream. The river channel becomes wider and deeper, with the river valley becoming wider and flatter. Its sides are less steep compared with its V-shaped appearance further upstream.

In reality there will be variations in places. For example, river management can alter the shape of a river channel, and different types of rock or human activities such as quarrying can affect the cross profile of a valley.

These changes downstream are due to the amount of water flowing in the river. As tributaries bring water from other parts of the drainage basin the river becomes bigger. With more water and more energy it is able to erode its channel, making it wider and deeper.

The changes to the valley cross profile are mainly due to channel erosion broadening and flattening the base of the valley. Together with weathering and mass movement, these processes make the sides of the valley less steep.

Did you know?

The UK's longest river is the River Severn. It is 354 km in length compared to the River Thames which is 346 km.

ACTIVITIES

1 a Copy the long profile (diagram **B**).
  b Locate the three cross profiles shown in diagram **A** on your diagram. Draw each cross profile and add labels to describe the valley and the river.
  c Describe how a river and its valley change with distance downstream.

2 Photo **C** shows the River Tees in County Durham.
  a Describe the river. Comment on its width, depth and type of flow (turbulent or smooth).
  b Describe the shape of the valley.
  c Suggest where in the long profile of the river this photo was taken. Explain your answer.

Stretch yourself

Investigate the changes in a river close to your home or school. Use a map or photos to show how the river and its valley change with distance downstream.

Practice question

Describe how the shape of a river valley changes downstream.
(4 marks)

11.2 Fluvial (river) processes

11.2 Fluvial (river) processes

On this spread you will find out how rivers erode, transport and deposit material

What are the processes of erosion?

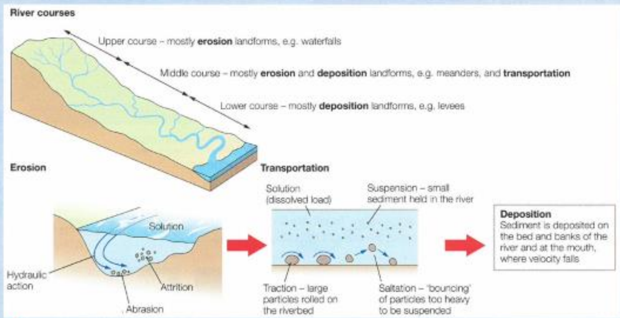
Photo **A** shows a small river on Exmoor in south west England. There is very little water in the river and very little is happening! It is like this for much of the year. The river is using all its energy to overcome friction and just transport water downstream.

It is only after heavy rainfall that the river has enough energy to erode and enlarge its channel and the river valley. It is possible to identify two types of erosion:

- **vertical erosion** (downwards)
- **lateral erosion** (sideways).

These combine to cause the downstream changes to the river channel and the river valley described on pages 114–15.

A *An Exmoor river at low flow during the late summer*



B *River courses and fluvial processes*

Diagram **B** shows the four processes of erosion that take place in a river:

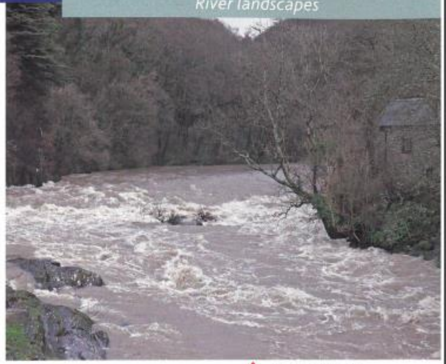
- **Hydraulic action** – the force of the water hitting the river bed and banks. This is most effective when the water is moving fast and when there is a lot of it.
- **Abrasion** – when the load carried by the river repeatedly hits the bed or banks dislodging particles into the flow of the river.
- **Attrition** – when stones carried by the river knock against each other, gradually making the stones smaller and more rounded.
- **Solution** – when the river flows over limestone or chalk, the rock is slowly dissolved. This is because it is soluble in mildly acidic river water.

What are the processes of transportation?

The material transported by a river is called its *load*. Diagram **B** shows the four main types of *transportation* that occur in a river:

- **traction**
- **saltation**
- **suspension**
- **solution**.

The size and total amount of load that can be carried will depend on the river's rate of flow – its *velocity*. After a rainstorm rivers often look very muddy because they are flowing fast and transporting a large amount of sediment (photo **C**). At low flow, when rivers are clear, very little sediment is being transported (photo **A**).



C *A river in high flow*

When does deposition take place?

Deposition occurs when the velocity of a river decreases. It no longer has enough energy to transport its sediment so it is deposited.

- Larger rocks tend to be deposited in the upper course of a river. They are only transported for very short distances, mostly by *traction*, during periods of very high flow.
- Finer sediment is carried further downstream, mostly held in *suspension*. This material will be deposited on the river bed or banks, where velocity is slowed by *friction*.
- A large amount of deposition occurs at the river mouth, where the interaction with tides, along with the very gentle gradient, greatly reduces the river's velocity.

ACTIVITIES

1 a What is the evidence in photo **A** that this river is experiencing low flow conditions?
  b Do you think the river is transporting any load? Explain your answer.
  c What evidence is there that erosion and deposition take place in this river?
  d Under what conditions would you expect active erosion to take place?
2 Use diagram **B** to draw a labelled diagram describing the processes of river erosion.
3 How do the size of the sediment and the velocity of the river affect the processes of river transportation?
4 Where and when does deposition take place in a river?

Stretch yourself

1 Investigate how velocity affects the processes of erosion, transportation and deposition.
2 Find out about the Hjulstrom Curve and make a simple copy of the graph. Add annotations to describe what it shows.

Practice question

To what extent is the size and shape of a river valley the result of the work of the river under flood conditions? *(9 marks)*

River erosion landforms

On this spread you will find out how rivers erode their valleys to form distinctive landforms

What are the distinctive river landforms?

Diagram **A** shows a typical river from source to mouth and its distinctive landforms.

- In the river's upper course, erosion dominates to form landforms such as *interlocking spurs*, *waterfalls* and *gorges*.
- Further downstream, erosion and deposition combine to form *meanders* and *ox-bow lakes*.
- As the river nears the sea, deposition dominates to form a *floodplain*, *levees* and the river estuary. You need to be able to recognise these features and describe how they form.

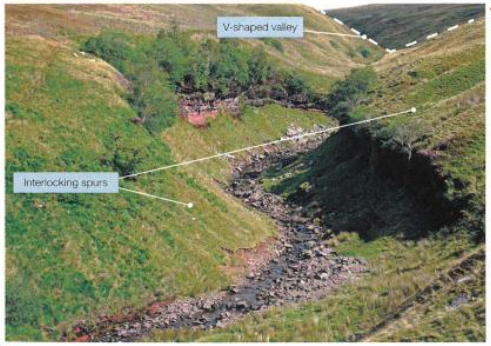
Of course, not all rivers are 'typical' and it's possible to find landforms of erosion and deposition at various points along the course of a river.

A *River landforms from source to mouth*

Distinctive river erosion landforms

Interlocking spurs

Notice in photo **B** how the Welsh mountain stream weaves its way through the V-shaped valley and around the 'fingers' of land that jut out. These are called *interlocking spurs*. The river is near its source, and is not powerful enough to cut through the 'spurs' of land, so has to flow around them.

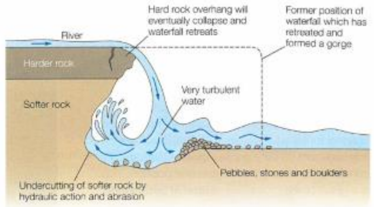


B *Blaen Taff Fawr mountain stream, Wales*

Waterfalls

As it makes its way from source to mouth a river often flows over a variety of different rock types. Tougher, more resistant rocks are less easily eroded than weaker rocks and they will form 'steps' in the long profile of a river. These steps form waterfalls (diagram **C**).

Waterfalls are most commonly formed when a river flows over a relatively resistant band of hard rock. When the river plunges over a waterfall it forms a deep and turbulent *plunge pool*. Here the processes of erosion, particularly hydraulic action and abrasion, are active and they combine to undercut the waterfall. Eventually the overhanging rock collapses and the waterfall retreats upstream. Over many years the retreating waterfall will leave behind a steep-sided gorge (diagram **A**).



C *Formation of a waterfall*

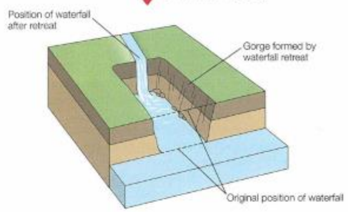
Waterfalls can also form when a drop in sea level causes a river to cut down into its bed creating a step in the long profile of a river. This step is called a *knick point* and it is marked by the presence of a waterfall. Waterfalls can also be found in glacial hanging valleys (see page 135).

Gorges

A gorge is a narrow steep-sided valley that is usually found immediately downstream of a waterfall. It is formed by the gradual retreat of a waterfall over hundreds or even thousands of years (diagram **D**).

Gorges may sometimes form in other ways. At the end of the last glacial period, around 8000 years ago, huge quantities of water from melting glaciers poured off upland areas to form gorges such as Cheddar Gorge in Somerset. More rarely, some gorges form on limestone as a result of the collapse of underground caverns.

D *Formation of a gorge*



ACTIVITIES

1. Draw a sketch of the river and its valley in Photo **B**. Label the interlocking spurs and the V-shaped valley. Add labels to describe the valley sides and the river channel. Is it high or low flow?
2. Make a copy of diagram **C**. Add another diagram to show what happens when the overhanging rock collapses.
3. With the aid of diagrams explain how a gorge is formed as a waterfall retreats.

Stretch yourself

1. Search online for a photo to show each of the three landforms described on this spread. They should be examples in the UK.
2. Add detailed labels to describe the main characteristics of each landform. (Don't use a photo of the High Force waterfall on the River Tees, as that appears later in the chapter!)

Practice question

Explain why a waterfall is only a temporary feature on a river's course. *(4 marks)*

11.4 River erosion and deposition landforms

On this spread you will find out about river landforms created by deposition and erosion

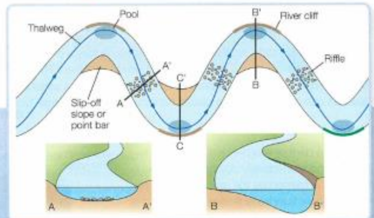
River landforms

Meanders

Meanders are the wide bends of a river found mainly in lowland areas (photo **A**). They are the most efficient channel for a heavily-laden river as it flows over fine sediment on very gentle slopes. Meanders are constantly changing their shape and position. This is a result of the processes of **lateral (sideways) erosion** and deposition in the river channel.

Ⓐ *Meanders on the River Cuckmere, East Sussex*

Diagram **B** shows the main features and processes taking place in a meandering river. The *thalweg* is the line of fastest flow (velocity) within the river. It swings from side to side causing erosion on the *outside* bend and deposition on the *inside* bend. Over time this process of erosion and deposition causes meanders to migrate across the valley floor.



Ⓑ *Processes and landforms of a meandering river*

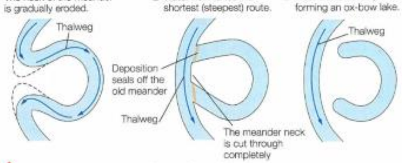
Pools and riffles

Meandering streams carrying coarse sediment may develop alternating deep sections (called *pools*) and shallow sections (called *riffles*). Pools are usually found on the outside bends of meanders where, during periods of high flow, the faster flow erodes a deep channel.

Riffles result from the deposition of coarse sediment, also at times of high flow, and are characterised by more turbulent slower-flowing water. During low-flow conditions, however, water tends to flow more slowly through a pool section, depositing fine muddy sediment. Under these low-flow conditions, water may flow slightly faster in a riffle section, accounting for the lack of fine sediment here. This is what you are most likely to see when conducting fieldwork.

Ox-bow lakes

Over time, as meanders migrate across the valley floor, they may start to erode towards each other (diagram **C**). Gradually the neck of the meander narrows until it is completely broken through (usually during a flood) to form a new straighter channel. The old meander loop is cut off by deposition to form an ox-bow lake.



Ⓒ *Stages in the formation of an ox-bow lake*

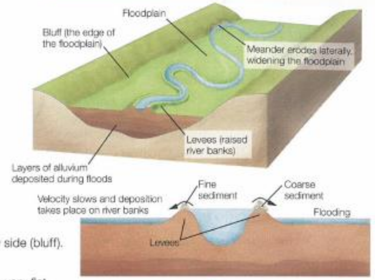
River deposition landforms

Floodplains and levees

A floodplain is a wide, flat area of marshy land on either side of a river, and found in the middle and lower courses. Floodplains are made of *alluvium*, a sediment (*silt*) deposited by a river when it floods. Floodplains are used for farming as the soils are very fertile.

There are two processes responsible for the formation of a floodplain (diagram **D**).

- Meanders migrate across the floodplain due to lateral erosion. When they reach the edge of the floodplain they erode the valley side (bluff). This explains why floodplains are very wide.
- When the river floods it deposits silt, creating a very flat floodplain. Layer upon layer builds up over many years to form a thick deposit of fertile alluvium.



Ⓓ *The formation of floodplains and levees*

A levee is a raised river bed (*levé* in French means 'rise') found alongside a river in its lower course (diagram **D**). It is formed by flooding over many years. A ridge of sediment is deposited naturally to build up the levee.

During low flow conditions deposition takes place, raising the river bed and reducing the capacity of the channel. When flooding occurs, water flows over the sides of the channel. Here the velocity of the river decreases rapidly leading to deposition of sediment on the river banks. First the coarser sands are deposited and then the finer silt and mud. Gradually after many floods the height of the banks can be raised by as much as two metres.

Estuaries

In the UK most river mouths form wide tidal estuaries, especially in areas where sea levels have risen. Estuaries are *transitional zones* between river and coastal environments and are affected by wave action as well as river processes. The main process operating in estuaries is deposition. During a rising tide river water is unable to be discharged into the sea. The river's velocity falls and sediment is deposited. At low tide these fine deposits form extensive *mudflats*. Over time, mudflats develop into important natural habitats called *saltmarshes*.

ACTIVITIES

1 **a** Sketch a cross-section of the meander C–C' in diagram **B**.
  b Draw and label the following: thalweg, deposition, lateral erosion, river cliff, slip-off slope (or point bar).
2 Draw a sequence of labelled diagrams to show how an ox-bow lake forms. Make sure you show the importance of both erosion and deposition in this process.
3 Describe with the aid of a diagram how a levee is formed.

Stretch yourself

Search for an aerial photograph of a floodplain in the UK. Make sure it shows meanders, ox-bow lakes, a floodplain and levees.

- Label these features on your photo.
- Describe how the land is used.

Practice question

The gradient of the River Mississippi drops on average, only 10 cm/km for the last 1000 km of its course to the Gulf of Mexico. Consider how this can result in the river changing course.
(4 marks)

11.5 River landforms on the River Tees

On this spread you will find out about the erosion and deposition landforms along a stretch of the River Tees in County Durham, in north east England

Example

Where is the River Tees?

The River Tees is an important river in the north east of England. Its source is high in the Pennine Hills near Cross Fell (height 893 m). From there it flows roughly east for around 128 km to reach the North Sea at Middlesbrough (map **A**). Look back to page 95 to locate the River Tees on the atlas map of the UK.

A The location of the River Tees in north-east England

High Force waterfall and gorge

High Force on the River Tees is one of the UK's most impressive waterfalls. It is located close to Forest-in-Teesdale in the river's upper course. The river drops 20 m as a single sheet of water into the foaming and turbulent plunge pool below. It then continues its course through a spectacular gorge.

The waterfall was formed due to a resistant band of igneous rock (cooled volcanic lava) called *dolerite*, which cuts across the river valley. Unable to erode this tougher band of rock, the river has formed a step in the long profile of the river. This has developed over hundreds of years to form High Force waterfall.

The underlying darker rock with horizontal layers (called *beds*) is the *Carboniferous limestone*. The overlying slightly lighter-coloured rock with vertical joints is the dolerite. As the river plunges over the waterfall, it undercuts the weaker limestone forming an overhang. This eventually collapses and the waterfall gradually retreats upstream to form a gorge. You can see the steep side of the gorge to the left of the waterfall in photo **B**.

B *High Force on the River Tees*

Meanders, levees and floodplains near Darlington

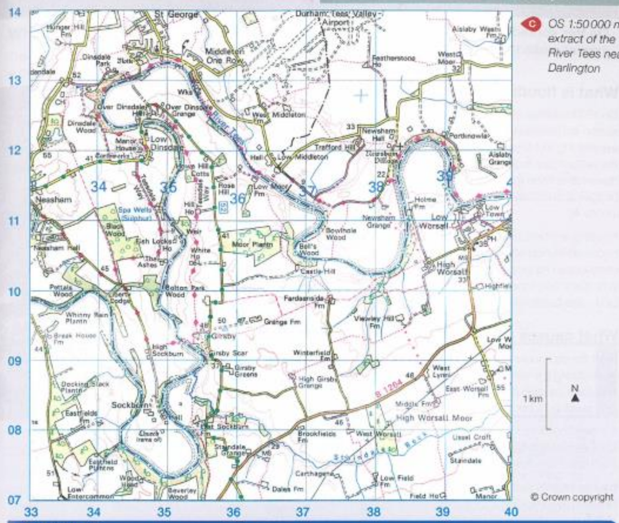
Map **C** is a 1:50 000 extract of the River Tees south of Darlington (map **A**). Here the river is flowing from west to east over relatively flat and low-lying land. All along this stretch of the River Tees there are good examples of meanders, levees and floodplains.

Locate grid square 3810 on map **C**. Look closely at the river and notice the embankments, or levees, running alongside the river meander. Notice also the extensive white area of the map alongside the river. The lack of brown contour lines in this area tells us that the land is flat. This is the river's floodplain.

Stretch yourself

Use online mapping to find an aerial satellite photograph of the mouth of the River Tees at Teesport (Middlesbrough).

- Add labels to identify the wide river estuary (what is its width?) and the mudflats.
- Try to identify the industries located alongside the river.
- Why do you think this area has been developed for industries?



C *OS 1:50 000 map extract of the River Tees near Darlington*

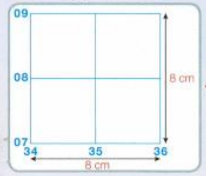
ACTIVITIES

1 Draw a sketch of High Force waterfall using photo **B**. Add detailed labels to describe its main characteristics and the fluvial processes that are operating.

2 **a** What is the evidence from photo **B** that the waterfall used to be more extensive in the past?
b What is the evidence that the waterfall is retreating to leave a gorge?

3 Locate Sockburn on map **C** in 3408. Here a sweeping meander passes through four grid squares.
a Draw an enlarged sketch map of the four grid squares but doubling the scale, so that each square is 4 cm (diagram **D**).
b Now draw the course of the river and the 20 m contour that runs alongside the river on either side.
c Draw any levees that have formed on either side of the river.
d Carefully label the following:
- the meander
- the floodplain
- the direction of river flow
- levees.

e How might the course of this meander change in the future? Use a simple sketch to support your answer.



D *Sketch map area for activity 3*

Practice question

To what extent does the River Tees illustrate the features normally associated with a river's course from its source to its mouth? *(6 marks)*

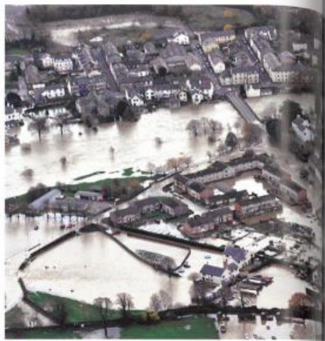
11.6 Factors increasing flood risk

On this spread you will find out about how physical and human factors can increase the risk of flooding

What is flooding?

On 19 November 2009 a remote mountain weather station at Seathwaite in the Lake District recorded an astonishing 314.4 mm of rain in just 24 hours. This was the wettest day ever recorded in the UK. It unleashed a devastating flood that tore through valleys, washing away bridges and inundating the small town of Cockermouth (photo **A**).

Flooding is where land that is not normally underwater becomes inundated. A river **flood** occurs when a river channel can no longer hold the amount of water flowing in it. Water overtops the banks and floods the adjacent land – the floodplain.



A Cockermouth floods, 2009

What causes flooding?

River floods usually occur after a long period of rainfall, often during the winter. The volume of water steadily increases causing river levels to rise. Eventually the river may overtop its banks to cause a flood.

Sudden floods can occur following torrential storms. These are called *flash floods*. They are more often associated with heavy rainstorms that occur in the summer.

We can identify both physical and human factors that increase *flood risk*.

Physical factors

- **Precipitation** – torrential rainstorms can lead to sudden flash floods as river channels cannot contain the sheer volume of water flowing into them. Steady rainfall over several days can also lead to flooding in lowland river basins.
- *Geology (rock type) – impermeable rocks* (rocks that do not allow water to pass through them) such as shales and clays encourage water to flow overland and into river channels. This speeds up water flow and makes flooding more likely.
- *Steep slopes* – in mountain environments steep slopes encourage a rapid transfer of water towards river channels. This increases the risk of flooding.

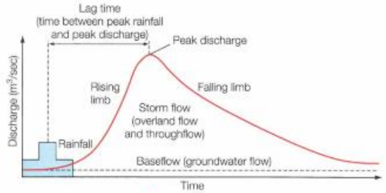
Human factors (land use)

- *Urbanisation* – building on a floodplain creates impermeable surfaces such as tarmac roads, concrete driveways and slate roofs. Water is transferred quickly to drains and sewers and then into urban river channels. This rapid movement of water makes flooding more likely.
- *Deforestation* – much of the water that falls on trees is evaporated or stored temporarily on leaves and branches. Trees also use up water as they grow. When trees are removed much more water is suddenly available and transferred rapidly to river channels, increasing the flood risk.
- *Agriculture* – in arable farming, soil is left unused and exposed to the elements for periods of time. This can lead to more surface runoff. This is increased if the land is ploughed up and down steep slopes, as water can flow quickly along the furrows.

What is a hydrograph?

The volume of water flowing along a river is its **discharge**. It is measured in *cumecs* – cubic metres per second. A **hydrograph** is a graph that plots river discharge after a storm (graph **B**). It shows how discharge rises after a storm, reaches its peak and then returns to the normal rate of flow.

One of the most important aspects of a hydrograph is the *lag time*. This is the time in hours between the highest rainfall and the highest (peak) discharge. This shows how quickly water is transferred into a river channel and is a key factor in the flood risk. The shorter the time lag the greater the risk of flooding.

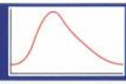
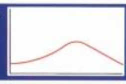


B A flood hydrograph

What affects the shape of a hydrograph?

The shape of a hydrograph is affected by rainfall and by drainage basin characteristics (table **C**).

C *Factors affecting the shape of a hydrograph*

Drainage basin and precipitation characteristics	'Flashy' hydrograph with a short lag time and high peak 	Low, flat hydrograph with a low peak 
Basin size	Small basins often lead to a rapid water transfer.	Large basins result in a relatively slow water transfer.
Drainage density	A high density speeds up water transfer.	A low density leads to a slower transfer.
Rock type	Impermeable rocks encourage rapid overland flow.	Permeable rocks encourage a slow transfer by groundwater flow.
Land use	Urbanisation encourages rapid water transfer.	Forests slow down water transfer, because of interception.
Relief	Steep slopes lead to rapid water transfer.	Gentle slopes slow down water transfer.
Soil moisture	Saturated soil results in rapid overland flow.	Dry soil soaks up water and slows down its transfer.
Rainfall intensity	Heavy rain may exceed the infiltration capacity of vegetation, and lead to rapid overland flow.	Light rain will transfer slowly and most will soak into the soil.

ACTIVITIES

1 Describe the effects of the flooding in Cockermouth (photo **A**). Consider the social, economic and environmental impacts.
2 What is the difference between a normal river flood and a flash flood?
3 What features of the urban environment increase the risk of flooding? Give reasons for your answer.
4 What physical and human factors are likely to produce a hydrograph (table **C**) with a short time lag and a high peak?

Stretch yourself

Research online about the Cockermouth flood of 2009.

- What were the main physical and human causes of the flood?
- What were the impacts?
- What has been done since 2009 to reduce the likelihood of future flooding?
- How successful were the post-2009 defences in coping with the extreme rainfall in December 2015?

Practice question

'River flooding is a natural phenomenon.'
To what extent do you consider this statement to be correct? *(9 marks)*

11.7 Managing floods – hard engineering

On this spread you will find out about the costs and benefits of hard engineering to manage river flooding

What is hard engineering?

Hard engineering involves using man-made structures to prevent or control natural processes from taking place. This form of flood management is usually very expensive – individual projects can cost several million pounds. But this is the preferred option for protecting expensive property or land, such as housing estates, railways and water treatment works. The costs have to be weighed against the benefits.

- *Costs* – the financial cost of the scheme, and any negative impacts on the environment and on people's lives
- *Benefits* – financial savings made by preventing flooding, along with any environmental improvements

Diagram **A** shows a drainage basin with hard and soft engineering options.

Dams and reservoirs

Dams and reservoirs are widely used around the world to regulate river flow and reduce the risk of flooding. Most dam projects are multi-purpose, having several functions, for example:

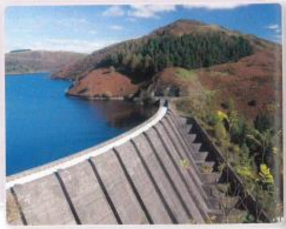
- flood prevention
- irrigation
- water supply
- hydro-electric power generation
- recreation.

Dams can be very effective in regulating water flow. During periods of high rainfall, water can be stored in the reservoir. It can then be released when rainfall is low. But the construction of dams can be very controversial. They cost huge amounts of money and the reservoir often floods large areas of land. Many people may have to be moved from their homes.

A *Flood prevention – some hard and soft engineering options*

Clywedog reservoir, Llanidloes, Wales

The Clywedog reservoir (photo **B**) was constructed in the 1960s to help prevent flooding of the River Severn. Its concrete dam is over 70 m high and 230 m wide and the reservoir stretches for nearly 10 km. It has been in continuous use since 1967, filling up in the winter and gradually releasing water in the summer to retain a constant flow. Although some flooding has continued to affect settlements further downstream, Clywedog has undoubtedly prevented catastrophic floods.



B *The Clywedog dam and reservoir*

Channel straightening

River straightening involves cutting through meanders to create a straight channel. This speeds up the flow of water along the river. Whilst river straightening may protect a vulnerable location from flooding, it may increase the flood risk further downstream. The problem is not really solved but shifted somewhere else!

In some places straightened sections of river are lined with concrete. This speeds up the flow and prevents the banks from collapsing, which can cause the channel to silt up. But the concrete channels create a very unattractive and unnatural river environment and can damage wildlife habitats.

Embankments

An embankment is a raised riverbank. Raising the level of a riverbank allows the river channel to hold more water before flooding occurs.

Hard engineering structures involving concrete walls or blocks of stone are frequently used in towns or cities to prevent flooding of valuable property. Sometimes mud dredged from the river may be used. This is cheaper and more sustainable and looks more natural.

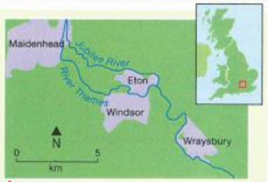
Flood relief channels

A flood relief channel is a man-made river channel constructed to by-pass an urban area.

During times of high flow, sluice gates can be opened to allow excess water to flow away into the flood relief channel and reduce the threat of flooding.

The Jubilee River, Maidenhead

In the UK a flood relief channel, named the Jubilee River, has been constructed on the River Thames near Maidenhead in Berkshire (map **C**). The 11 km channel was opened in 2002. It cost £110 million to construct and with a length of nearly 12 km is the longest man-made channel in the UK. As well as reducing the risk of flooding for over 3000 properties, the Jubilee River has had a positive impact on the environment by creating new wetlands. It is also popular for recreational activities such as walking and fishing.



C *The Jubilee River*

ACTIVITIES

1. Draw a diagram in the style of diagram **A** to illustrate the different types of hard engineering described on this spread.
2. Consider the costs (disadvantages) and benefits (advantages) of dams and reservoirs such as at Clywedog.
3. Construct a summary table to describe the costs and benefits of the following hard engineering options:
   - channel straightening
   - embankments
   - flood relief channels.

Stretch yourself

Search online for more information about the Jubilee River flood relief channel.

- Why was it built? (Had there been some serious floods in the past?)
- What have been the environmental and social benefits of the flood relief channel?
- Try to assess the costs and benefits of the Jubilee River.

Practice question

To what extent are hard engineering schemes sustainable? *(9 marks)*

11.8 Managing floods – soft engineering

On this spread you will find out about the costs and benefits of managing river flooding using soft engineering

What is soft engineering?

Soft engineering involves working with natural river processes to manage the flood risk. Unlike hard engineering it does not involve building artificial structures or trying to stop natural processes. It aims to reduce and slow the movement of water into a river channel to help prevent flooding. In common with all forms of management there are costs (disadvantages) and benefits (advantages).

Planting trees to establish a woodland or forest is called *afforestation*. Trees obstruct the flow of water and slow down the transfer to river channels. Water is soaked up by the trees or evaporated from leaves and branches. Tree planting is relatively cheap and has environmental benefits.

A *Flood storage area, near Rye, East Sussex*

Wetlands and flood storage areas

Wetland environments on river floodplains are very efficient in storing water (photo **A**). Wetlands are deliberately allowed to flood to form flood storage areas. Water can be stored to reduce the risk of flooding further downstream.

Floodplain zoning

Floodplain zoning restricts different land uses to certain locations on the floodplain (diagram **B**). Areas close to the river and at risk from flooding can be kept clear of high-value land uses such as housing and industry. Instead these areas can be used for pasture, parkland or playing fields. Floodplain zoning can reduce overall losses caused by flood damage. But it can be difficult to implement on floodplains that have already been developed and can cause land prices to fall.

B *Floodplain zoning*

River restoration

Where the course of a river has been changed artificially, river restoration can return it to its original course . River restoration uses the natural processes and features of a river, such as meanders and wetlands to slow down river flow and reduce the likelihood of a major flood downstream (photo **C**).

C *Restoration of the River Glaven, Norfolk*

Preparing for floods

Rivers and river basins are monitored remotely using satellites and computer technology. Instruments are used to measure rainfall and to check river levels. Computer models can then be used to predict discharges and identify areas at risk from flooding.

In England and Wales the Environment Agency issues **flood warnings** if flooding is likely. Warnings are sent to the emergency services and the public using social media, text and email. There are three levels of warning:

- *Flood Watch* – flooding of low-lying land and roads is expected. People should be prepared and watch river levels.
- *Flood Warning* – there is a threat to homes and businesses. People should move items of value to upper floors and to turn off electricity and water.
- *Severe Flood Warning* – extreme danger to life and property is expected. People should stay in an upper level of their home or leave the property.

The Environment Agency makes maps identifying areas at risk from flooding. People living in these areas are encouraged to plan for floods. This might include:

- planning what to do if there is a flood warning (e.g. moving valuable items upstairs)
- using flood gates to prevent floodwater from damaging property (photo **D**)
- using sandbags to keep floodwater away from buildings.

Local authorities and emergency services use these maps to plan responses to floods. For example, installing temporary flood barriers, evacuating people, closing roads and securing buildings and services.

Flood prediction is based on probability and one of the 'costs' is that places can become blighted by being 'at risk' from flooding. This can cause property values to drop and insurance premiums to increase.

Think about it

Is your town, city or village at risk from flooding? What defences are in place to protect the area from floods?

D *Flood gate protecting property from the rising River Severn, Deerhurst, Gloucestershire*

ACTIVITIES

1 What is the purpose of a flood storage area (photo **A**).

2 a What is the evidence in photo **C** that this river channel and its floodplain have been modified?

b Suggest *three* reasons why these changes may lead to a reduction in the flood risk further downstream.

3 Suggest why some river engineers and local people prefer soft rather than hard engineering schemes.

Stretch yourself

Imagine a builder has submitted a planning application to build new houses on the area labelled 'Playing fields' on diagram **B**. Explain why, as the planner considering the proposal, you have rejected the scheme. Propose a better option.

Practice question

Use an example of one soft engineering river flood management strategy to show how it has a limited effect on the environment. *(4 marks)*

11.9 Managing floods at Banbury

Example

On this spread you will find out about the flood management scheme in Banbury

Where is Banbury?

Banbury is located in the Cotswold Hills about 50 km north of Oxford (map **A**). The town has a population of around 45 000 people. Much of the town is on the floodplain of the River Cherwell, a tributary of the River Thames.

A *The location of Banbury*

How has Banbury been affected by flooding?

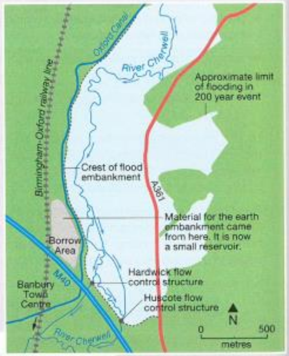
Banbury has a history of devastating floods. In 1998, flooding led to the closure of the town's railway station, shut local roads and caused £12.5 million of damage (photo **B**). More than 150 homes and businesses were affected. In 2007, the town was hit again by floods that extended over much of central and western England. Many more homes and businesses were affected as the river burst its banks after very heavy rain.

What has been done to reduce the risk of flooding?

In 2012, Banbury's new flood defence scheme was completed. A 2.9 km earth embankment was built parallel to the M40 motorway to create a flood storage area (map **C**). The embankment has a maximum height of 4.5 m. It is capable of holding around 3 million cubic metres of water – that's 1200 Olympic-size swimming pools!

The flood storage area is located mainly on the natural floodplain of the River Cherwell. It collects rainwater that otherwise would have swelled the river and caused it to burst its banks.

Photo **D** shows one of the two flow control structures in the embankment. The specially designed aperture (opening) controls the rate of flow downstream towards Banbury. Any excess water backs up behind the structure, filling up the reservoir rather than continuing towards Banbury. The design avoids the need to open and close flood gates. Map **C** shows how this works.

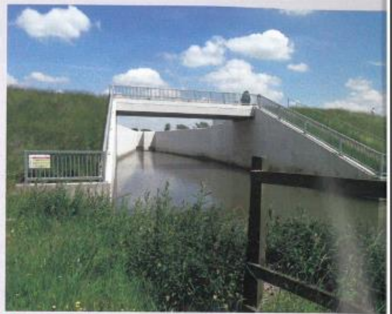


C *Main features of the Banbury Flood Storage Reservoir*

B *Banbury station flooded in 1998*

Additional flood defence measures that are part of the scheme include:

- raising the A361 road in the flood storage area (map **C**) plus improvements to drainage beneath the road to prevent flooding
- new earth embankments and floodwalls to protect property and businesses, such as the motorsport business Prodrive
- a new pumping station to transfer excess rainwater into the river below the town
- the creation of a new Biodiversity Action Plan (BAP) habitat with ponds, trees and hedgerows to absorb and store excess water.



D *Flow control structure looking upstream towards the embankment*

What have been the social, economic and environmental costs and benefits?

The table below outlines some of the main costs and benefits associated with the project.

Social	Economic	Environmental
• The raised A361 route into Banbury will be open during a flood, to avoid disrupting people's lives. • Quality of life for local people is improved with new footpaths and green areas. • Reduced levels of anxiety and depression through fear of flooding.	• The cost of the scheme was about £18.5 million. • Donors included Environment Agency and Cherwell District Council. • By protecting 441 houses and 73 commercial properties, the benefits are estimated to be over £100 million.	• Around 100 000 tonnes of earth were required to build the embankment. This was extracted from nearby, creating a small reservoir (map **C**). • A new Biodiversity Action Plan habitat has been created with ponds, trees and hedgerows. • Part of the floodplain will be deliberately allowed to flood if river levels are high.

ACTIVITIES

1 Use photo **B** to help describe the problems associated with flooding in Banbury.
2 Make a large copy of map **C**. Find photos to show some of the main features of the flood storage area. Add labels or captions to describe what they show.
3 Describe how the flood storage area works and how it is designed to prevent flooding in Banbury.

Practice question

Use the example of Banbury to show how the flood defence scheme benefits both the local people and the environment. *(6 marks)*

Stretch yourself

Work in pairs to list additional social, economic and environmental issues related to the flood defence scheme. Consider the costs and benefits. Research the 'Banbury Flood Alleviation Scheme' to help get you started.