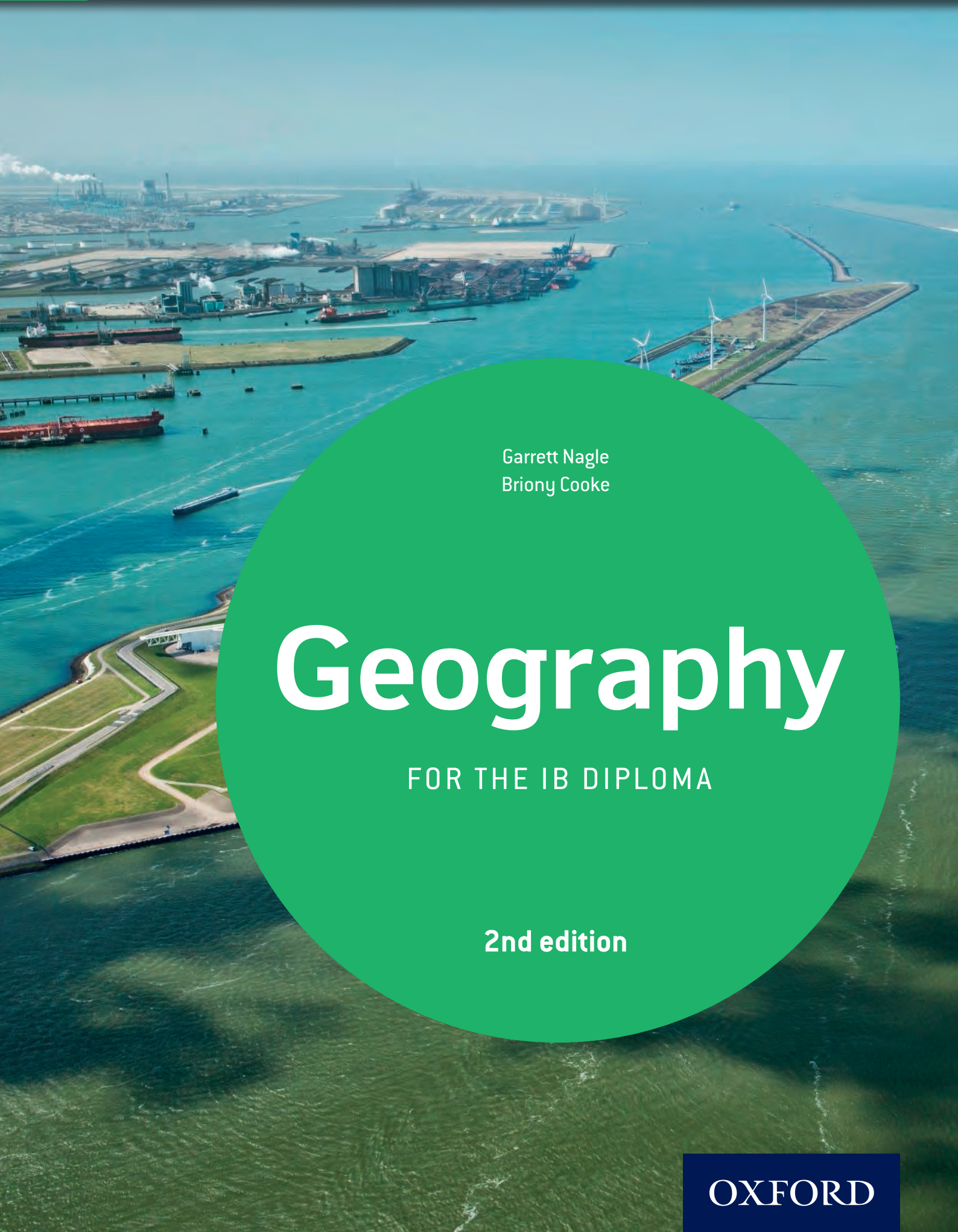
OXFORD IB STUDY GUIDES



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Geography

FOR THE IB DIPLOMA

2nd edition

OXFORD

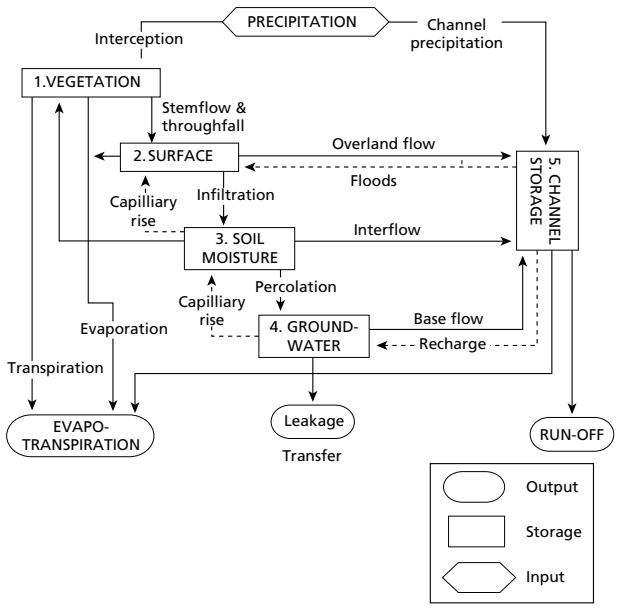
1 DRAINAGE BASIN HYDROLOGY AND GEOMORPHOLOGY

The drainage basin

DEFINITIONS

The **drainage basin** is an area that is drained by a river and its tributaries. Drainage basins have inputs, stores, processes and outputs. The inputs and outputs cross the boundary of the drainage basin, hence the drainage basin is an open system. The main input is precipitation, which is regulated by various means of storage. The outputs include evaporation and transpiration. Flows include infiltration, throughflow, overland flow and base flow, and stores include vegetation, soil, aquifers and the cryosphere (snow and ice).

Drainage basin hydrology



Precipitation is the transfer of moisture to the earth's surface from the atmosphere. It includes dew, hail, rain, sleet and snow. Precipitation total and intensity are important for overland flow.

Interception refers to the capture of raindrops by plant cover that prevents direct contact with the soil. If rain is prolonged, the retaining capacity of leaves will be exceeded and water will drop to the ground (throughfall). Some will trickle along branches and down the stems or trunk (stemflow). Some is retained on the leaves and later evaporated.

Evaporation is the physical process by which a liquid becomes a gas. It is a function of:

- vapour pressure
- air temperature
- wind
- rock surface, for example, bare soils and rocks have high rates of evaporation compared with surfaces which have a protective tilth where rates are low.

Transpiration is the loss of water from vegetation. **Evapotranspiration** is the combined loss of water from vegetation and water surfaces to the atmosphere. **Potential evapotranspiration** is the rate of water loss from an area if there were no shortage of water.

FLOWS

Infiltration is the process by which water sinks into the ground. **Infiltration capacity** refers to the amount of moisture that a soil can hold. By contrast, the **infiltration rate** refers to the speed with which water can enter the soil. **Throughflow** refers to water moving in soil, laterally following natural pipes (percolines) or between horizons. **Overland run-off occurs** when precipitation intensity exceeds the infiltration rate, or when the infiltration capacity is reached and the soil is saturated. **Percolation** refers to water moving deep into the groundwater zone. **Baseflow** refers to the movement of groundwater – for groundwater to flow the water table must rise above the river level to provide the hydraulic gradient needed for water movement.

STORES

There are many stores including vegetation, soils, aquifers and the cryosphere. **Aquifers** are rocks that hold water. They provide the most important store of water, regulate the hydrological cycle and maintain river flow.

Soil moisture varies with porosity (the amount of pore spaces) in a soil, and with permeability (the ability to transmit water).

The **cryosphere** is the largest store of freshwater, and water may be stored for millennia. **Vegetation** is another important store – trees store more water than grasses or crops.

EXAM TIP

You may be asked to draw a diagram of a drainage basin hydrological cycle. A systems diagram – with inputs, stores, flows and outputs – is a much better diagram that a diagram that tries to show trees, clouds, rainfall, glaciers, rivers, lakes and oceans, for example.

CHECK YOUR UNDERSTANDING

1. Identify five forms of storage in a drainage basin.
2. Briefly explain why drainage basins can be considered as open systems.

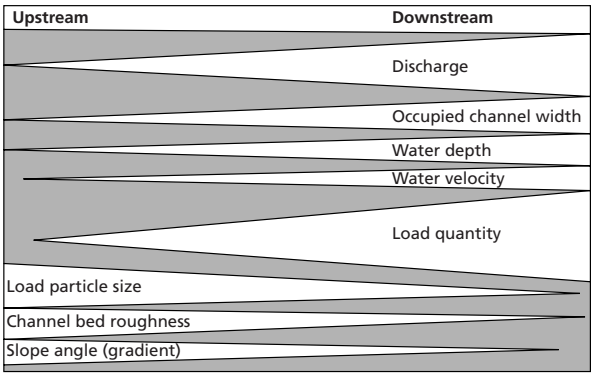
River discharge

DEFINITIONS

Discharge refers to the volume of water passing a certain point per unit of time. It is usually expressed in cubic metres per second (cumecs). Normally, discharge increases downstream as shown by the Bradshaw model.

BRADSHAW MODEL OF CHANNEL VARIABLES

Bradshaw's model shows changes to channel characteristics over the course of a river. Water velocity and discharge increase downstream while channel bed roughness and load particle size decrease.



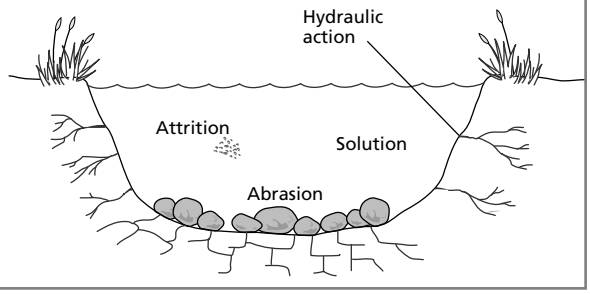
THE MAIN TYPES OF EROSION

Abrasion (or **corrasion**) is the wearing away of the bed and bank by the load carried by a river.

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

Hydraulic action is the force of air and water on the sides of rivers and in cracks.

Solution (or **corrosion**) is the removal of chemical ions, especially calcium, which causes rocks to dissolve.



CHECK YOUR UNDERSTANDING

3. Define the terms hydraulic action, attrition and abrasion.

4. Outline the ways in which a river transports its load.

FACTORS AFFECTING EROSION

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

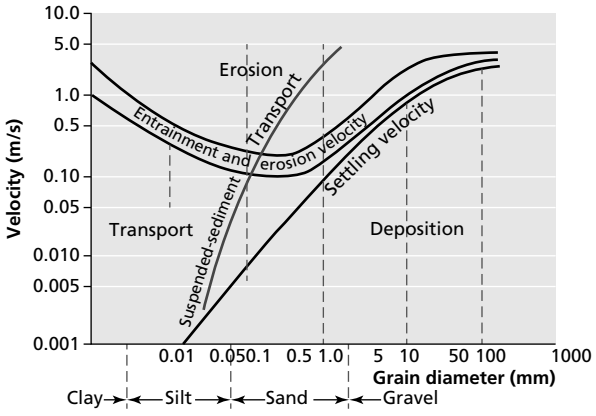
TRANSPORT

The main types of transportation include:

- **Suspension** – small particles are held up by turbulent flow in the river.
- **Saltation** – heavier particles are bounced or bumped along the bed of the river.
- **Solution** – the chemical load is dissolved in the water.
- **Traction** – the heaviest material is dragged or rolled along the bed of the river.
- **Floatation** – leaves and twigs are carried on the surface of the river.

THEORY OF RIVER CHANNEL LOAD

The **capacity** of a stream refers to the largest amount of debris that a stream can carry; its **competence** refers to the diameter of the largest particle that can be carried. The **critical erosion velocity** is the lowest velocity at which grains of a given size can be moved. The relationship between these variables is shown by means of a **Hjulström curve**.



There are three important features on Hjulström curves:

- the smallest and largest particles require high velocities to lift them
- higher velocities are required for entrainment than for transport
- when velocity falls below a certain level (settling or fall velocity) particles are deposited.

Temporal variations in processes: River landforms (1)

RIVER REGIME

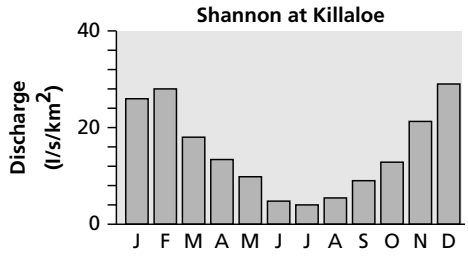
A **river regime** is the annual variation in the flow of a river.

The character or **regime** of the resulting stream or river is influenced by several variable factors:

- the amount and nature of precipitation
- the local rocks, especially porosity and permeability
- the amount and type of vegetation cover.

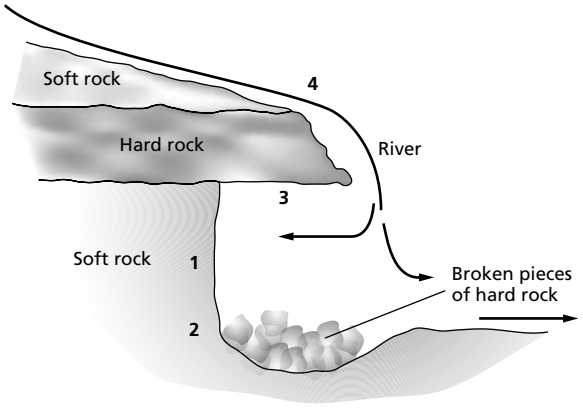
When there is more precipitation, rivers are more likely to erode. Certain rocks, such as chalk and limestone, are likely to be affected by solution.

The regime of the River Shannon, Ireland



WATERFALLS

Waterfalls frequently occur on horizontally bedded rocks. The soft rock is undercut by hydraulic action and abrasion. The weight of the water and the lack of support cause the waterfall to collapse and retreat. Over thousands of years, the waterfall may retreat enough to form a gorge of recession.



1 Hydraulic impact.
2 Abrasion of soft rock by hard fragments.
3 Lack of support by soft rock.
4 Weight of water causes unsupported hard rock to collapse.

DEPOSITION

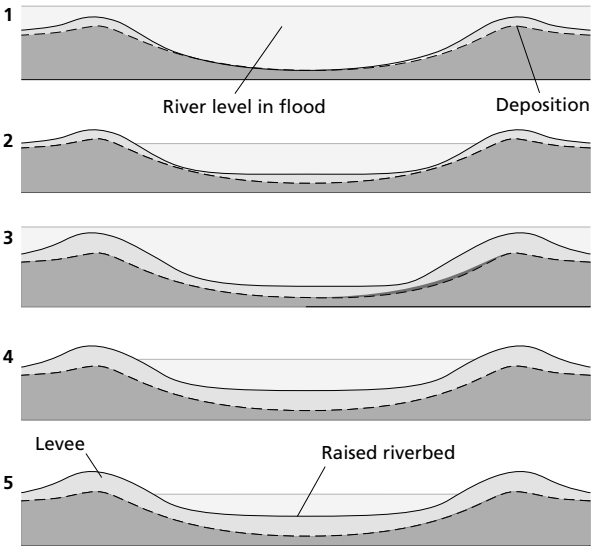
Deposition occurs as a river slows down and loses its energy. Typically, this occurs as a river floods across a floodplain, enters the sea or behind a dam. It is also more likely during low flow conditions (such as in a drought) than during high flow (flood) conditions – as long as the river is carrying sediment. The larger, heavier particles are deposited first, the smaller, lighter ones later. Features of deposition include floodplains, levees and deltas.

FLOODPLAINS

Floodplains are flat areas found in the lower parts of a river, comprising of clay, silt or alluvium deposited when the river is in flood.

LEVEES

When a river floods, its speed is reduced, slowed down by friction caused by contact with the floodplain. As its velocity is reduced the river has to deposit some of its load. It drops the coarser, heavier material first to form raised banks, or **levees** at the edge of the river. This means that over centuries the levees are built up of coarse material, such as sand and gravel, while the floodplain consists of fine silt and clay.



1 When the river floods, it bursts it banks. It deposits its coarsest load (gravel and sand) closer to the bank and the finer load (silt and clay) further away.
2, 3, 4. This continues over a long time, for centuries.
5 The river has built up raised banks called levees, consisting of coarse material, and a floodplain of fine material.

EXAM TIP

Make sure that you use units – it would be easy here to just refer to high discharge and low discharge (or high flow and low flow). A scale is provided – please make sure that you make use of it.

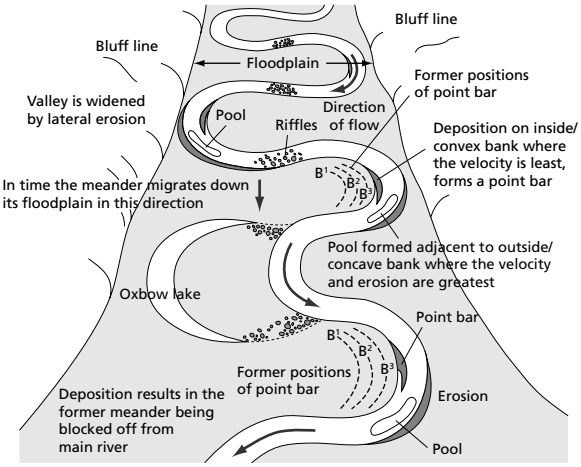
CHECK YOUR UNDERSTANDING

5. Describe the regime of the River Shannon.
6. Suggest reasons for the variation in flow between December and July.

River landforms (2)

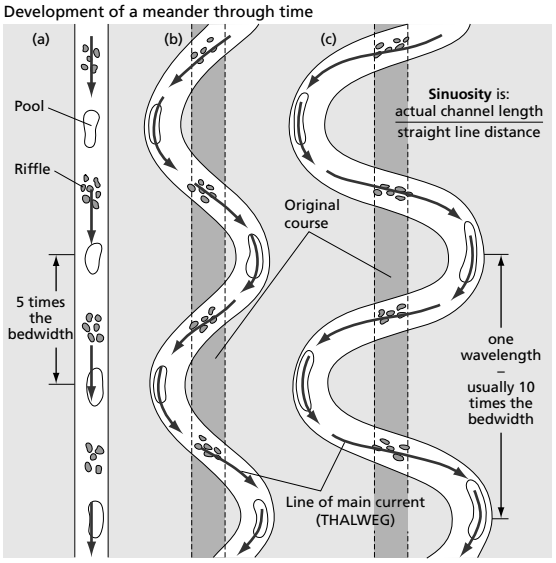
MEANDERS

Meandering is the normal behaviour of fluids and gases in motion. Meanders can occur on a variety of materials from ice to solid rock. Meander development occurs in conditions where channel slope, discharge and load combine to create a situation where meandering is the only way that the stream can use up the energy it possesses equally throughout the channel reach.



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

Development of a meander through time



Meanders

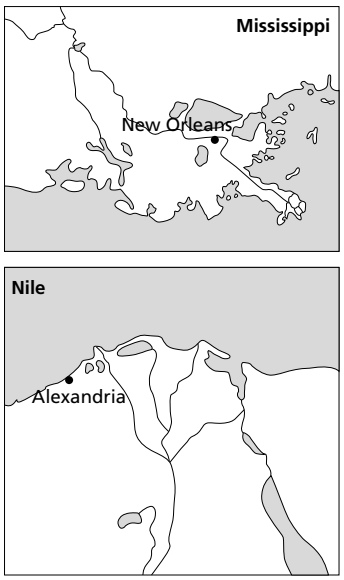
DELTAS

Deltas are formed as river sediments are deposited when a river enters a standing body of water such as a lake, lagoon, or ocean. Deposition occurs because velocity is reduced. A number of factors affect the formation of deltas:

- the amount and size of load – rivers must be heavily laden, and coarse sediments will be deposited first
- salinity – salt-water causes clay particles to stick together, they get heavier and are deposited
- gradient of coastline – delta formation is more likely on gentle coastlines
- vegetation – plant waters will slow waters and so increase deposition
- low energy river discharge and/or low energy wave or tidal energy.

Deltas occur in three main forms:

- arcuate – many distributaries which branch out radially, for example, the Nile Delta
- cuspate – a pointed delta formed by a dominant channel
- bird's foot – long, projecting fingers which grow at the end of distributaries, for example, the Mississippi Delta.



Different forms of deltas

COMMON MISTAKES

✗ *Most erosion occurs in upland areas and deposition in lowland areas.*

✓ Both erosion and deposition occur throughout the course of a river. Most erosion takes place when the river is in flood.

EXAM TIP

For most landforms (of erosion and deposition) you should learn an annotated diagram, and ensure that you can explain how the landform is formed. For many features, for example, waterfalls and levees, you may need to learn a sequence of diagrams.

CHECK YOUR UNDERSTANDING

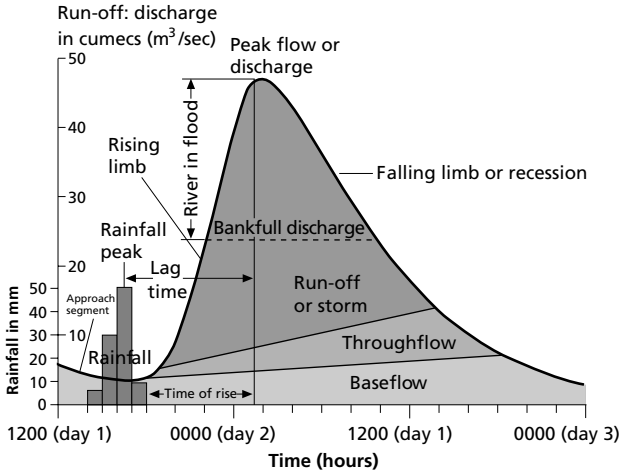
7. Outline the main factors required for the formation of deltas.

8. Briefly explain how waterfalls are formed by rivers.

Hydrographs

DEFINITION

A **storm** or **flood hydrograph** is a graph that shows how a river changes over a short period, such as a day or a couple of days. It shows how a river channel responds to the key processes of the hydrological cycle. It measures the speed at which rainfall falling on a drainage basin reaches the river channel. It is a graph on which river discharge during a storm or run-off event is plotted against time.



CHARACTERISTICS

- **Discharge** (Q) is the volume of flow passing through a cross-section of the river during a given period of time (usually measured in cumecs, that is, m^3/s).
- The **rising limb** indicates the amount of discharge and the speed at which it is increasing. It is very steep in a flash flood or in small drainage basins where the response is rapid. It is generally steep in urbanized catchments.
- **Peak flow or discharge** is higher in larger basins. Steep catchments will have lower infiltration rates; flat catchments will have high infiltration rates, so more throughflow and lower peaks.
- **Lag time** is the time interval between peak rainfall and peak discharge. It is influenced by basin shape, steepness, and stream order.
- The **run-off** curve reveals the relationship between overland flow and throughflow. Where infiltration is low, high antecedent moisture, impermeable surface and rainfall strong overland flow will dominate
- **Baseflow** is the seepage of groundwater into the channel – this can be very important where rocks have high pore spaces. Baseflow is a slow movement and is the main, long-term supplier of the river's discharge.
- The **recessional limb** is influenced by basin size, geological composition and behaviour of local aquifers.
- Larger catchments, flatter gradients and permeable rocks have gentler recessional limbs.

HYDROGRAPH SIZE (AREA UNDER THE GRAPH)

Generally, the higher the rainfall, the greater the discharge, and the larger the basin size, the greater the discharge.

VARIATION IN HYDROGRAPHS

A number of factors affect flood hydrographs:

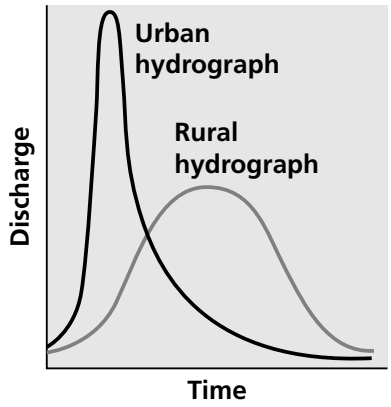
- climate (rainfall total, intensity, seasonality)
- soils (impermeable clay soils create more flooding)
- vegetation (vegetation intercepts rainfall and so flooding is less likely)
- infiltration capacity (soils with a low infiltration capacity cause much overland flow)
- rock type (permeable rocks will allow water to infiltrate, thereby reducing the flood peak)
- slope angle (on steeper slopes there is greater run-off)
- drainage density (the more stream channels there are the more water that gets into rivers
- dams disrupt the flow of water; afforestation schemes increase interception
- basin size, shape, and relief (small, steep basins reduce lag time, while basin shape influences where the bulk of the floodwaters arrive).

URBAN HYDROLOGY AND THE STORM HYDROGRAPH

Urban hydrographs are different to rural ones. They have:

- a shorter lag time
- a steeper rising limb
- a higher peak flow (discharge)
- a steeper recessional limb.

This is because there are more impermeable surfaces in urban areas (roofs, pavements, roads, buildings) as well as more drainage channels (gutters, drains, sewers).



CHECK YOUR UNDERSTANDING

9. Briefly explain how climate and soils influence hydrographs.

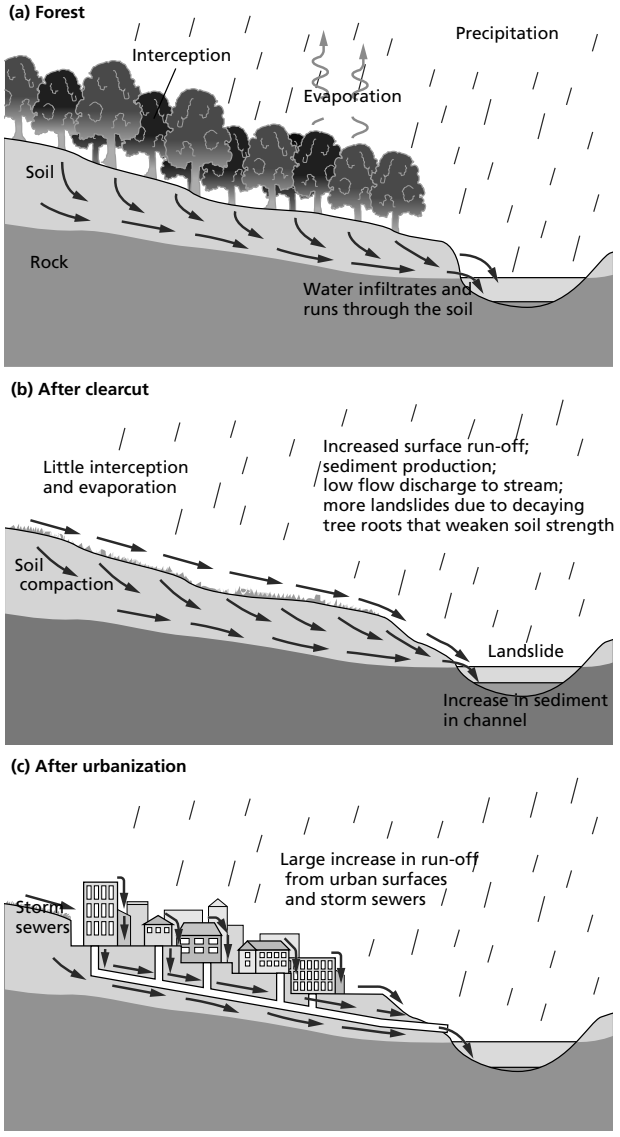
10. Explain how an urban hydrograph differs from a rural one.

Land-use change and flood risk

POTENTIAL HYDROLOGICAL EFFECTS OF URBANIZATION

Urbanizing influence	Potential hydrological response
Removal of trees and vegetation	Decreased evapotranspiration and interception; increased stream sedimentation
Initial construction of houses, streets and culverts	Decreased infiltration and lowered groundwater table; increased storm flows and decreased baseflows during dry periods
Complete development of residential, commercial and industrial areas	Decreased porosity, reducing time of run-off concentration, thereby increasing peak discharges and compressing the time distribution of the flow; greatly increased volume of run-off and flood damage potential
Construction of storm drains and channel improvements	Local relief from flooding; concentration of floodwaters may aggravate flood problems downstream

Urbanization has a greater impact on processes in the lower part of a drainage basin than the upper course. This is because more urban areas are found in the lower parts of drainage basins.



DEFORESTATION

Deforestation can have a similar impact to urbanization on flood hydrographs. The presence of vegetation increases interception, reduces overland flow, and increases evapotranspiration. In contrast, deforestation reduces interception, increases overland flow, and reduces evapotranspiration. This causes flood hydrographs to have shorter time lags and higher peak flows.

In deforested areas flood risk is increased. The risk of higher magnitudes, greater frequencies, and reduced recurrence intervals becomes greater when the vegetation cover is removed.

Deforestation is likely to occur over a much broader area than urbanization. This is because deforestation may occur for land-use changes (for example, conversion to agriculture), industrial development, to make way for tourist developments and to allow urbanization to occur. Hence it likely to have a more widespread impact on hydrological processes.

CHANNEL MODIFICATIONS

Channel modifications include channelization, enlargement and straightening. Channelization may create new channels. These are likely to be quite straight. This speeds up water movement and so time lags are likely to be reduced. Enlarging channels through levees (raised banks) enables rivers to carry more water. Thus the peak flow may be higher. However, the purpose of channelization and straightening is to remove water from an area, and so reduce the threat of a flood.

CHECK YOUR UNDERSTANDING

11. Describe the hydrological impacts of the removal of trees and vegetation.

12. Describe the impact of urbanization on channels in an urban area.

COMMON MISTAKE

✗ *All floods have the same impact.*

✓ An annual flood may be only a few centimetres deep whereas a 50-year flood could be a metre deep. The low-frequency high-magnitude flood events are much more powerful and damaging than the high-frequency low-magnitude flood events.

Flood prediction and mitigation

FORECASTING AND WARNING

According to the United Nations Environment Programme's publication *Early warning and assessment* there are a number of things that could be done to improve flood warnings. These include:

- improved rainfall and snow-pack estimates, better and longer forecasts of rainfall
- better gauging of rivers, collection of meteorological information and mapping of channels
- better and more-current information about human populations, and infrastructure, elevation and stream channels need to be incorporated into flood risk assessment models
- better sharing of information is needed between forecasters, national agencies, relief organizations and the general public
- more complete and timely sharing of information of meteorological and hydrological information is needed among countries within international drainage basins
- technology should be shared among all agencies involved in flood forecasting and risk assessment both in the basins and throughout the world.

EMERGENCY MEASURES

Emergency action includes the removal of people and property, and flood-fighting techniques, such as sandbags. Much depends on the efficiency of forecasting and the time available to warn people and clear the area. Flood-proofing includes sealing walls, sewer adjustment by the use of valves, covering buildings and machinery.

PREVENTION AND AMELIORATION OF FLOODS

Loss-sharing adjustments include disaster aid and insurance. **Disaster aid** refers to any aid, such as money, equipment, staff and technical assistance that are given to a community following a disaster. In developed countries **insurance** is an important loss-sharing strategy. However not all flood-prone households have insurance and many of those that are insured may be underinsured. Its lack of availability in many poor countries makes it of limited use.

Event modification adjustments include environmental control and hazard-resistant design. Physical control of floods depend on two measures – flood abatement and flood diversion.

Flood abatement involves decreasing the amount of run-off, thereby reducing the flood peak in a drainage basin. There are a number of ways of reducing flood peaks. These include:

- reforestation
- reseeding of sparsely vegetated areas to increase evaporative losses
- treatment of slopes such as contour ploughing or terracing to reduce the run-off coefficient
- comprehensive protection of vegetation from wildfires, overgrazing, and clearcutting of forests
- clearance of sediment and other debris from headwater streams
- construction of small water and sediment holding areas
- preservation of natural water storage zones, such as lakes.

Flood diversion measures, by contrast, include the construction of levees, reservoirs, and the modification of river channels. **Levees** are the most common form of river engineering. **Reservoirs** store excess rainwater in the upper drainage basin. However, this may only be appropriate in small drainage networks.

CASE STUDY

PROTECTING THE MISSISSIPPI

For over a century the Mississippi has been mapped, protected and regulated. The river drains one-third of the USA and it affects some of the USA's most important agricultural regions. A number of methods have been used to control flooding and the effects of flooding including:

- stone and earthen levees to raise the banks of the river
- dams to hold back water in times of flood
- straightening of the channel to remove water speedily.

Altogether over $10 billion has been spent on controlling the Mississippi, and annual maintenance costs are nearly $200 million.

In 1993, following heavy rain, many of the levees collapsed allowing the river to flood its floodplain. The damage was estimated to be over $12 billion yet only 43 people died. Over 25,000 km^2 of land were flooded. In 2005 more than 50 breaches in New Orleans's hurricane surge protection occurred during Hurricane Katrina leading to death and destruction on a massive scale.

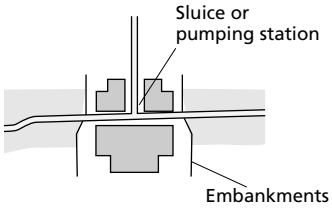
According to some geographers, if the Mississippi were left to its own devices a new channel would have been created by the mid-1970s, so much so that the ports at New Orleans and Baton Rouge would be defunct. However, river protection schemes have prevented this. For example, at New Orleans 7-metre levees flank the river. New Orleans is 1.5 metres below the average river level and 5.5 metres below flood level.

CHECK YOUR UNDERSTANDING

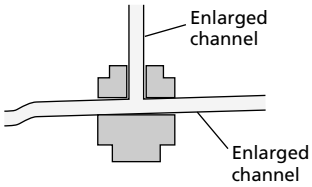
13. Distinguish between a levee and a flood relief channel.

14. Explain the term "flood abatement".

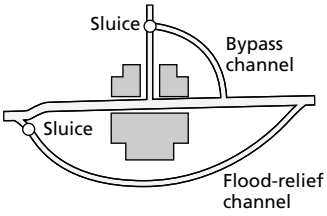
Flood control – protective measures along flood channels



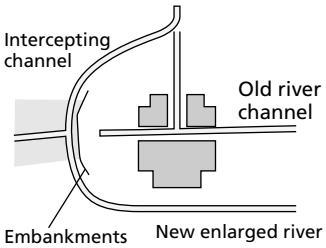
1 Flood embankments with sluice gates. The main problem with this is it may raise flood levels upstream and downstream.



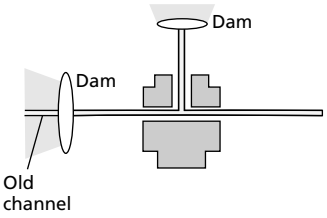
2 Channel enlargement to accommodate larger discharges. One problem with such schemes is that as the enlarged channel is only rarely used it becomes clogged with weed.



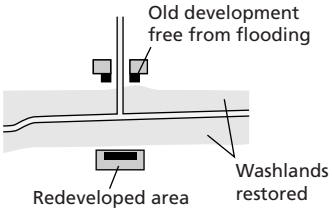
3 Flood-relief channel. This is appropriate where it is impossible to modify original channel as it tends to be rather expensive, e.g. the flood-relief channels around Oxford UK.



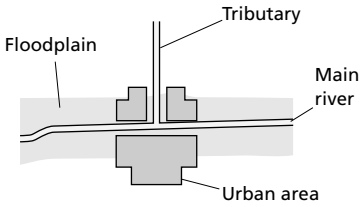
4 Intercepting channels. These divert only part of the flow away, allowing flow for town and agricultural use, e.g. the Great Ouse Protection Scheme in the UK.



5 Flood storage reservoirs. This solution is widely used, especially as many reservoirs created for water-supply purposes may have a secondary flood control role, such as the intercepting channels along the Loughton Brook, UK.



6 The removal of settlements. This is rarely used because of cost, although many communities were forced to leave as a result of the 1993 Mississippi floods, e.g. Valmeyer, Illinois.



CHANNEL MODIFICATION

Modification of river channels includes raising the banks (to hold more water), straightening the river (to speed up flow and remove the water as quickly as possible) and creating new channels (flood-relief channels) to carry water when the river is in flood. Channels can also be strengthened with steel or concrete to make them less vulnerable to erosion.

Artificial **levees** are the most common form of river engineering. This is when the banks of the river are increased in height so that the river can carry more water and sediment. Levees can also be used to divert and restrict water to low-value land on the flood plain. Over 4,500 km of the Mississippi River has levees. Channel improvements such as dredging the river bed of sediment will increase the carrying capacity of the river.

EXAM TIP

When writing about floods, make sure you use a named, located example, with dates of the floods and details such as the loss of life, economic loss or number of people made homeless.

COMMON MISTAKE

✗ *Flood protection measures will protect a settlement against all floods.*

✓ Flood protection measures protect against a flood of a given magnitude/recurrence interval. For example, levees on the Mississippi at New Orleans are designed to withstand a 100-year flood. However, the floodwaters caused by Hurricane Katrina were a 150–200-year flood so the levees were breached.

CHECK YOUR UNDERSTANDING

15. Identify two ways in which flood warnings could be improved.

16. Explain how revegetation of an area could help reduce flooding.

Water scarcity

SCARCITY THAT AFFECTS LICs

Where water supplies are inadequate, two types of **water scarcity** affect LICs in particular:

- **Physical water scarcity** occurs where water consumption exceeds 60% of the usable supply. To help meet water needs some countries such as Saudi Arabia and Kuwait import much of their food and invest in desalinization plants.
- **Economic water scarcity** occurs where a country physically has sufficient water resources to meet its needs, but additional storage and transport facilities are required – this will mean embarking on large and expensive water-development projects as in many in sub-Saharan countries.

In addition, in LICs, access to adequate water supplies is affected by the exhaustion of traditional sources, such as wells and seasonal rivers.

Water scarcity 2025

DROUGHT

Drought is an extended period of dry weather leading to conditions of extreme dryness. Absolute drought is a period of at least 15 consecutive days with less than 0.2 mm of rainfall. Partial drought is a period of at least 29 consecutive days during which the average daily rainfall does not exceed 0.2 mm.

The severity of a drought depends upon the length of the drought and how severe the water shortage is. The impacts of drought can include reduced crop yields, increased animal mortality, an increase in illnesses in humans (linked to dehydration), an increase in forest fires, hosepipe bans, a ban on watering private gardens or washing cars.

WATER QUANTITY AND WATER QUALITY DISTRIBUTION

The world's available freshwater supply is not distributed evenly around the globe, either seasonally or from year to year.

- About three-quarters of annual rainfall occurs in areas containing less than a third of the world's population.
- Two-thirds of the world's population live in the areas receiving only a quarter of the world's annual rainfall.

QUALITY

Water also needs to be of an adequate quality for consumption. In developing countries too many people lack access to safe and affordable water supplies and sanitation. The World Health Organization (WHO) estimates that around 4 million deaths each year are from water-related disease, particularly cholera, hepatitis, malaria and other parasitic diseases. Water quality may be affected by organic waste from sewage, fertilizers and pesticides from farming, and by heavy metals and acids from industrial processes and transport. Factors affecting access to safe drinking water include:

- water availability
- water infrastructure
- cost of water.

CHECK YOUR UNDERSTANDING

17. Distinguish between physical water scarcity and economic water scarcity.

18. Define the term "drought".

Environmental impacts of agricultural activities

IRRIGATION

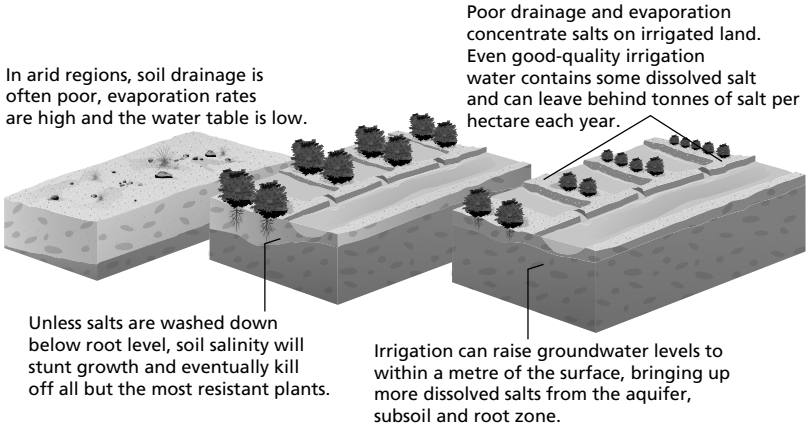
Irrigation is the addition of water to areas where there is insufficient water for adequate crop growth. Water can be taken from surface stores, such as lakes, dams, reservoirs and rivers, or from groundwater. Types of irrigation range from total flooding, as in the case of paddy fields, to drip irrigation, where precise amounts are measured out to each individual plant

CONSEQUENCES OF IRRIGATION

- In Texas, irrigation has reduced the water table by as much as 50 m. By contrast, in the Indus Plain in Pakistan, irrigation has raised the water table by as much as 6 m since 1922, and caused widespread salinization.
- Irrigation can reduce the earth's albedo (reflectivity) by as much as 10%.This is because a reflective sandy surface may be replaced by one with dark green crops.
- Irrigation can also cause changes in precipitation. Large-scale irrigation in semi-arid areas, such as the High Plains of Texas, have been linked with increased rainfall, hailstorms and tornadoes. Under natural conditions semi-arid areas have sparse vegetation and dry soils in summer. However, when irrigated these areas have moist soils in summer and complete vegetation cover. Evapotranspiration rates increase and there have been increases in the amount of summer rainfall.

SALINIZATION

- Irrigation frequently leads to an increase in the amount of salt in the soil. This occurs when groundwater levels are close to the surface. Capillary forces bring water to the surface where it may be evaporated leaving behind any soluble salts that it is carrying. This is known as **salinization**.
- Some irrigation, especially paddy rice, requires huge amounts of water. As water evaporates in the hot sun, the salinity levels of the remaining water increase. This also occurs behind large dams.

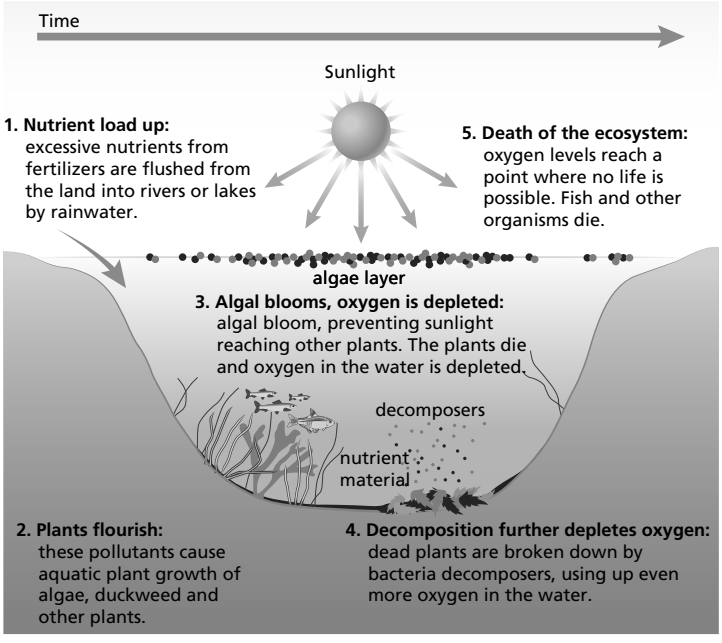


EUTROPHICATION

Eutrophication, or nutrient enrichment, of water bodies has led to algal blooms, oxygen starvation and a decline in species diversity. While there is a strong body of evidence to link increased eutrophication with increased use of nitrogen fertilizers, some scientists argue that increased phosphates from farm sewage are the cause.

There are a number of stakeholders involved in the eutrophication process:

- chemical fertilizer companies that wish to sell fertilizers to farmers
- governments that wish to produce more food
- farmers who want to grow more food and make a greater profit
- health organizations and environmental organizations that wish to have safe water
- consumers who want cheaper food, but who may also end up paying the cost of making drinking water clean.



CHECK YOUR UNDERSTANDING

19. Briefly explain the process of salinization.

20. Briefly explain the changes in a stream that result from eutrophication.

Human pressures on lakes and aquifers

POPULATION GROWTH

As populations grow, pressure on water resources increases. Population growth is uneven so there is increased pressure in certain locations. Urban areas experiencing rapid economic growth are likely to face the greatest increases in water stress.

The Middle East and North Africa (MENA) region contains over 6% of the world's population but only 1.4% of its freshwater. As the population increases, pressure on the water resources is likely to intensify. Twelve of the world's 15 water-scarce countries are in the MENA region. The Nubian Sandstone Aquifer System under the Sahara Desert is over 2 million km^2 in area and offers great potential for the region. Careful use of the aquifer and irrigation channels such as the Great Man-made River Project (from the Sahara to Libya) would enable the MENA region to access more freshwater resources.

POLLUTION

Lakes may be polluted by run-off from chemical fertilizers, phosphates, sewage, oil, acidification and industrial effluent. The largest sources of sulphur and nitrogen are China and India. Over recent decades there has been an increase in the acidification of lakes there, and also transboundary impacts on lakes in South Korea and Japan. The results of a UNEP survey are shown below.

Global variations in eutrophication

Region	Percentage of lakes and reservoirs suffering from eutrophication
Asia-Pacific	54
Europe	53
Africa	28
North America	48
South America	41

CASE STUDY

GROUNDWATER POLLUTION IN BANGLADESH

There has been an increase in the incidence of cancers in Bangladesh. It has been caused by naturally occurring arsenic in groundwater pumped up through the tube wells. Estimates by the World Health Organization suggest that as many as 85 million of its 125 million population will be affected by arsenic-contaminated drinking water.

For 30 years, following the lead of Unicef, Bangladesh has sunk millions of tube wells, providing a convenient supply of drinking water free from the bacterial contamination of surface water that was killing one-quarter of a million children a year. But the water from the wells was never tested for arsenic contamination, which occurs naturally in the groundwater. One in 10 people who drinks the water containing arsenic will ultimately die of lung, bladder or skin cancer.

The first cases of arsenic-induced skin lesions were identified across the border in West Bengal, India, in 1983. Arsenic poisoning is a slow disease. Skin cancer typically occurs 20 years after people start ingesting the poison. The real danger is internal cancers, especially of the bladder and lungs, which are usually fatal. Bangladeshi doctors were warned to expect an epidemic of cancers by 2010. The victims will be people in their thirties and forties who have been drinking the water all their lives – people in their most productive years.

One solution to the problem is to use concrete water butts to collect water from gutters. Other possible solutions include a filter system. Neither is as convenient as the tube wells they are designed to replace. Tube wells are easy to sink in the delta's soft alluvial soil, and for tens of millions of peasants the wells have revolutionized access to water.

COMMON MISTAKE

✗ *All groundwater is renewable.*

✓ Some groundwater can be considered a non-renewable resource as the water that helped fill the aquifer fell thousands of years ago in a wetter climate. If the annual use of groundwater exceeds its regeneration, the aquifer will decrease in size.

CHECK YOUR UNDERSTANDING

21. Explain how lakes may become polluted.

22. State the term used to identify a water-bearing rock.

Internationally shared water resources

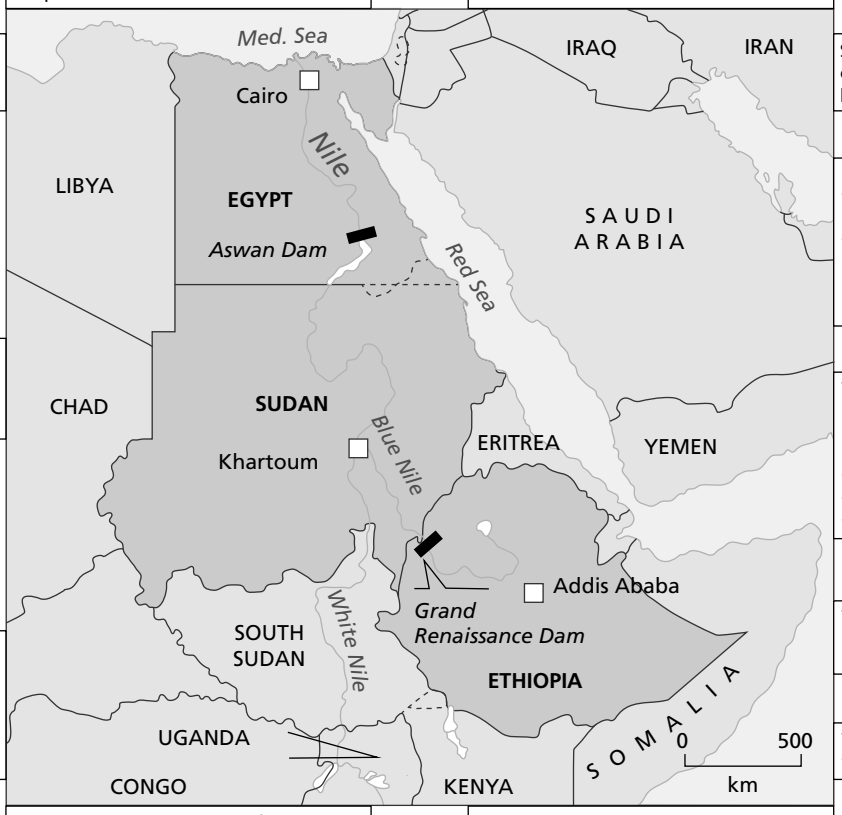
A SOURCE OF CONFLICT

As populations grow, greater demands are made on water resources. Water resources are now becoming a limiting factor in many societies, and the availability of water for drinking, industry and agriculture needs to be considered. Many societies are now dependant primarily on groundwater, which is non-renewable. As societies develop, water needs increase. The increased demand for freshwater can lead to inequity of usage and political consequences. When water supplies fail, populations will be forced to take drastic steps, such as mass migration. Water shortages may also lead to civil unrest and wars.

The Grand Ethiopian Renaissance Dam

Ethiopia is building Africa's largest dam, the Grand Ethiopian Renaissance Dam, on the Blue Nile. It is designed to produce 6,000 megawatts of electricity, more than double Ethiopia's current output.

This opportunity for Ethiopia could spell disaster for Egypt.



The Nile provides nearly all of Egypt's water.

Sudan will receive some of the power produced by the dam.

By stabilizing the Nile's flow, it will also allow Sudan to prevent flooding, consume more water and increase agricultural output.

Egypt claims two-thirds of the flow based on a treaty it signed with Sudan in 1959.

The stakeholders include the governments of Egypt, Ethiopia and Sudan, as well as the people who will make use of the water.

This is no longer enough water to satisfy the growing population (1.8% growth in 2015) and agricultural sector.

The project will cost approximately US$4.8 bn.

The dam is just 20 km from the Sudan border.

In March 2015 the leaders of Egypt, Ethiopia and Sudan signed a declaration that approved construction of the dam as long as there is no "significant harm" to downstream countries.

There is uncertainty over the dam's ultimate use. Ethiopia insists that it will produce only power. Egyptians fear it will also be used for irrigation, reducing downstream supply.

EXAM TIP

Consider different ways that you could use the information about the Renaissance Dam. For example, the impact of dams, the management of international drainage basins, water security, water supply, renewable energy, sustainability, etc.

CHECK YOUR UNDERSTANDING

23. Outline the benefits to Sudan of the GERD.

24. Suggest reasons why Egypt does not approve of the development of the GERD.

Increased dam building

THE BUILDING OF LARGE DAMS

The number of large dams (more than 15 m high) that are being built is increasingly rapidly and is reaching a level of almost two completions every day. Famous dams include the Akosombo (Ghana), Tucurui (Brazil), Hoover (USA), and Kariba (Zimbabwe).

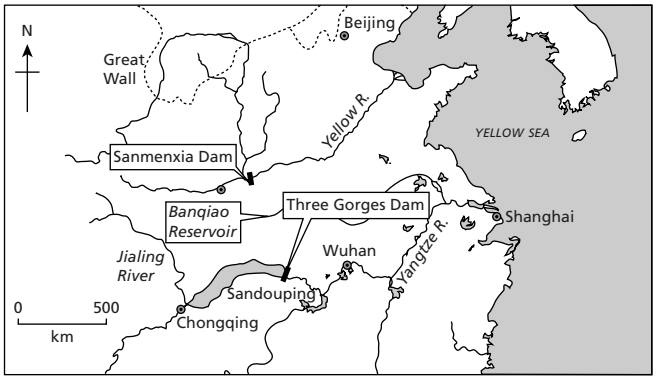
CASE STUDY

THE THREE GORGES DAM

The Three Gorges Dam on China's Yangtze River is the world's largest dam, at over 2 kilometres long and 100 metres high. The lake behind the dam is over 600 kilometres long. The dam was built to help meet China's ever-increasing need for electricity and water storage, as the population moves from a sustainable existence to a more western-style urban culture. Over a million people were moved out of the valley to make way for the dam and the lake. The Yangtze river basin provides 66% of China's rice and contains 400 million people. The river drains 1.8 million square kilometres and discharges 700 cubic kilometres of water annually.

Advantages and disadvantages of the Three Gorges Dam

Advantages	Disadvantages
The dam can generate up to 18,000 megawatts, eight times more than the Aswan Dam and 50% more than the world's next largest HEP dam, the Itaipu in Paraguay.	Up to 1.2 million people had to be moved to make way for the dam. Dozens of towns, for example, Wanxian and Fuling with 140,000 and 80,000 people respectively, had to be flooded. Much of the land available for resettlement is over 800 metres above sea level, therefore it is colder with infertile thin soils and on relatively steep slopes.
It has reduced China's dependency on coal.	To reduce the silt load, afforestation is needed but resettlement of people is causing greater pressure on the slopes above the dam.
It will supply energy to Shanghai and Chongqing, an area earmarked for economic development.	Up to 530 million tonnes of silt are carried through the Gorge annually. The port at the head of the lake may become silted up as a result of increased deposition and the development of a delta at the head of the lake. The mouth of the river may be starved of silt, and erosion of the coastline may result.
It protects 10 million people from flooding (over 300,000 people in China died as a result of flooding in the 20th century).	Most floods in recent years have come from rivers which join the Yangtze below the Three Gorges Dam.
It allows shipping above the dam: the dams have raised water levels by 90 metres, and turned the rapids in the gorge into a lake.	The region is seismically active and landslides are frequent. The weight of the water behind the lake may contribute to seismic instability.
It has generated thousands of jobs, both in its construction and the industrial development associated with the availability of cheap energy.	Archaeological treasures were drowned, including the Zhang Fei temple. The dam has interfered with aquatic life: the Yangtze River Dolphin is now believed to be extinct.
	It cost as much as $70 billion.



CHECK YOUR UNDERSTANDING

25. Describe the distribution of large dams built between 1945 and 2005 (as shown on page 17).

26. Outline the main advantages of large dams.

Integrated drainage basin management (IDBM)

IDBM PLANS

Integrated drainage basin management (IDBM) plans aim to deliver sustainable use of the world's limited freshwater resources. It uses a basin-wide framework for water management that is economically, socially and environmentally sustainable. It is not always possible, especially when neighbouring countries are in conflict with each other.

Examples of poor drainage basin management are frequent. For example, post-1940s development on the Missouri and Mississippi rivers in the USA focused on dam building, which benefitted downstream states at the expense of upstream states. Indigenous people were not consulted over their needs, and ecosystem needs were often ignored compared with economic needs. The 1993 floods cost an estimated $16 billion, due to a combination of floodplain construction and the failure of artificial levees.

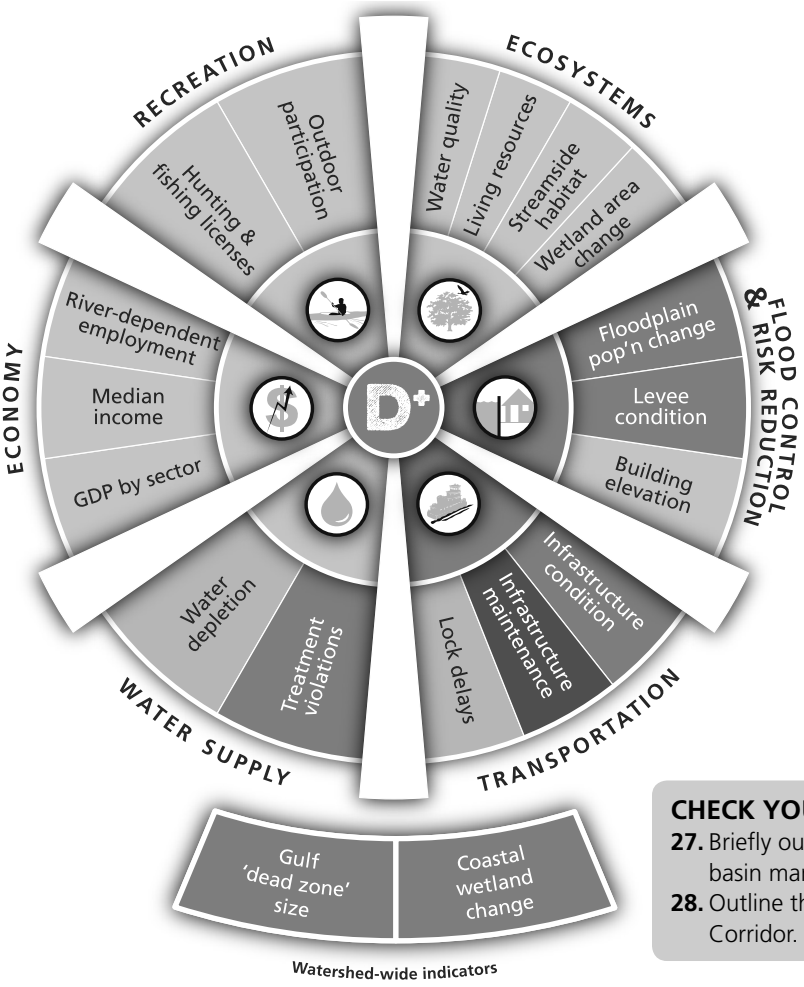
In contrast, management of the Danube, Europe's second longest river, is seen as a success. The Danube has high biodiversity, and is well known for its lakes, wetlands, floodplain forests, and meadows and it provides important spawning grounds for fish. It is also a source of drinking water for 20 million people, and is economically important for industry, mining, farming and energy production. It is an important transport route. Over 80% of the original floodplain was lost due to construction projects, and other problems included river erosion, declining biodiversity, draining of wetlands for biodiversity, pollution from industry and agriculture, toxic spills and flooding.

The basin is occupied by 17 countries, some of whom were divided by the Cold War, which made inert-basin management impossible. With political change in the late 1980s and 1990s, a new era of political and economic development occurred in much of Eastern Europe.

An International Commission for the Protection of the Danube River (ICPDR) was established, and it focuses on water quality, risks from accidents, monitoring and information management, river basin management and implementation of the EU Water Framework directive.

In addition, the lower basin countries (Bulgaria, Moldova, Romania and Ukraine) established the Lower Danube Green Corridor. This consists of a 400,000 ha network of protected wetland areas, 100,000 ha of newly protected wetlands, and the restoration of 200,000 other sites. This has increased the capacity of the Danube to reduce pollution, purify water, retain floodwaters, support fisheries and tourism, and provide new habitats for wildlife.

Another example comes from Costa Rica, where a tax on fossil-fuel use and payments from private hydroelectric companies is used to pay forest owners for maintaining their forests in upland areas. This benefits users in lowland areas through regulation of water quality and quantity. The power companies benefit through reduced sedimentation behind dams. However, some forest owners have complained that the payments made are not enough to be economically viable.



CHECK YOUR UNDERSTANDING

27. Briefly outline the main aims of integrated drainage basin management plans.

28. Outline the successes of the Lower Danube Green Corridor.

Wetlands

RAMSAR CONVENTION

The Ramsar Convention, an international treaty to conserve wetlands, defines wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt". Thus, according to the Ramsar classification, there are marine, coastal and inland types, subdivided into 30 categories of natural wetland and nine human-made ones, such as reservoirs, barrages and gravel pits. Wetlands now represent only 6% of the earth's surface, of which 30% are bogs, 26% are fens, 20% are swamps, 15% are floodplains and 2% are lakes.

THE VALUE OF WETLANDS

Wetlands provide many important social, economic and environmental benefits.

Functions	Products	Attributes
Flood control	Fisheries	Biological diversity
Sediment accretion and deposition	Game	Culture and heritage
Groundwater recharge	Forage	
Groundwater discharge	Timber	
Water purification	Water	
Storage of organic matter		
Food-chain support/cycling		
Water transport		
Tourism/recreation		

LOSS AND DEGRADATION

The loss and degradation of wetlands is caused by several factors, including:

- increased demand for agricultural land
- population growth
- infrastructure development
- river flow regulation
- invasion of non-native species and pollution
- natural causes such as drought and hurricanes.

CASE STUDY

CHANGING RIVER MANAGEMENT – THE KISSIMMEE RIVER

Between 1962 and 1971 engineering changes were made to deepen, straighten and widen the Kissimmee River, which was transformed into a 90-kilometre, 10-metre deep drainage canal. The river was **channelized** to provide flood protection for land adjacent to the river.

The channelization of the Kissimee River had several unintended impacts:

- the loss of 2,000 to 14,000 hectares of wetlands
- a 90% reduction in wading bird and waterfowl usage
- a continuing long-term decline in game fish populations.

Concerns about the **sustainability** of existing ecosystems led to a state and federally supported restoration study. The result was a massive restoration project, on a scale unmatched elsewhere.

Between 1999 and 2015 over 100 square kilometres of river and associated wetlands were restored. The project created over 11,000 hectares of wetlands.

The costs of restoration

- The project cost over $410 million.
- Restoration of the river's floodplain may result in higher losses of water due to evapotranspiration during wet periods.

Benefits of restoration

- Higher water levels should ultimately support a natural river ecosystem again.
- Reestablishment of floodplain wetlands and the associated nutrient filtration function should result in decreased nutrient loads to Lake Okeechobee.
- Populations of key bird species such as wading birds and waterfowl have returned to the restored area, and in some cases numbers have more than tripled.
- Dissolved oxygen levels have doubled, which is critical for the survival of fish and other aquatic species.

Potential revenue associated with increased recreational usage (such as hunting and fishing) and ecotourism on the restored river could significantly enhance local and regional economies.

CHECK YOUR UNDERSTANDING

29. Outline the main advantages of wetlands.
30. Distinguish between natural and human-induced loss of wetlands.

Community participation

WATER SUPPLY

Water resources can be managed sustainably if individuals and communities make changes locally and this is supported by national government. Use can be reduced by self-imposed restraint. For example, using water only when it is essential, minimizing waste, and reusing supplies such as bath water. Education campaigns can increase local awareness of issues and encourage water conservation. There are many opportunities to increase freshwater supplies:

- retain water in reservoirs for use in dry seasons
- redistribute water from wetter areas to drier areas
- water conservation (for example, recycle grey water – water that has already been used so is not fit for drinking but could be used for other purposes).

Water harvesting includes:

- extraction from rivers and lakes (for example, by primitive forms of irrigation such as the shaduf and Archimedes screw), aided by gravity
- trapping behind dams and banks (bunds)
- pumping from aquifers (water-bearing rocks).

These can be achieved with either high-technology or low-technology methods.

Water can be collected from rivers and lakes, although this places a burden on those collecting it, especially women and children. In other locations, groundwater may be tapped by using pumps, but it is important that the rate of use does not exceed the rate of recharge.

Check dam, Eastern Cape, South Africa

EXAM TIP

It is always useful to back up your answers with evidence. Some examples are given on this page. You could find out what is done in your home area to provide water, and what is being done to make sure that it is used (more) sustainably.

SUSTAINABLE USE OF WATER

Water law principles of South Africa

All water is a resource common to all, the use of which should be subject to national control.
There shall be no ownership of water but only a right to its use.
The objective of managing the nation's water resources is to achieve optimum long-term social and economic benefit for our society from their use, recognizing that water allocations may have to change over time.
The water required to meet peoples' basic domestic needs should be reserved.
The development, apportionment and management of water resources should be carried out using the criteria of public interest, sustainability, equity and efficiency of use in a manner which reflects the value of water to society while ensuring that basic domestic needs, the requirements of the environment and international obligations are met.
Responsibility should, where possible, be *delegated* to a catchment or regional level in such a manner as to enable interested parties to participate and reach consensus.
The right of all citizens to have access to basic water services (the provision of potable water supply and the removal and disposal of human *excreta* and waste water) necessary to afford them a healthy environment on an equitable and economically and environmentally sustainable basis should be supported.

Source: Adapted from Department of Water Affairs and Forestry, South Africa, Water law principles

Stone plinth for water collection, Antigua

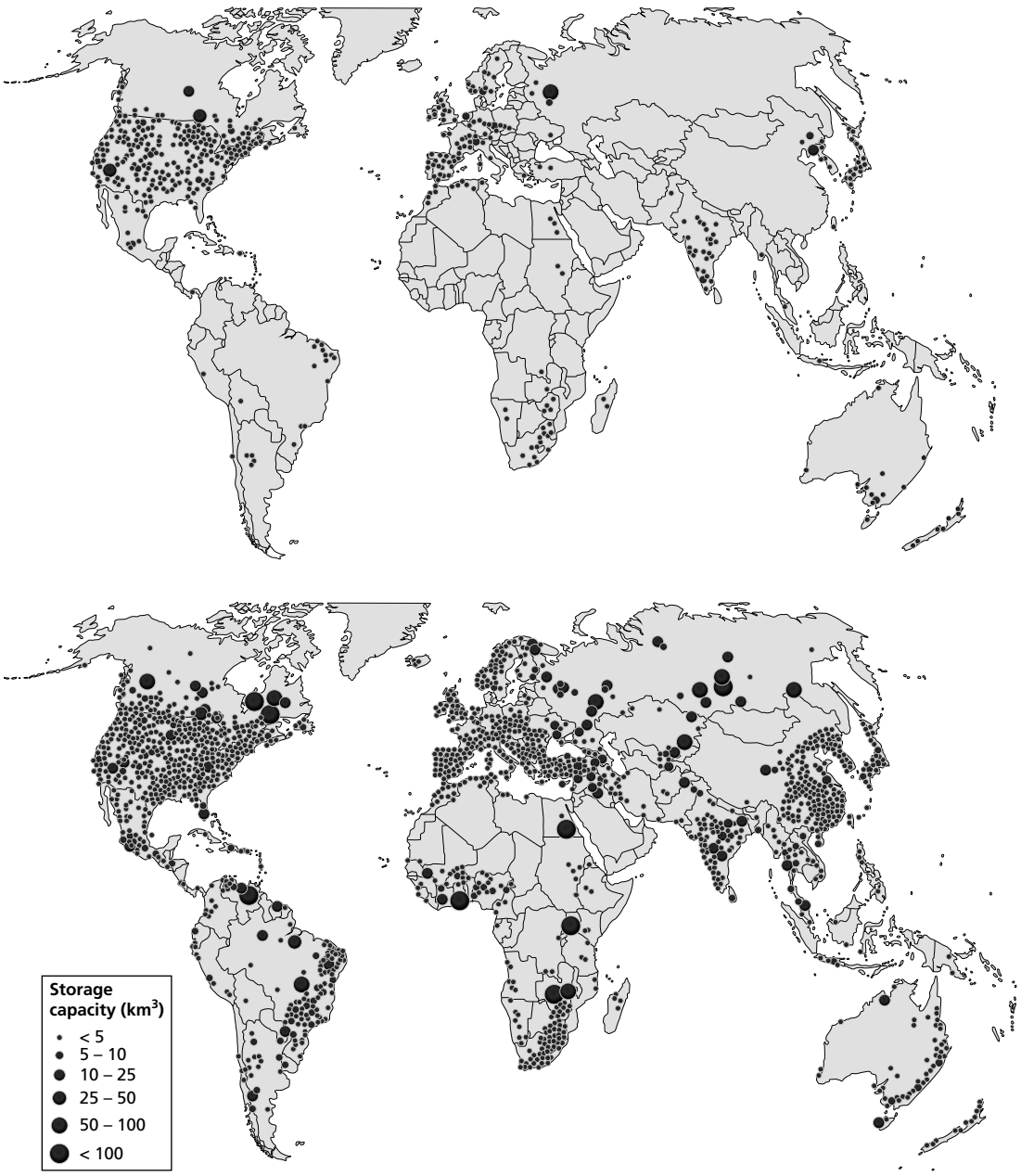
CHECK YOUR UNDERSTANDING

31. Explain the meaning of the term "water harvesting".

32. Outline the main objective of South Africa's water law principles.

Exam practice

The maps below show the number of large dams around the world in 1945 and 2005.



(a) **(i)** Describe the distribution of large dams in 1945. (2 marks)

(ii) Outline the main changes to the distribution of large dams by 2005. (2 marks)

(b) Explain one advantage and two disadvantages of the development of large dams. (2 + 2 + 2 marks)

(c) **Either**

Discuss the view that agricultural activities inevitably lead to a decline in water quality. (10 marks)

Or

Evaluate the efforts to protect wetlands from increasing human pressures. (10 marks)