Core physical topic

Rivers, floods and management

The drainage basin hydrological cycle

The drainage basin is considered to be an open system, with inputs and outputs of energy (solar radiation and evapotranspiration) and stores and transfers of water. A drainage basin is defined as the area of land drained by a river and all its tributaries. The boundary around a drainage basin is known as the watershed and is often marked by a ridge of high land. Within each drainage basin the river system can be described using the hydrological cycle.

Key terms

- **Base flow** That part of a river's discharge which is produced by groundwater seeping slowly into the bed of the river.
- **Channel store** Water stored in a river.
- **Channel flow** Water flowing in a river.
- **Evaporation (output)** The change of water from liquid to gas, returning water to the atmosphere.
- **Groundwater flow (transfer)** Water flowing through the rocks towards the river.
- **Groundwater store** Water stored in permeable rocks below the surface of the ground.
- **Infiltration (transfer)** The process by which water enters the soil.
- **Interception storage** Precipitation that is trapped or stored temporarily on the vegetation.
- **Overland flow (transfer)** The movement of water over the surface of the ground to rivers.
- **Percolation (transfer)** Water draining through rock towards the water table.
- **Precipitation (input)** Water and ice that fall from clouds into the drainage basin.
- **Runoff** The total discharge from the drainage basin.
- **Soil water store** Water stored in the soil.
- **Stemflow (transfer)** Precipitation that runs down plant stems and tree trunks to the ground.
- **Surface store** Water lying on the ground.
- **Throughfall (transfer)** Precipitation that drips through vegetation to the ground.
- **Throughflow (transfer)** Water flowing through the soil towards rivers.
- **Transpiration (output)** The evaporation of moisture from vegetation into the atmosphere.
- **Vegetation store** Water stored within plants and trees.

Any changes to inputs, transfers or stores, by people or by natural means, will have a knock-on effect elsewhere in the system. For example, deforestation in a river basin will result in less interception and transpiration and an eventual increase in channel flow. A drought may cause a reduction in runoff and a decrease in other stores and transfers such as infiltration and soil water storage.

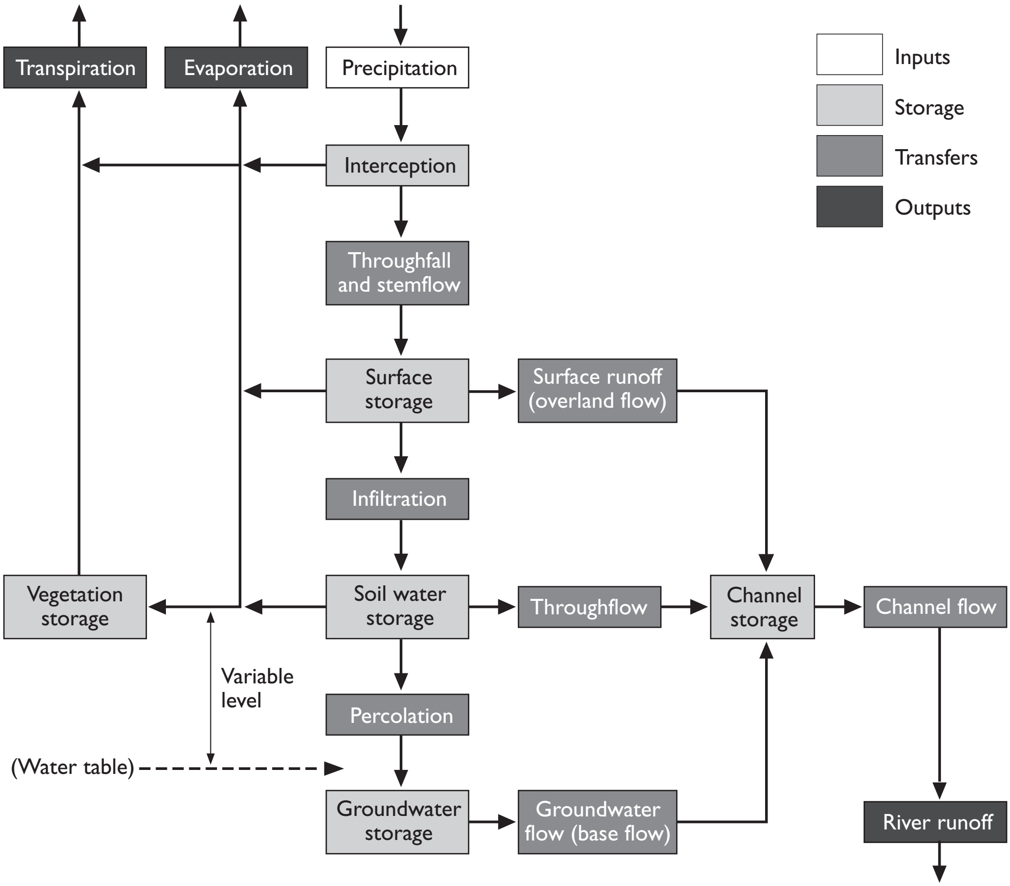

Figure 2 The hydrological cycle in the drainage basin

The **water balance** shows the state of equilibrium in the drainage basin between the inputs (precipitation) and outputs (runoff and evapotranspiration) and changes in groundwater storage. The water balance can change with the seasons. In the UK there is usually a water surplus during the winter and early spring, resulting in considerable runoff. This is because precipitation is relatively high, temperatures are low and there is reduced interception and uptake of water by vegetation. When the water balance is positive, the increases in infiltration and percolation allow groundwater stores to be recharged. At other times of the year there may be a moisture deficit as temperatures rise and vegetation is actively growing. This causes the water table to fall as discharge from springs continues to replenish river flows. A graph of mean monthly precipitation and evaporation throughout the year can be used to show periods of water surplus, deficit and groundwater recharge.

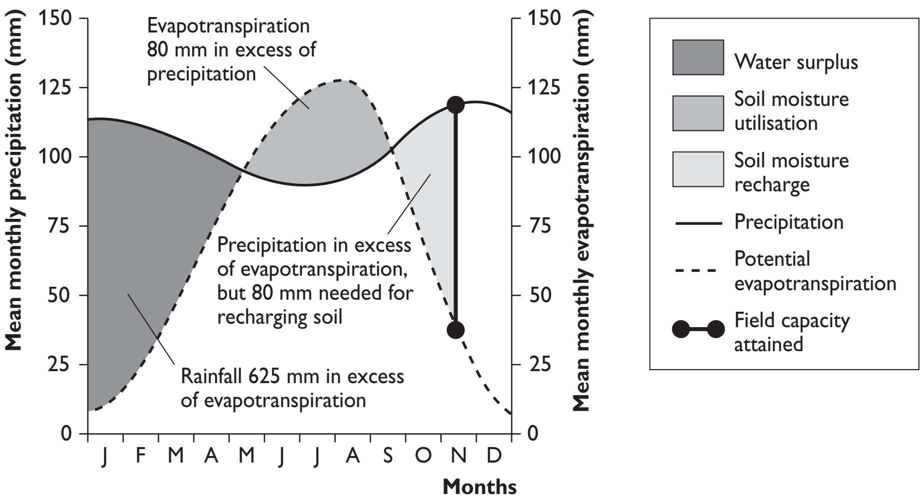

Figure 3 A graph showing the water balance

Factors affecting river discharge

The **storm hydrograph** shows variations in a river's discharge over a short period of time, usually during and immediately following a rainstorm. **River discharge** is the volume of water passing through a point in the river and is measured in cubic metres per second (cumecs). The starting and finishing level shows the **base flow** of the river. As storm water enters the drainage basin the discharge rises, shown by the **rising limb**, to reach a peak. This indicates the highest flow in the channel. The **receding limb** shows the fall in discharge back to the base level. The time delay between maximum rainfall amount and the peak discharge is the **lag time**.

Various factors affect river discharge levels and the storm hydrograph:

- If both the intensity and duration of the storm are high they produce a steep rising limb.
- Heavy rain falling onto saturated soil from previous wet weather (antecedent rainfall) produces a steep rising limb.
- Porous soil types and/or permeable rock types produce less steep (or less flashy) hydrographs, as water is regulated more slowly through the natural systems.
- A small drainage basin tends to respond more rapidly to a storm than a larger one, so the lag time is shorter.
- The influence of vegetation in the drainage basin varies from season to season. In summer there are more leaves on deciduous trees so interception is higher, thus reducing peak discharge. Coniferous vegetation, planted by humans, has a less variable effect over the year.
- Other human activities also have an influence. The construction of roads and the extension of urban areas create impermeable surfaces over which water runs more quickly into rivers, reducing lag time and increasing peak discharge. The grazing

of cattle on the lower slopes of valleys causes trampling in some areas, which can have a similar effect.

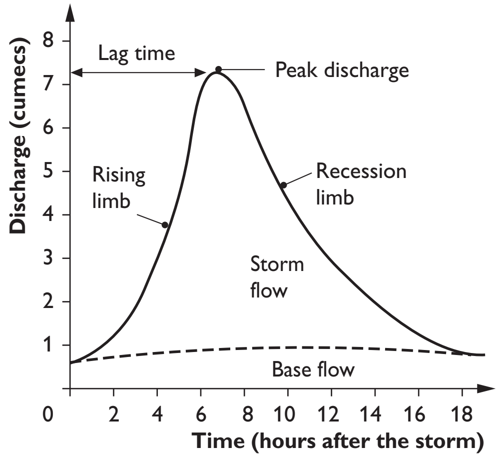

Figure 4 The storm hydrograph

Processes affecting the long profile

The long profile of a river shows the changes in altitude along its course from the source to the mouth. In theory, a long profile is smoothly concave in shape, with a steeper gradient in the upper course becoming progressively less steep towards the mouth. However, irregularities such as waterfalls, rapids and lakes frequently exist.

Variations in the long profile can be explained in terms of:

- **gradient:** steeper in the upper part of the basin, more gentle in the lower part
- **varying rock types:** resistant rocks produce kinks in the long profile, evident as waterfalls and rapids
- **natural lakes/artificial reservoirs:** these flatten out the long profile
- **rejuvenation:** a fall in sea level relative to the level of the land, or a rise of the land relative to the level of the sea, which revives the erosional activity of the river. The steepening of the long profile that results is called a **knickpoint**

Types of erosion

The amount of energy available within a river determines its ability to erode. Two types of energy exist, **potential** (a result of the weight of the water) and **kinetic** (produced by gravity). The rate of erosion is generally related to the discharge. The river has most energy available for erosion when close to bankfull conditions, so erosion is not the dominant process under normal flow conditions. The type of erosion changes down the river's long profile. **Headward erosion** occurs at the source, where the river erodes back towards its watershed as it undercuts the soil and rock. In the upper course the river attempts to cut down **vertically** to its base level. For most rivers, base level is sea level. In the middle and lower courses the river is close to base level so it uses its energy to erode **laterally** (sideways), widening the valley.

Erosion processes include:

- **abrasion (corrosion):** the erosion of the bed and banks by load transported by a fast-flowing current
- **corrosion (solution):** chemical action that dissolves the bed and banks
- **hydraulic action:** the sheer force and power of moving water on the sides of the river bed and in cracks in the rock
- **attrition:** erosion of the bedload by contact with other load, the bed and the banks. Attrition rounds and smoothens the bedload

Transportation

The transported load of the river varies with velocity and discharge. Generally, both increase as a river progresses downstream. The amount and type of load that is transported is also related to capacity and competence. The **capacity** of a river is the largest amount of material that can be transported and its **competence** is the size of the largest particle that can be transported. Both competence and capacity increase as discharge increases. However, the relationship between river velocity and capacity is not straightforward. It is shown by Hjulström's curve.

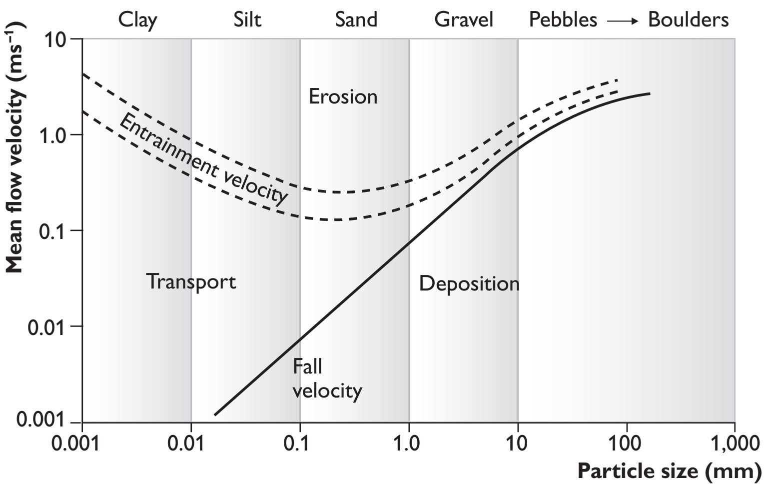

Figure 5 Hjulström's curve, showing the relationship between river velocity and particle size

Sand is transported at lower velocities than is clay, as it is easier for the river to pick up sand; clay particles are more cohesive. The velocity required to keep particles in suspension is less than that needed to pick them up, so once they are in motion particles can remain afloat. Deposition of particles occurs with just a small decrease in velocity.

Transportation processes include:

- **traction:** the movement of the largest particles of bedload, often boulders, by rolling along the river bed
- **saltation:** the movement of bedload by bouncing along the river bed

- **suspension:** smaller particles float in the flowing river
- **solution:** chemical load that has been dissolved into the river water

Types of load

The type of load carried by the river is partly dependent on the geology of the drainage basin. Weathering of the valley sides loosens material which is transferred by mass movement to the channel in the valley bottom. Material also comes from erosion of the river bed and channel sides. It consists of particles varying in size from clay to silt, sand, gravel, pebbles, cobbles and boulders. **Bedload** is the material lying on the bed of the channel. This is transported only when river levels are high. Generally the size of the bedload decreases with distance downstream.

Deposition

Deposition occurs when the river has reduced energy. This happens when velocity and discharge decrease. Reasons for deposition include:

- reduced precipitation leading to a reduction in discharge
- the river entering a lake or the sea
- a sudden increase in river load
- shallow water within the channel, either where riffles occur or on the concave, inside bend of a meander
- as a river floods out onto the floodplain

Valley profiles

The valley **cross profile** is the view of the valley from one side to the other. For example, the cross profile of a river in an upland area has a typical V shape, with steep sides and a narrow bottom.

Variations in the cross profile downstream can be described and explained as follows.

- In the upper course the river flows in a narrow, steep-sided valley where it occupies the entire valley floor. This is the result of dominant vertical erosion by the river.
- In the middle course the cross profile shows a wider valley with distinct valley bluffs, and a flat floodplain. This is the result of lateral erosion, which widens the valley floor.
- In the lower course there is a wide, flat floodplain where the valley sides are difficult to locate. Here there is a lack of erosion and reduced competence of the river that results in large-scale deposition.

The graded profile

Rivers achieve a smooth, concave long profile or graded profile over a long period of time. This is a state of balance, or dynamic equilibrium, where slope, width and other channel characteristics have adjusted to the volume of water and load carried by a river under the prevailing conditions. All factors are in balance, all kinetic energy is used to transport the water and sediment load, with no excess for erosion or deficit for deposition. If the volume and load change then both the long profile and channel morphology will also change.

Changing channel characteristics

Key terms

- **Channel cross profile** The shape of the river bed and banks from one side to the other. The channel is narrow and uneven in the upper course and wide and smooth downstream.
- **Channel roughness** A rough, uneven channel lined with boulders creates friction which slows down the velocity of the river. Channel roughness decreases with distance downstream.
- **Discharge** This is calculated by multiplying cross-sectional area by velocity. Discharge increases with distance downstream.
- **Efficiency** The hydraulic radius is used to measure a river's efficiency. A deep, smooth channel is more efficient than a wide, narrow channel.
- **Hydraulic radius** The cross-sectional area of a river divided by the wetted perimeter. The higher the ratio the lower the frictional loss and the more efficient the stream. Generally the hydraulic radius increases with distance downstream.
- **Velocity** This is usually measured in metres per second. Velocity tends to increase with distance downstream and is influenced by a number of factors including the volume of water, roughness of the bed, gradient of the stream, and width, depth and shape of the channel.
- **Wetted perimeter** The length of the channel margin (bed and banks) along the cross profile in contact with water. In its upper course a river generally has a lower wetted perimeter than in the lower course.

Landforms of fluvial erosion and deposition

- **Braiding** This occurs when a river is forced to divide into several channels after a sudden fall in discharge causes it to deposit its load in the channel. Islands of deposition, called eyots, can result from braiding and they force the river to split into a number of channels.
- **Delta** A landform produced by deposition of sediment at the mouth of a river. The main river is split by deposition into a number of channels called distributaries. Deltas are classified according to their shape as arcuate, bird's foot or cuspate.
- **Floodplain** The area onto which the river floods when bankfull stage has been exceeded. A thin layer of alluvium is deposited each time the river floods, causing the depth of accretions to increase.
- **Levée** The build-up of coarser sediment on the banks of the river as it overflows its channel onto the floodplain, resulting in a small natural embankment.
- **Meander** A pronounced bend in the river's course. The shape changes because of erosion on the outside of the bend and deposition on its inner side, causing the meander to migrate downstream.
- **Pothole** A rounded hole in the river bed created by abrasion trapped in the hollow.
- **Rapid/waterfall** A break in slope along the river's long profile, the result of a band of hard rock or a knickpoint caused by rejuvenation.

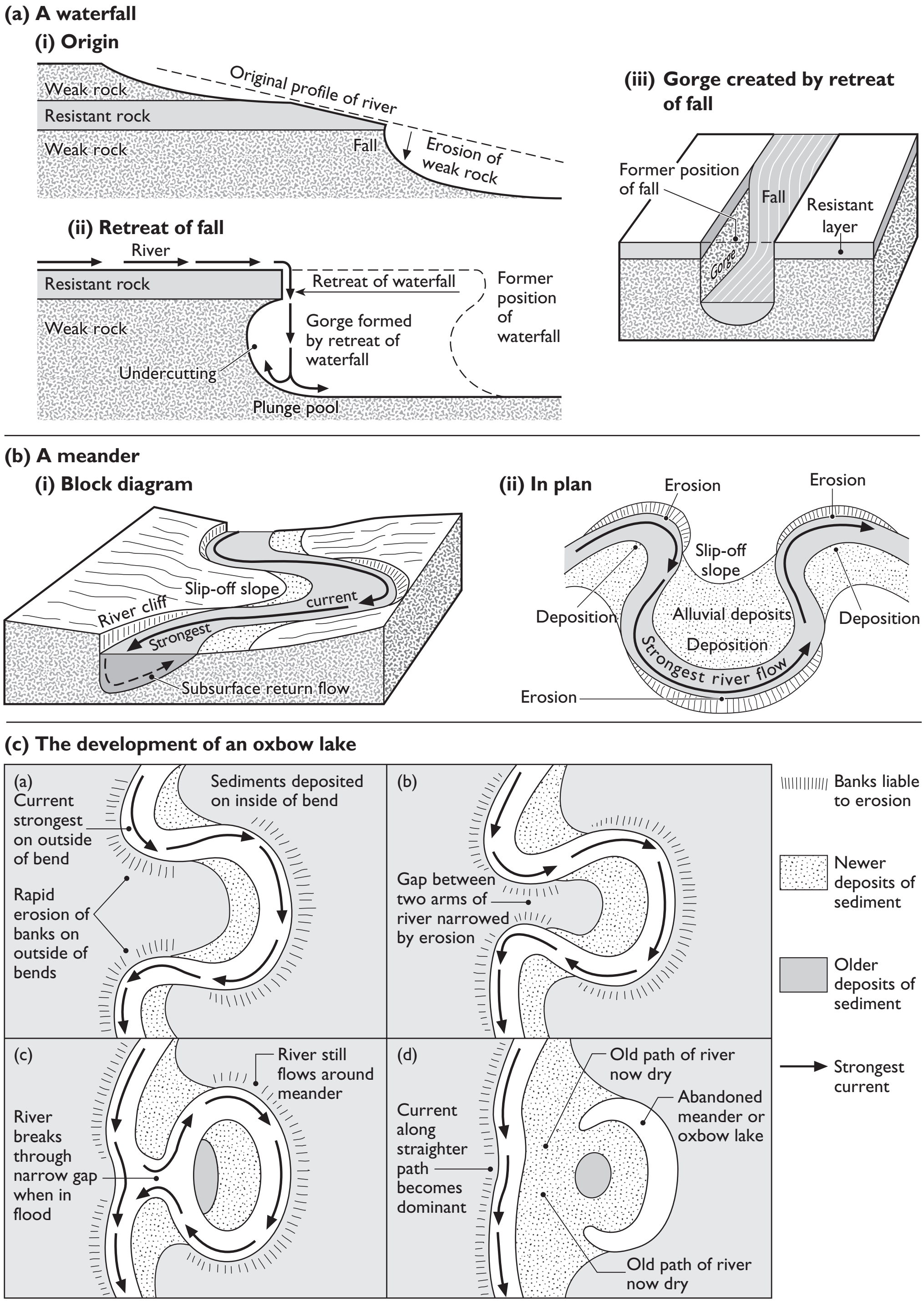

Figure 6 River landforms

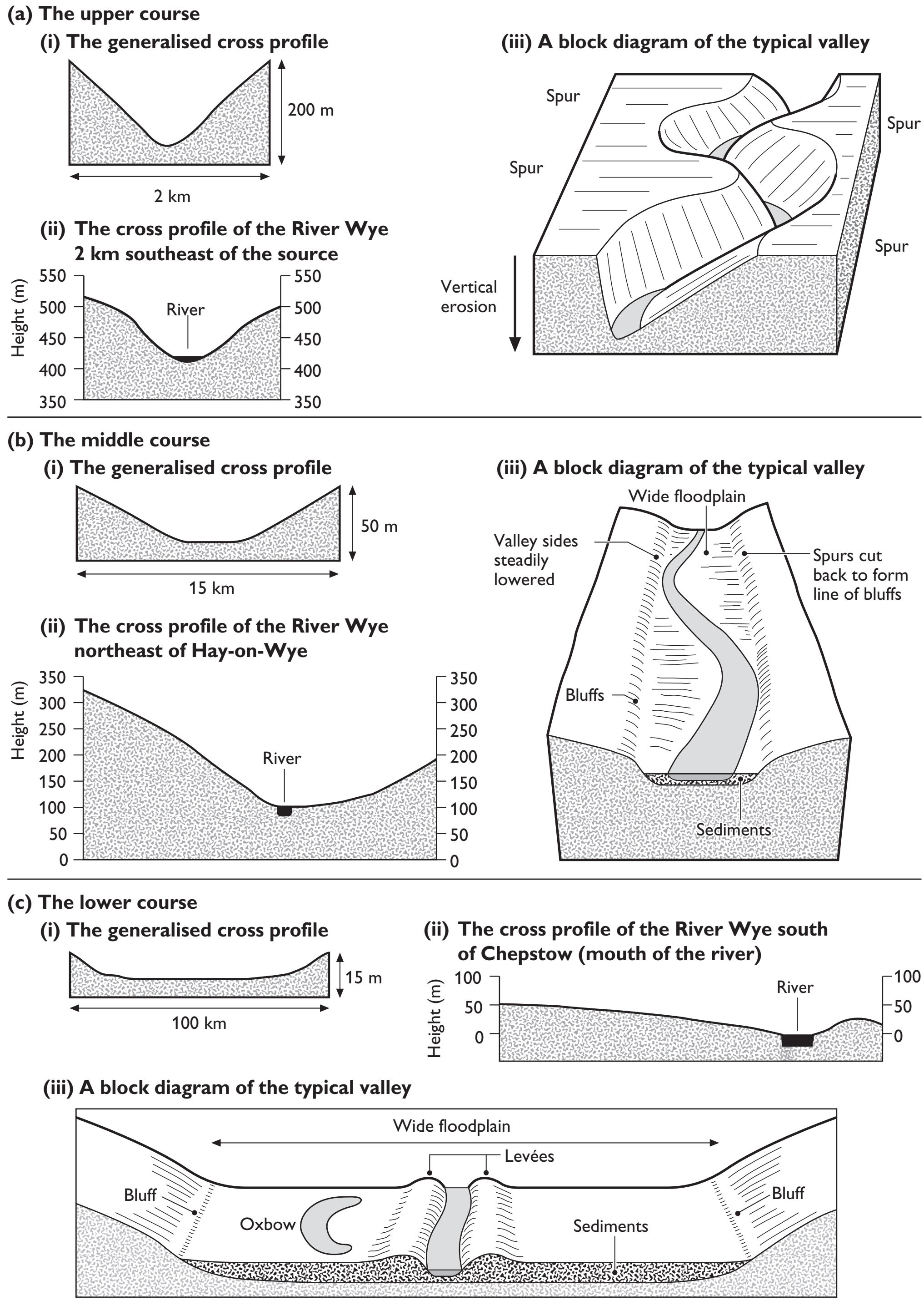

Figure 7 Characteristics of the valley cross profile

Rejuvenation

A fall in sea level relative to the level of the land, or a rise of the land relative to the level of the sea, enables a river to revive its erosional activity. A fall in the base level can occur through tectonic uplift of the land or isostatic recovery. The river will adjust to a new base level, at first in its lower course and then progressively upstream; in doing so it changes the graded profile. A number of landforms may be formed including the following:

- **Knickpoints:** breaks in gradient along the long profile of a river, usually marked by rapids or a waterfall. The knickpoint is where the old long profile joins the new.
- **River terraces:** the remnants of the former floodplain prior to rejuvenation. Terraces create steps in the valley cross profile and mark the height of the former floodplain. Following rejuvenation the river erodes the former floodplain vertically as it adjusts to its new base level.
- **Incised meanders:** deeply cut into the landscape and marked by cliff-like banks on either side of the channel. There are two types of incised meanders, **entrenched** and **ingrown**. Ingrown meanders occur when the uplift of the land or incision occurs slowly, also allowing lateral erosion to take place, creating an asymmetrical valley cross profile. On the other hand, when uplift is more rapid, a symmetrically shaped cross profile is created This is known as an entrenched meander.

Physical and human causes of flooding

Flooding is a natural event but human activity can contribute to its severity (magnitude) and frequency. The frequency of flooding in a particular area may vary over time, especially as a result of human activity. An understanding of frequency–magnitude relationships in river discharge allows some prediction of floods. Hydrologists can use past records of flood events to predict the probability and the risk of extreme 1 in 100-year floods. It is estimated that the recurrence interval is shortening because of changes to land use and other human activities.

- **Flood frequency:** records of past floods can be used to calculate the likelihood of their recurrence. An analysis of discharge data is conducted over the longest time period available, to establish the relationship between discharge and the probability of occurrence. The recurrence intervals can be plotted against the discharge on a graph.
- **Flood magnitude:** severe floods occur less frequently and their likely return period can also be estimated using hydrological records.

Physical causes of flooding include:

- **intense precipitation events** over a short period of time
- **higher than average precipitation** over a prolonged period of time
- **already saturated ground (antecedent moisture)** when the precipitation event takes place
- **rapid snowmelt**, particularly when the ground is still frozen
- **sea level rise**
- **storm surges** in coastal areas