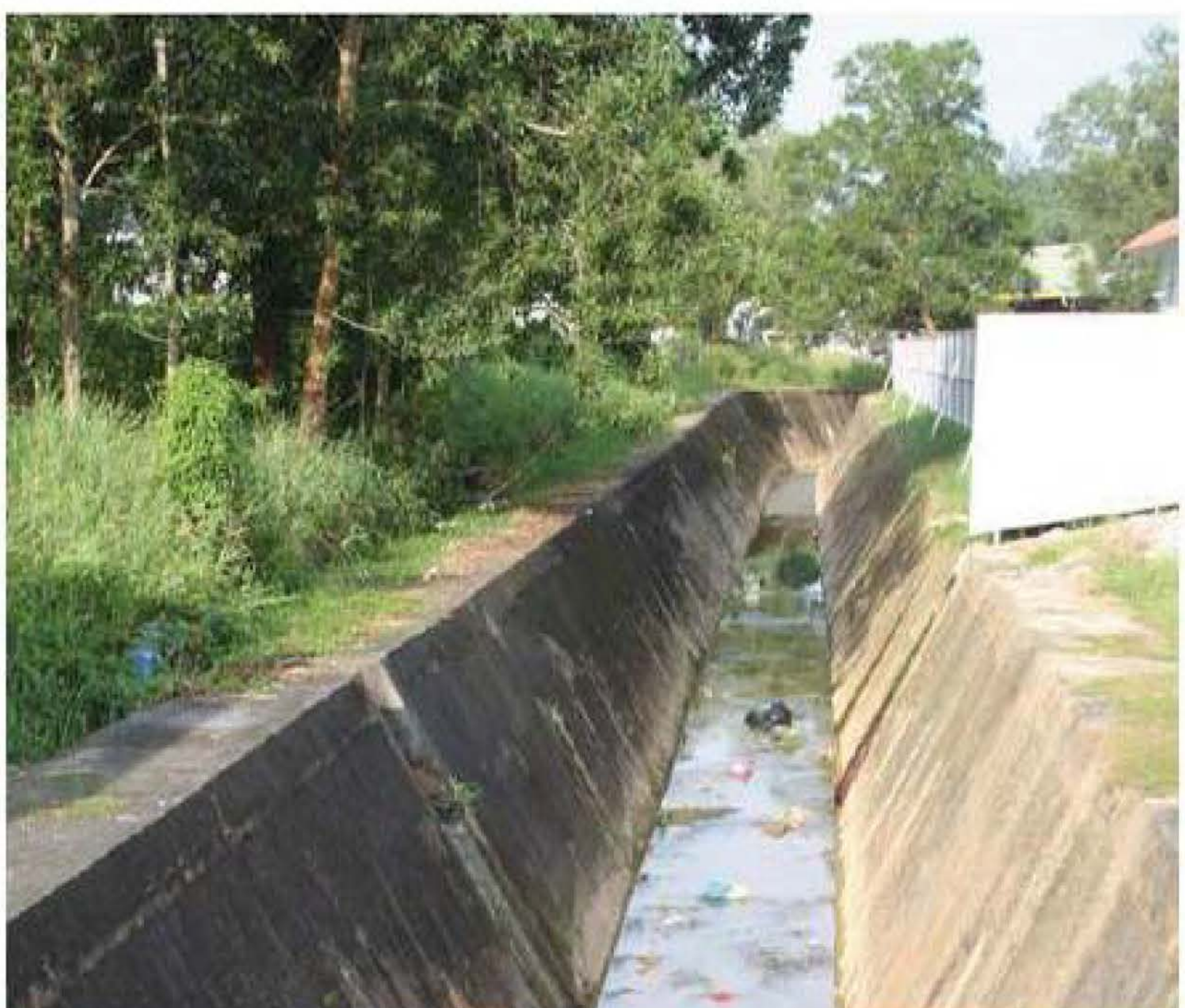
1.4 The human impact

Modifications to catchment stores and flows, and to channel flows

Evaporation and evapotranspiration

The human impact on evaporation and evapotranspiration is relatively small in relation to the rest of the hydrological cycle but is nevertheless important. There are a number of impacts:

- Dams – there has been an increase in evaporation due to the construction of large dams. For example, Lake Nasser behind the Aswan Dam loses up to a third of its water due to evaporation. Water loss can be reduced by using chemical sprays on the water, by building sand-fill dams and by covering the dams with some form of plastic.
- Urbanisation leads to a huge reduction in evapotranspiration due to the lack of vegetation. There may also be a slight increase in evaporation because of higher temperatures and increased surface storage (see Figure 1.24).



Urbanising 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 base flows during dry periods
Complete development of residential, commercial and industrial areas	Decreased porosity, reducing time of runoff concentration, thereby increasing peak discharges and compressing the time distribution of the flow; greatly increased volume of runoff and flood damage potential
Construction of storm drains and channel improvements	Local relief from flooding; concentration of floodwaters may aggravate flood problems downstream

Figure 1.24 Potential hydrological effects of urbanisation

Interception

Interception is determined by vegetation, density and type. Most vegetation is not natural but represents some disturbance by human activity. In farmland areas, for example, cereals intercept less than broad leaves. Row crops, such as wheat or corn, leave a lot of soil bare. For example, in the Mississippi basin, while sediment yields in woodland areas are just 1 unit, sediment from soil covered by pasture produces 30 units and areas under corn produce 350 units of sediment. Deforestation leads to:

- a reduction in evapotranspiration
- an increase in surface runoff
- a decline of surface storage
- a decline in time lag.

Afforestation is believed to have the opposite effect, although the evidence does not necessarily support it. For example, in parts of the Severn catchment, sediment loads increased four times after afforestation. Why was this? The result is explained by a combination of an increase in overland runoff, little ground vegetation, young trees, access routes for tractors, and fire- and wind-breaks. All of these allowed a lot of bare ground. However, after only five years the amount of erosion declined.

Infiltration and soil water

Human activity has a great impact on infiltration and soil water. Land-use changes are important. Urbanisation creates an impermeable surface with compacted soil. This reduces infiltration and increases overland runoff and flood peaks (Figure 1.25).

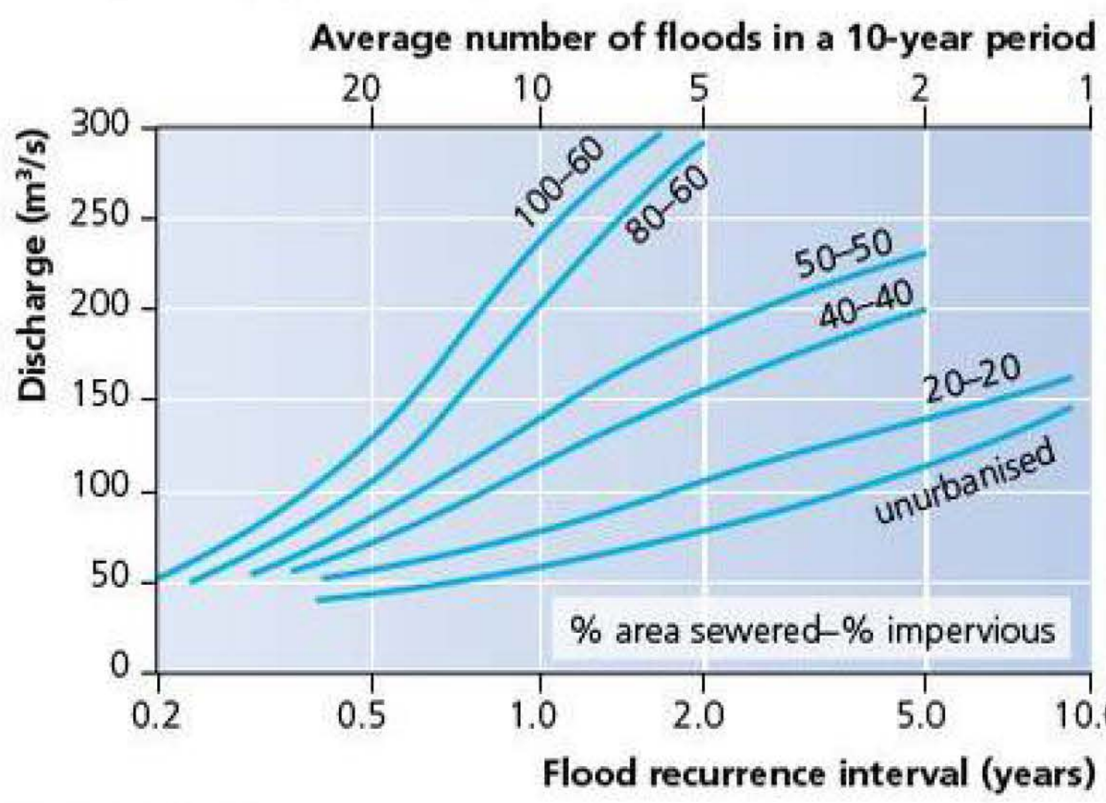


Figure 1.25 Flood frequency and urbanisation

Infiltration is up to five times greater under forest compared with grassland. This is because the forest trees channel water down their roots and stems. With deforestation there is reduced interception, increased soil compaction and more overland flow. Land-use practices are also important. Grazing leads to a decline in infiltration due to compaction and ponding of the soil. By contrast, ploughing increases infiltration because it loosens soils.

Waterlogging and salinisation are common if there is poor drainage. When the water table is close to the surface, evaporation of water leaves salts behind and may form an impermeable crust. Human activity also has an increasing impact on surface storage. There is increased surface storage due to the building of large-scale dams. These dams are being built in increasing numbers, and they are also larger in terms of general size and volume. This leads to:

- increased storage of water
- decreased flood peaks
- low flows in rivers
- decreased sediment yields (clear-water erosion)
- increased losses due to evaporation and seepage, leading to changes in temperature and salinity of the water
- decreased flooding of the land
- triggering of earthquakes
- salinisation, for example in the Indus Valley in Pakistan, 1.9 million hectares are severely saline and up to 0.4 million hectares are lost per annum to salinity
- large dams can cause local changes in climate.

In other areas there is a decline in the surface storage, for example in urban areas water is channelled away very rapidly over impermeable surfaces into drains and gutters.

Section 1.4 Activities

Study Figure 1.25. Describe and explain the changes in flood frequency and flood magnitude that occur as urbanisation increases.

Abstraction

Water availability problems occur when the demand for water exceeds the amount available during a certain period. This happens in areas with low rainfall and high population density, and in areas where there is intensive agricultural or industrial activity. Over-abstraction may lead to the drying up of rivers, falling water tables and saltwater intrusion in coastal areas.

In many parts of Europe, groundwater is the main source of fresh water. However, in many places water is being taken from the ground faster than it is being replenished.

Saline intrusion is widespread along the Mediterranean coastlines of Italy, Spain and Turkey (Figure 1.26), where the demands of tourist resorts are the major cause of over-abstraction. In Malta, most groundwater can no longer be used for domestic consumption or irrigation because it has been contaminated by saline intrusion. Consequently, Malta now has to use desalinated water. Intrusion of saline water due to excessive extraction of water is also a problem in northern countries, notably Denmark.

Irrigation is the main cause of groundwater overexploitation in agricultural areas. In Italy, overexploitation of the Po River in the region of the Milan aquifer has led to a 25 metre decrease in groundwater levels over the last 80 years.

Changing groundwater

Human activity has seriously reduced the long-term viability of irrigated agriculture in the High Plains of Texas. Before irrigation development started in the 1930s, the High Plains groundwater system was stable, in a state of dynamic equilibrium with long-term recharge equal to long-term discharge. However, groundwater is now being used at a rapid rate to supply centre-pivot irrigation schemes. In under 50 years, the water level has declined by 30–50 metres in a large area to the north of Lubbock, Texas. The aquifer has narrowed by more than 50 per cent

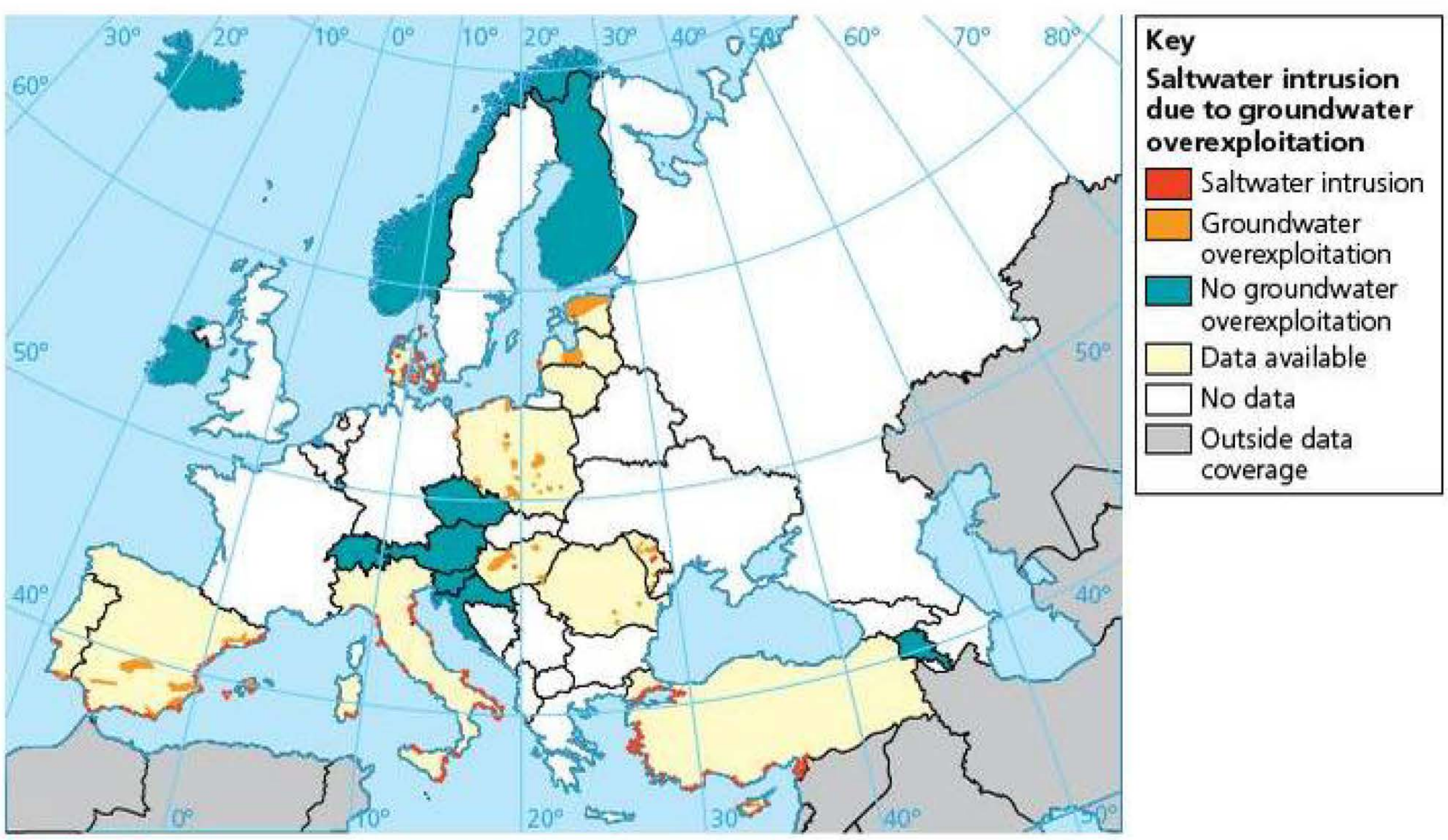


Figure 1.26 Groundwater abstraction and saline intrusion in Western Europe

in large parts of certain counties, and the area irrigated by each well is contracting as well as yields falling.

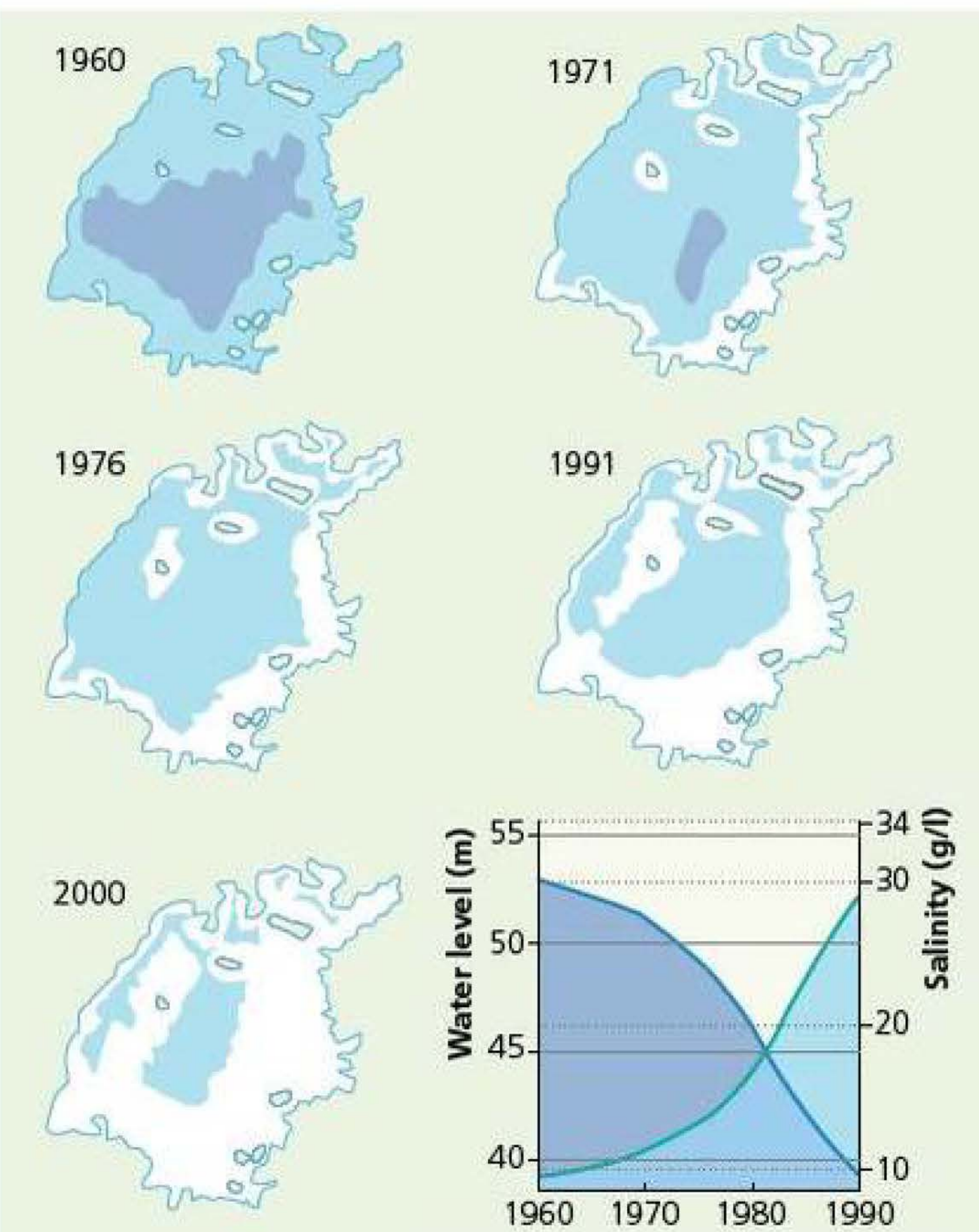
By contrast, in some industrial areas, recent reductions in industrial activity have led to less groundwater being taken out of the ground. As a result, groundwater levels in such areas have begun to rise, adding to the problem caused by leakage from ancient, deteriorating pipe and sewerage systems. Such a rise has numerous implications, including:

- increase in spring and river flows
- re-emergence of flow from 'dry springs'
- surface water flooding
- pollution of surface waters and the spread of underground pollution
- flooding of basements
- increased leakage into tunnels
- reduction in stability of slopes and retaining walls
- reduction in bearing capacity of foundations and piles
- swelling of clays as they absorb water
- chemical attack on building foundations.

There are various methods of recharging groundwater resources, provided that sufficient surface water is available. Where the materials containing the aquifer are permeable (as in some alluvial fans, coastal sand dunes or glacial deposits), water-spreading (a form of infiltration and seepage) is used. By contrast, in sediments with impermeable layers, such water-spreading techniques are not effective, and the appropriate method may then be to pump water into deep pits or into wells. This method is used extensively on the heavily settled coastal plain of Israel, both to replenish the groundwater reservoirs when surplus irrigation water is available, and in an attempt to diminish the problems associated with saltwater intrusions from the Mediterranean.

Case Study: Changing hydrology of the Aral Sea

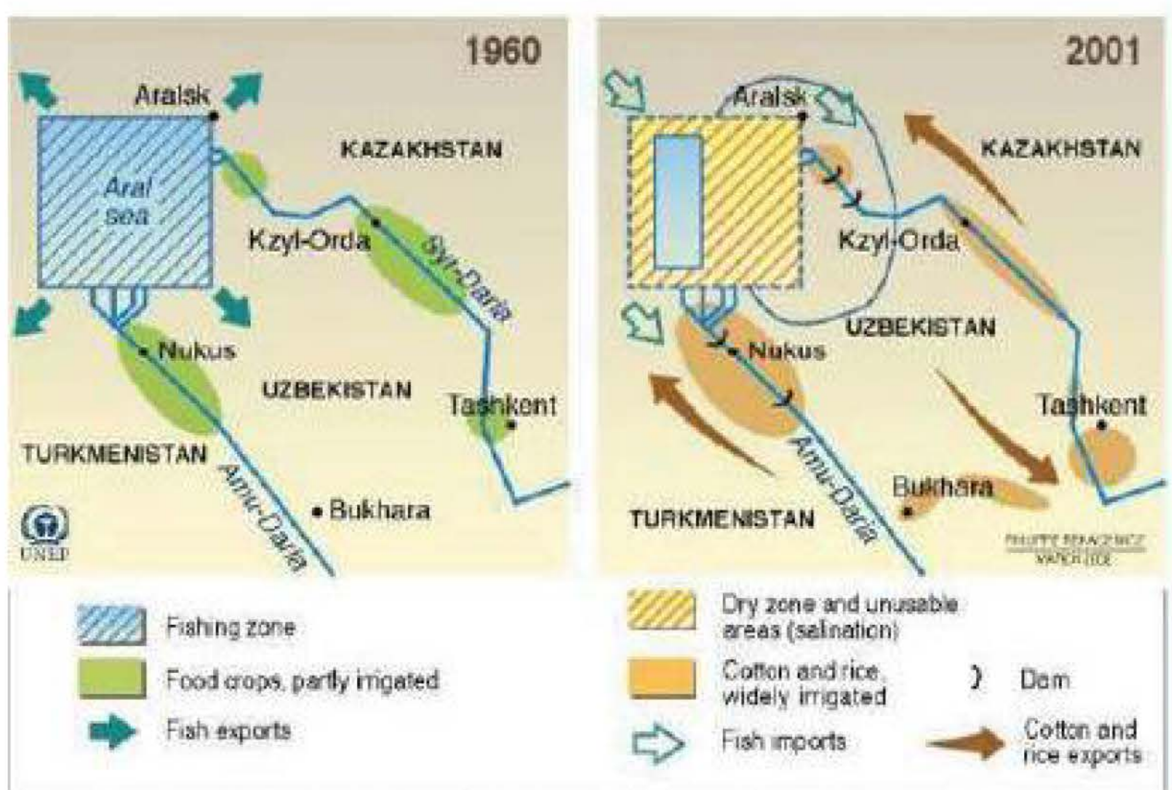
The Aral Sea began shrinking in the 1960s when Soviet irrigation schemes took water from the Syr Darya and the Amu Darya rivers. This greatly reduced the amount of water reaching the Aral Sea. By 1994, the shorelines had fallen by 16 metres, the surface area had declined by 50 per cent and the volume had been reduced by 75 per cent (Figure 1.27). By contrast, salinity levels had increased by 300 per cent.



Source: *Advanced Geography: Concepts & Cases* by P. Guinness & G. Nagle (Hodder Education, 1999), p.251

Figure 1.27 The changing hydrology of the Aral Sea

Increased salinity levels killed off the fishing industry. Moreover, ports such as Muynak are now tens of kilometres from the shore. Salt from the dry seabed has reduced soil fertility and frequent dust storms are ruining the region's cotton production. Drinking water has been polluted by pesticides and fertilisers and the air has been affected by dust and salt. There has been a noticeable rise in respiratory and stomach disorders and the region has one of the highest infant mortality rates in the former Soviet Union.



Source: Philippe Rekacewicz, *An Assassinated Sea*, in Histoire-Géographie, initiation économique, page 333, Classe de Troisième, Hatier, Paris, 1993 (data updated in 2002); *L'état du Monde*, 1992 and 2001 editions, La Découverte, Paris

Source: quoted at www.columbia.edu/~tmt2120/impacts%20to%20life%20in%20the%20region.htm

Figure 1.28 The economic impacts of the shrinking sea

Section 1.4 Activities

Study Figures 1.27 and 1.28.

1 Why do you think the Former Soviet Union (FSU) embarked on such a programme of large-scale irrigation? Use an atlas to produce detailed information.
2 Why have salinity levels increased so much?
3 What problems does the shrinking of the Aral Sea cause for towns such as Aralsk and Muynak?
4 What is the likely effect of the irrigation scheme on the two rivers in terms of velocity, erosion, sediment transport and deposition?

Water storage – dams

The number of large dams (more than 15 metres high) that are being built is increasing rapidly and is reaching a level of almost two completions every day (Figure 1.29).

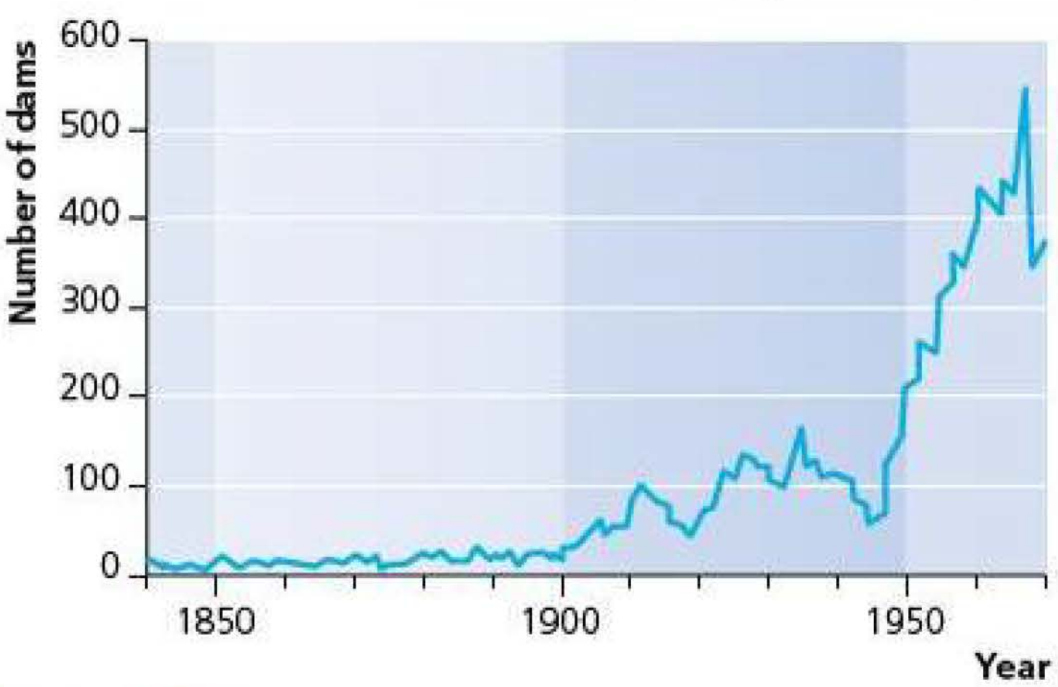


Figure 1.29 The trend in building large dams

The advantages of dams are numerous, as the following examples from the Aswan High Dam on the River Nile, Egypt, show:

- **flood and drought control** – dams allow good crops in dry years as, for example, in Egypt in 1972 and 1973
- **irrigation** – 60 per cent of water from the Aswan Dam is used for irrigation and up to 4000 km of the desert are irrigated
- **hydro-electric power** – this accounts for 7000 million kW hours each year
- **improved navigation**
- **recreation and tourism**.

It is estimated that the value of the Aswan High Dam is about $500 million to the Egyptian economy each year.

On the other hand, there are numerous disadvantages. For example:

- **water losses** – the dam provides less than half the amount of water expected
- **salinisation** – crop yields have been reduced on up to one-third of the area irrigated by water from the Aswan Dam, due to salinisation
- **groundwater changes** – seepage leads to increased groundwater levels and may cause secondary salinisation
- **displacement of population** – up to 100 000 Nubian people have been removed from their ancestral homes
- **drowning of archaeological sites** – the tombs of Ramases II and Nefertari at Abu Simbel had to be removed to safer locations – however, the increase in the humidity of the area has led to an increase in the weathering of ancient monuments
- **seismic stress** – the earthquake of November 1981 is believed to have been caused by the Aswan Dam; as water levels in the Dam increase so too does seismic activity
- **deposition within the lake** – infilling is taking place at about 100 million tonnes each year
- **channel erosion (clear-water erosion) on the channel bed** – lowering the channel by 25 mm over 18 years, a modest amount
- **erosion of the Nile delta** – this is taking place at a rate of about 2.5 cm each year
- **loss of nutrients** – it is estimated that it costs $100 million to buy commercial fertilisers to make up for the lack of nutrients each year
- **decreased fish catches** – sardine yields are down 95 per cent and 3000 jobs in Egyptian fisheries have been lost
- **diseases have spread** – such as schistosomiasis (bilharzia).

Figure 1.30 Paphos dam, Cyprus

Section 1.4 Activities

1 Study Figure 1.29. Describe the pattern shown and suggest reasons to explain the trend.
2 Evaluate the effectiveness of large dams.

Flood risk

Floods are one of the most common of all environmental hazards. This is because so many people live in fertile river valleys and in low-lying coastal areas. For much of the time, rivers act as a resource. However, extremes of too much water – or too little – can be considered a hazard (Figure 1.31).

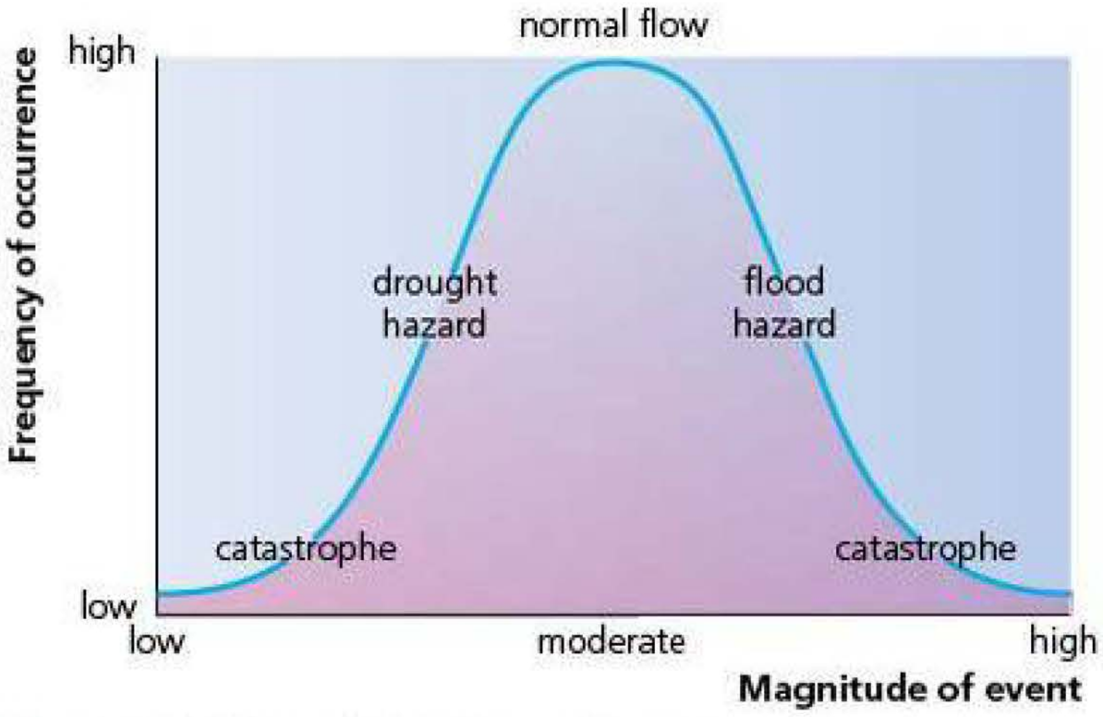


Figure 1.31 River discharge and frequency

In addition, extreme events occur infrequently. Many urban areas are designed to cope with floods that occur on a regular basis, perhaps annually or once in a decade. Most are ill-equipped to deal with the low-frequency/high-magnitude event that may occur once every 100 years or every 500 years (Figure 1.32). The recurrence interval refers to the regularity of a flood of a given size. Small floods may be expected to occur regularly. Larger floods occur less often. A 100-year flood is the flood that is expected to occur, *on average*, once every 100 years. Increasingly, larger floods are less common, but more damaging.

The nature and scale of flooding varies greatly. For example, less than 2 per cent of the population of England and Wales and in Australia live in areas exposed to flooding, compared with 10 per cent of the US population. The worst problems occur in Asia where floods damage about 4 million hectares of land each year and affect the lives of over 17 million people. Worst of all is China, where over 5 million people have been killed in floods since 1860.

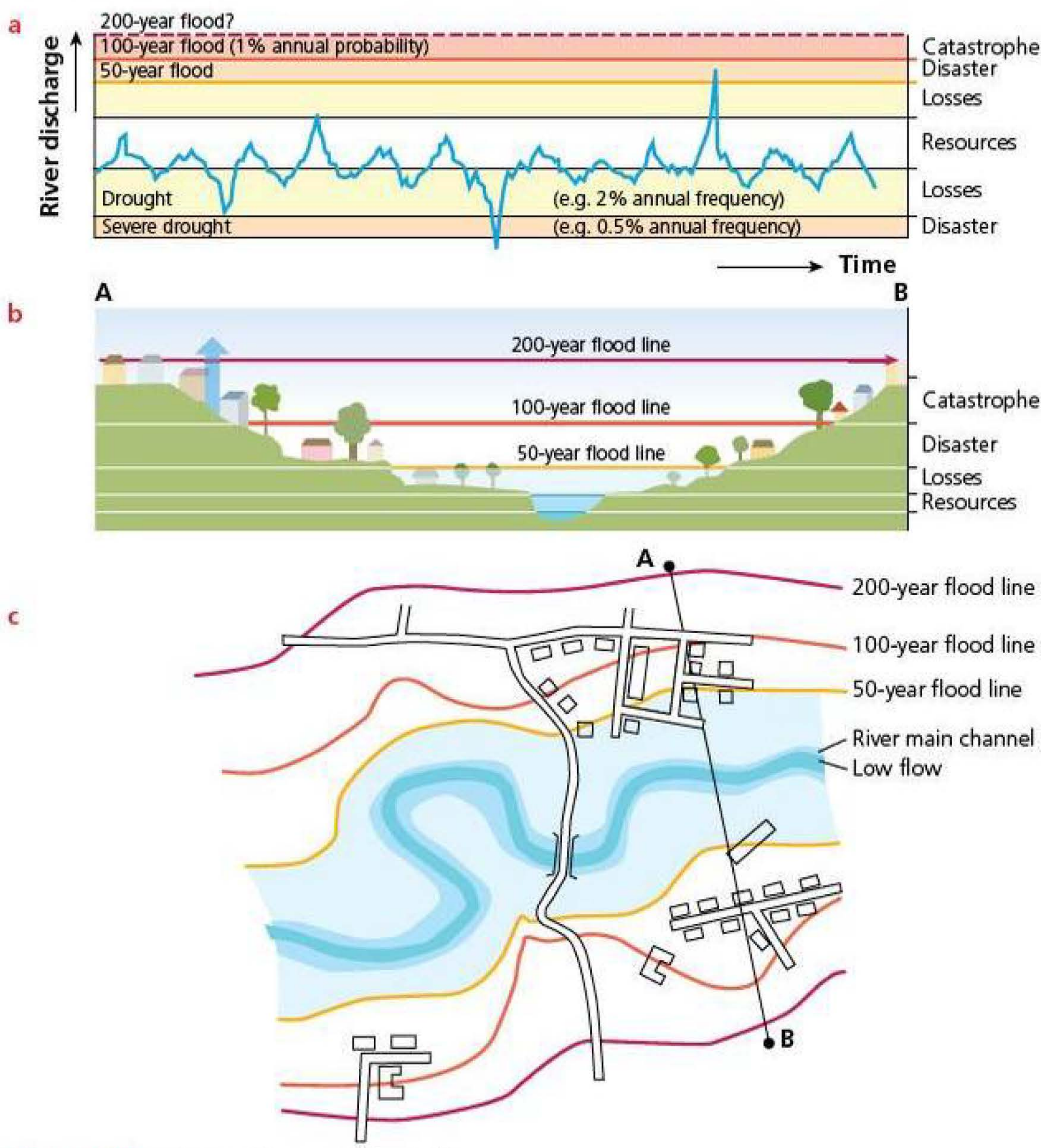


Figure 1.32 Urban land use and flood risk

Some environments are more at risk than others. The most vulnerable include the following:

- Low-lying parts of active floodplains and river estuaries. For example, in Bangladesh 110million people living on the floodplain of the Ganges and Brahmaputra rivers are relatively unprotected. Floods caused by the monsoon regularly cover 20–30per cent of the flat delta. In very high floods, up to half of the country may be flooded. In 1988, 46per cent of the land was flooded and more than 1500 people were killed.
- Small basins subject to flash floods. These are especially common in arid and semi-arid areas. In tropical areas, some 90per cent of lives lost through drowning are the result of intense rainfall on steep slopes.
- Areas below unsafe dams. In the USA, there are about 30000 large dams and 2000 communities are at risk from dams. Following the 2008 Sichuan earthquake in China, some 35 quake dams were created by landslides blocking river routes. These were eventually made safe by engineers and the Chinese military.
- Low-lying inland shorelines such as along the Great Lakes and the Great Salt Lake in the USA.

In most high-income countries (HICs), the number of deaths from floods is declining, while in contrast the economic cost of flood damage has been increasing. In low-income countries (LICs), on the other hand, the death rate due to flooding is much greater, although the economic cost is not as great. It is likely that the hazard in LICs will increase over time as more people migrate and settle in low-lying areas and river basins. Often newer migrants are forced into the more hazardous zones.

Since the Second World War (1939–45), there has been a change in the understanding of the flood hazard, in the attitude towards floods and in the policy towards reducing the flood hazard. The response to hazards has moved away from physical control (engineering structures) towards reducing vulnerability through non-structural approaches.

Causes of flooding

A flood is a high flow of water that overtops the bank of a river. The main causes of floods are climatic forces, whereas the flood-intensifying conditions tend to be drainage basin specific (Figure 1.33). Most floods in the UK, for example, are associated with deep depressions (low pressure systems) that are both long-lasting and cover a wide area. By contrast, in India up to 70per cent of the annual rainfall occurs in three months during the summer monsoon. In Alpine and Arctic areas, melting snow is responsible for widespread flooding.

Flood-intensifying conditions cover a range of factors, which alter the drainage basin response to a given storm (Figure 1.34). The factors that influence the storm hydrograph determine the response of the basin to the storm. These factors include topography, vegetation, soil type, rock type and characteristics of the drainage basin.

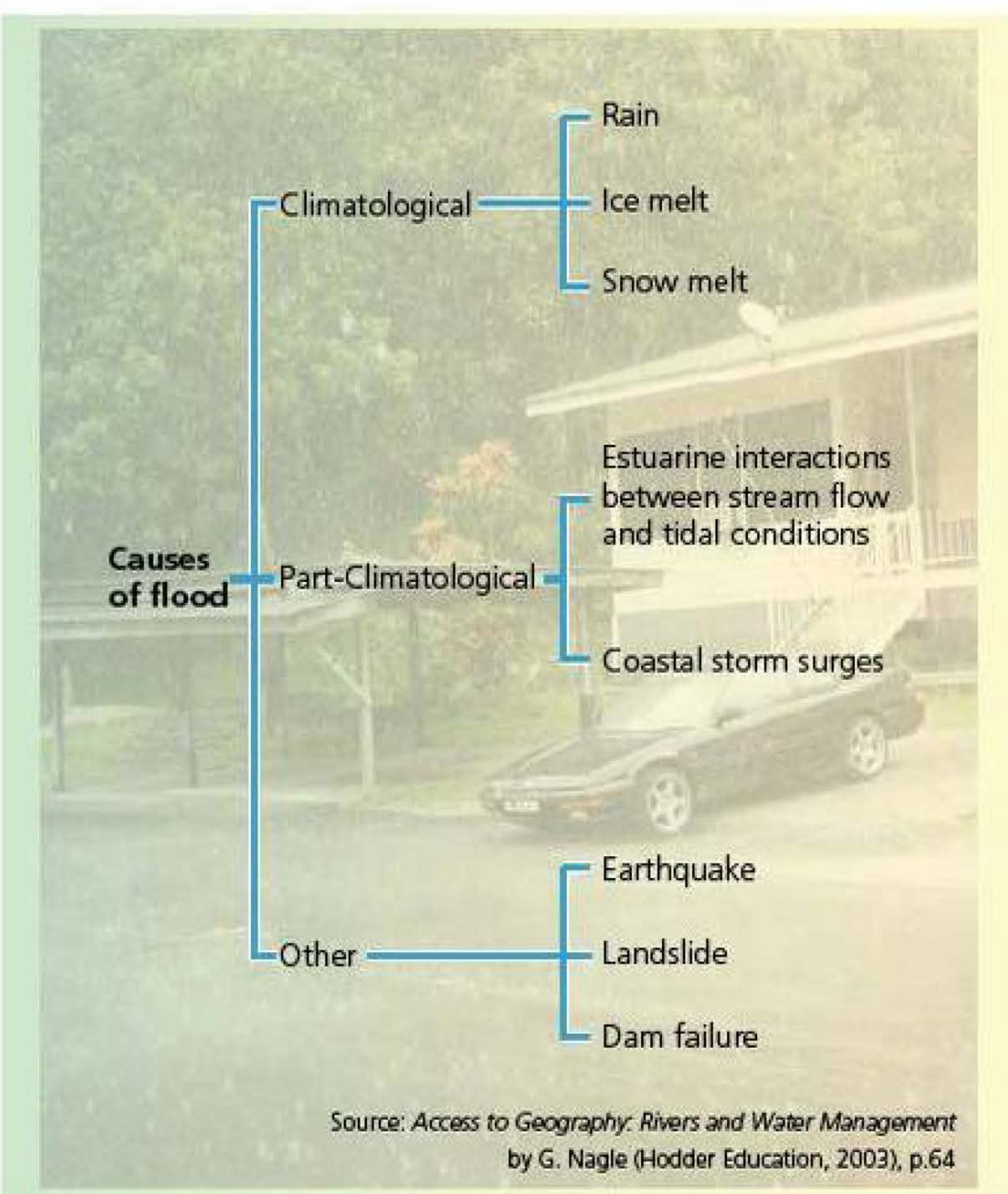


Figure 1.33 The causes of floods

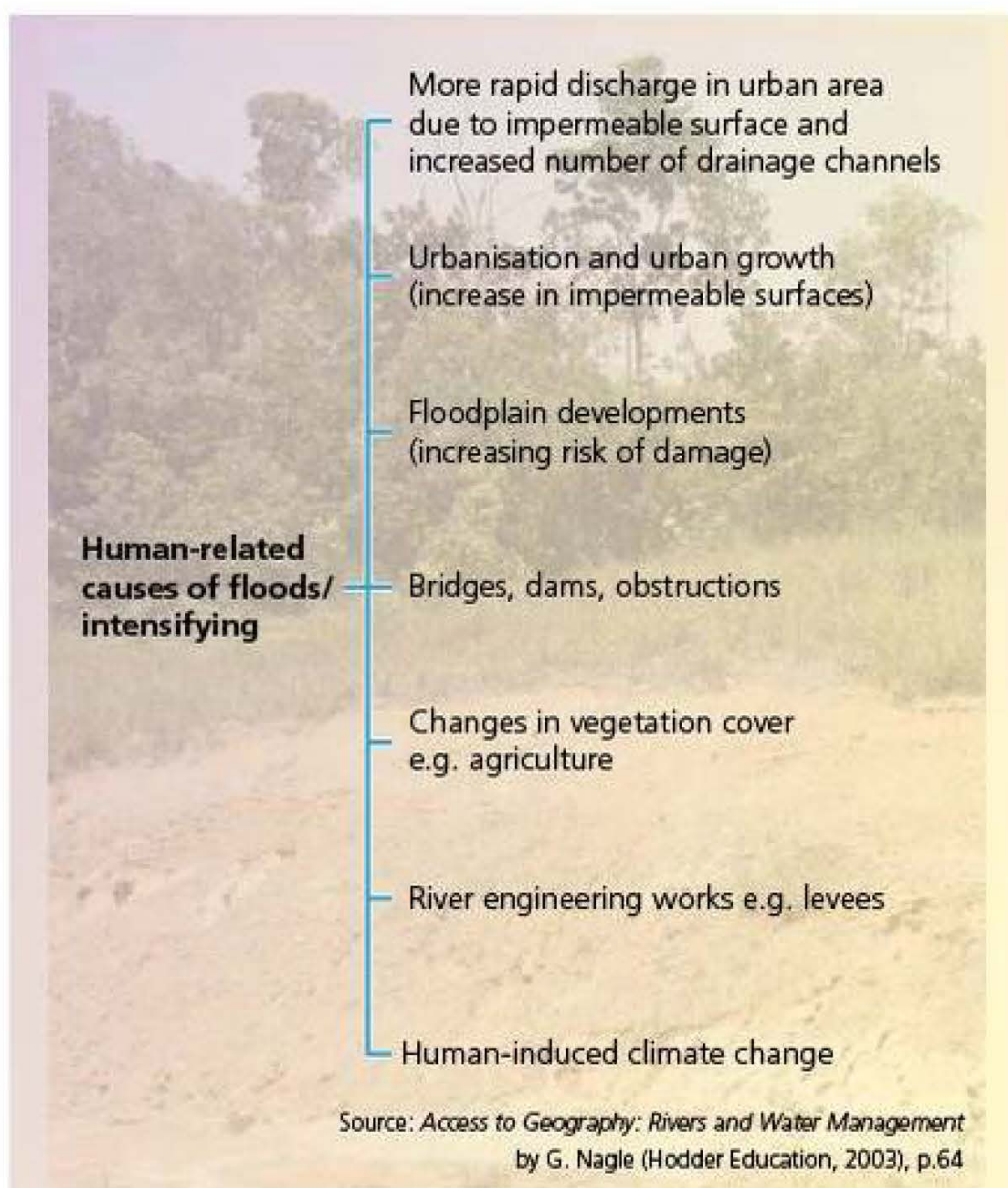


Figure 1.34 Flood-intensifying conditions

The potential for damage by floodwaters increases exponentially with velocity. The physical stresses on buildings are increased even more when rough, rapidly flowing water contains debris such as rocks, sediment and trees.

Other conditions that intensify floods include changes in land use. Urbanisation, for example, increases the magnitude and frequency of floods in at least three ways:

- creation of highly impermeable surfaces, such as roads, roofs, pavements
- smooth surfaces served with a dense network of drains, gutters and underground sewers increase drainage density
- natural river channels are often constricted by bridge supports or riverside facilities, reducing their carrying capacity.

Deforestation is also a cause of increased flood runoff and a decrease in channel capacity. This occurs due to an increase in deposition within the channel. However, the evidence is not always conclusive. In the Himalayas, for example, changes in flooding and increased deposition of silt in parts of the lower Ganges–Brahmaputra are due to the combination of high monsoon rains, steep slopes and the seismically unstable terrain. These ensure that runoff is rapid and sedimentation is high, irrespective of the vegetation cover.

The prevention and amelioration of floods

Forecasting and warning

During the 1980s and 1990s, flood forecasting and warning had become more accurate and these are now among the most widely used measures to reduce the problems caused by flooding. Despite advances in weather satellites and the use of radar for forecasting, over 50 per cent of all unprotected dwellings in England and Wales have less than six hours of flood warning time. In most LICs there is much less effective flood forecasting. An exception is Bangladesh. Most floods in Bangladesh originate in the Himalayas, so authorities have about 72 hours' 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, and better and longer forecasts of rainfall
- better gauging of rivers, collection of meteorological information and mapping of channels
- better and 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 organisations 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.

Loss sharing

Economic growth and population movements throughout the twentieth century have caused many floodplains to be built on. However, for people to live on floodplains there needs to be flood protection. This can take many forms, such as loss-sharing adjustments and event modifications.

Loss-sharing adjustments include disaster aid and insurance. Disaster aid refers to any aid, such as money, equipment, staff and technical assistance, that is given to a community following a disaster. In HICs, 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.

Hard engineering

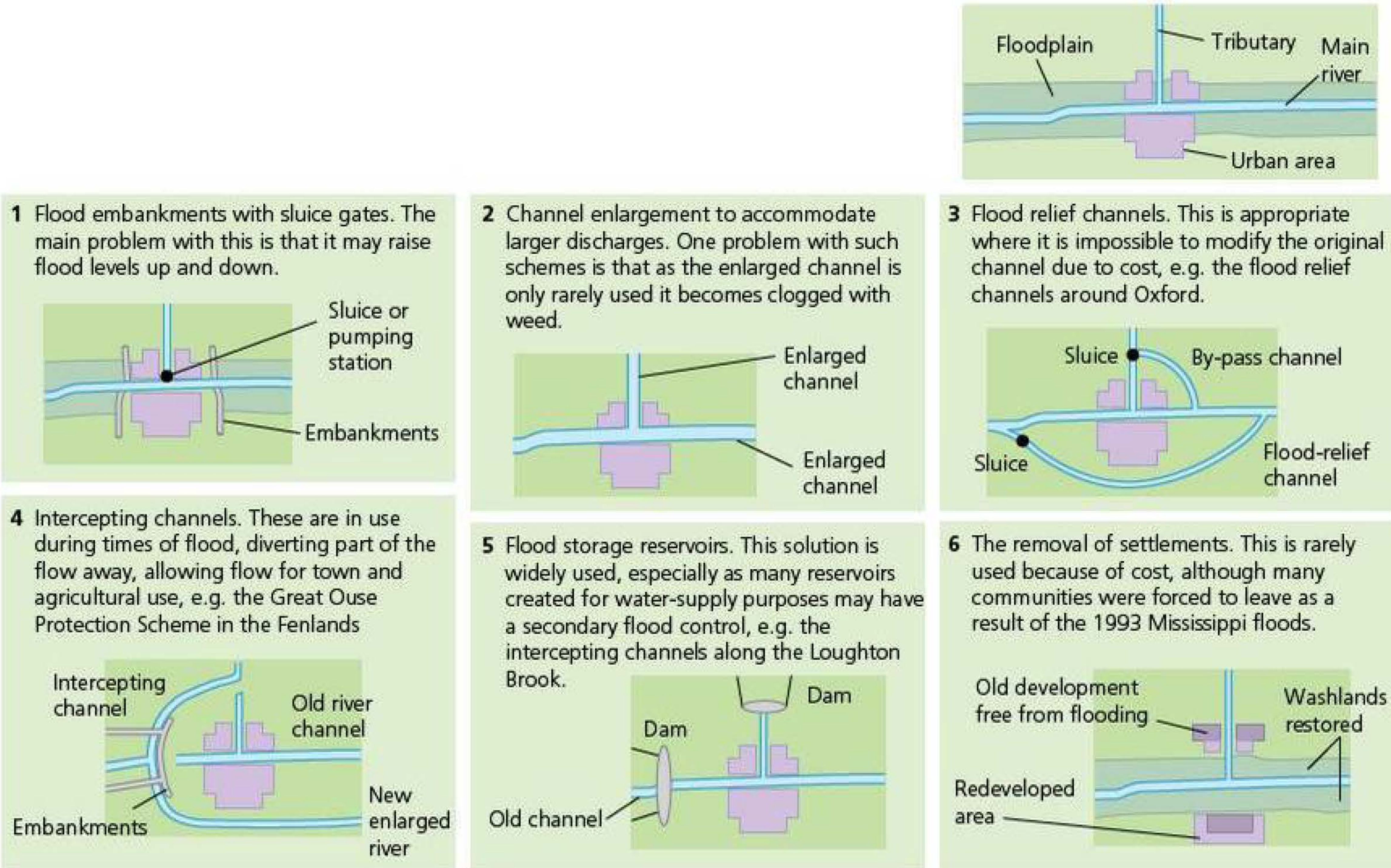
Traditionally, floods have been managed by methods of 'hard engineering'. This largely means dams, levees, wing dykes and straightened channels that are wider and deeper than the ones they replace. In some cases, new diversion spillways (flood-relief channels and intercepting channels) may be built (Figure 1.35). Although hard engineering may reduce floods in some locations, it may cause unexpected effects elsewhere in the drainage basin, for example decreased water quality, increased sedimentation, bed and bank erosion and loss of habitats.

Levees are the most common form of river engineering. They can also be used to divert and restrict water to low-value land on the floodplain. Over 4500 kilometres of the Mississippi River have levees. Channel improvements such as channel enlargement will increase the carrying capacity of the river. Reservoirs store excess rainwater in the upper drainage basin. However, this may only be appropriate in small drainage networks. It has been estimated that some 66 billion m^3 of storage is needed to make any significant impact on major floods in Bangladesh!

Hazard-resistant design

Flood-proofing includes any adjustments to buildings and their contents that help reduce losses. Some are temporary, such as:

- blocking up entrances
- sealing doors and windows
- removal of damageable goods to higher levels
- use of sandbags.



Source: *Access to Geography: Rivers and Water Management* by G. Nagle (Hodder Education, 2003), p.65

Figure 1.35 Channel diversions

Figure 1.36 Flood-relief channel, Zermatt, Switzerland

By contrast, long-term measures include moving the living spaces above the likely level of the floodplain. This normally means building above the flood level, but could also include building homes on stilts.

Land-use zoning

Most land-use zoning and land-use planning has been introduced since the Second World War. In the USA, land-use management has been effective in protecting new housing developments from 1 in 100-year floods (that is, the size of flood that we would expect to occur once every century).

One example where partial urban relocation has occurred is at Soldier's Grove on the Kickapoo River in south-western Wisconsin, USA. The town experienced a series of floods in the 1970s, and the Army Corps of Engineers proposed building two levees and moving part of the urban area. Following floods in 1978, they decided that relocation of the entire business district would be better than just flood-damage reduction. Although levees would have protected the village from most floods, they would not have provided other opportunities. Relocation allowed energy conservation and an increase in commercial activity in the area.

Soft engineering

Soft engineering generally refers to working with natural processes and features rather than attempts to control them. They include the management of whole catchments (catchment management plans), wetland conservation and river restoration.

Event modification adjustments include environmental control and hazard-resistant design. Physical control of floods depends on two measures: flood abatement and flood diversion. **Flood abatement** involves decreasing the amount of runoff, 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 by contour ploughing or terracing to reduce runoff
- comprehensive protection of vegetation from wildfires, overgrazing and clear-cutting 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 refers to the practice of allowing certain areas, such as wetlands and floodplains, to be flooded to a greater extent. Natural flooding may be increased through the use of flood-relief channels (diversion spillways) to direct more water into these areas during times of flood.

River restoration

Case Study: Costs and benefits of the Kissimmee River restoration scheme

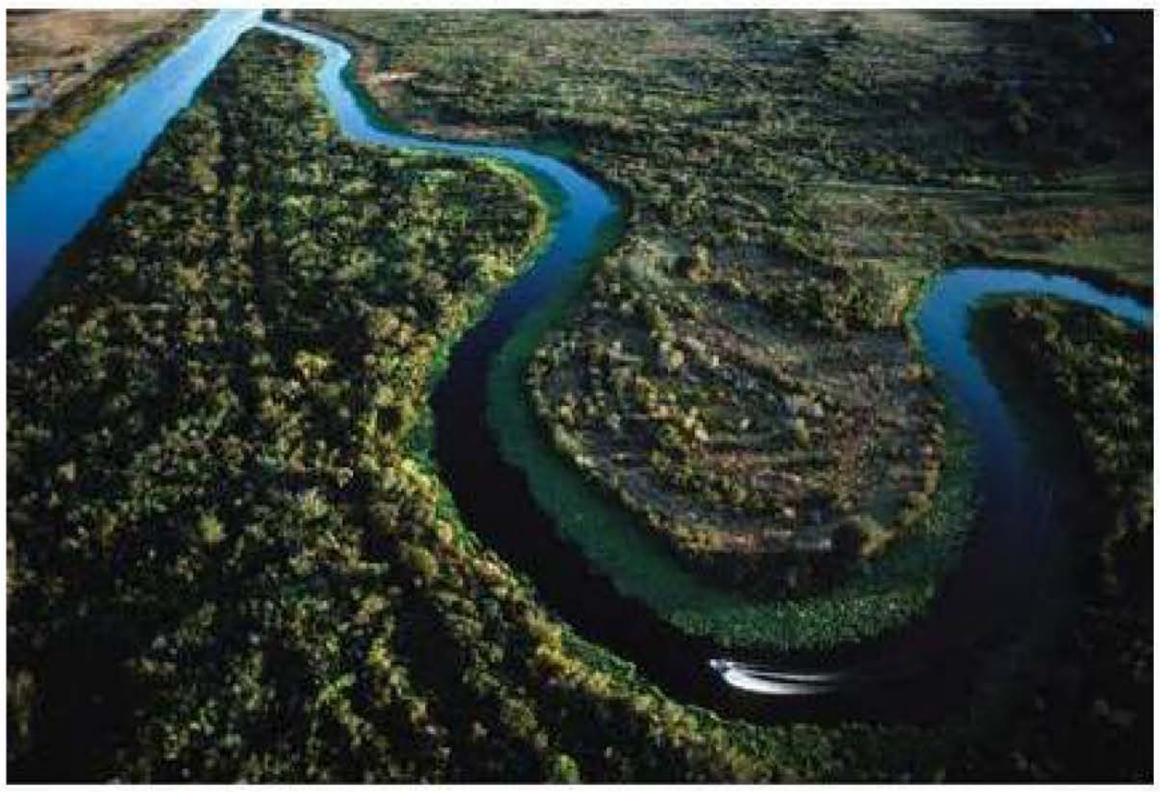


Figure 1.37 Part of the restored Kissimmee Restoration Scheme, Florida, USA

The 165 kilometre Kissimmee River once meandered through central Florida. Its floodplain, reaching up to 5 kilometres wide, was inundated for long periods by heavy seasonal rains. Wetland plants, wading birds and fish thrived there, but the frequent, prolonged flooding caused a severe impact on people.

Between 1962 and 1971, engineering changes were made to deepen, straighten and widen the river, which was transformed into a 90 kilometre, 10 metre-deep drainage canal. The river was channelised to provide an outlet canal for draining floodwaters from the developing upper Kissimmee lakes basin, and to provide flood protection for land adjacent to the river.

Impacts of channelisation

The channelisation of the Kissimee River had several unintended impacts:

- the loss of 2000 to 14 000 hectares of wetlands
- a 90 per cent reduction in wading bird and waterfowl usage
- a continuing long-term decline in game fish populations.

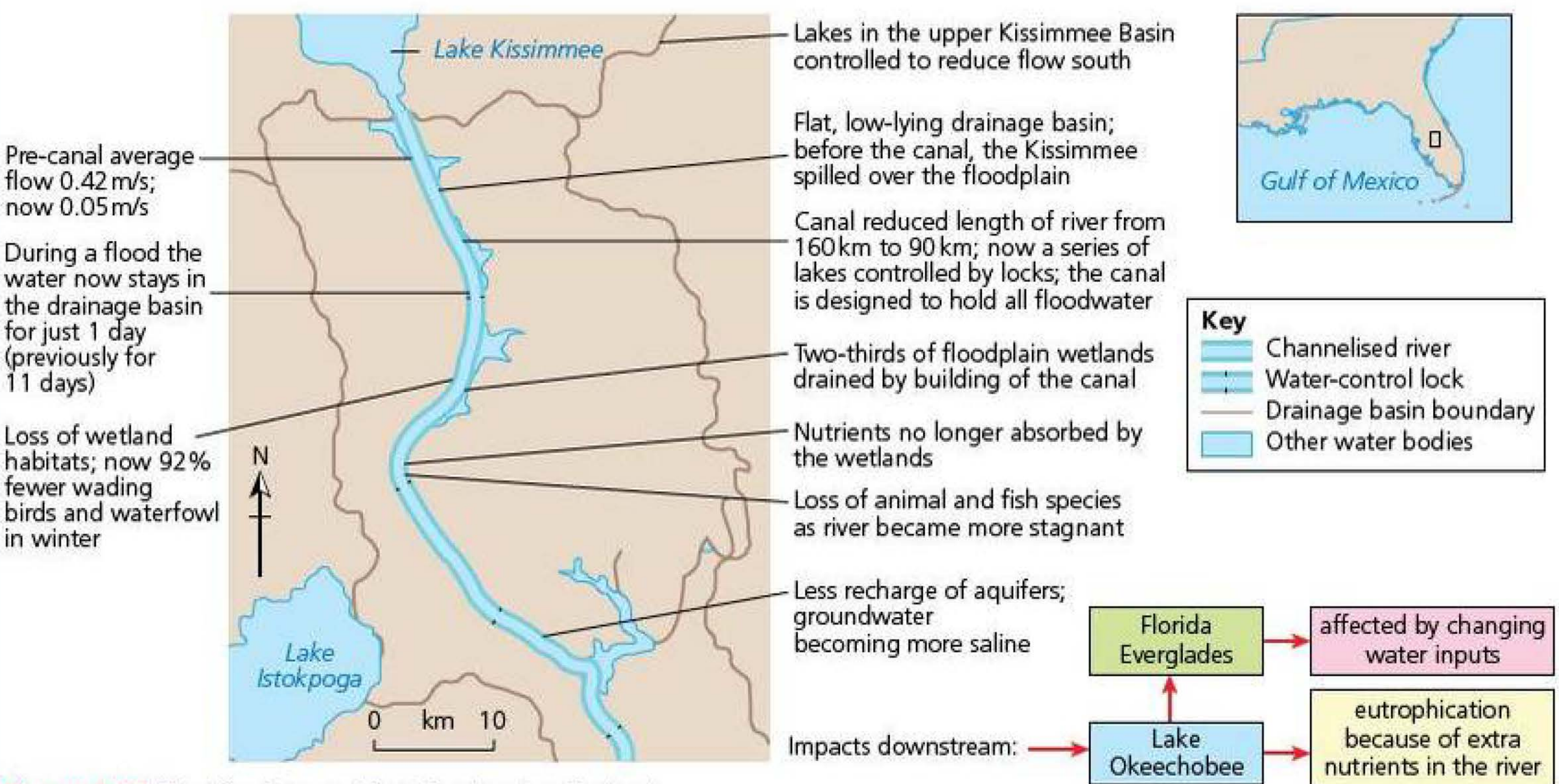


Figure 1.38 The Kissimmee River Restoration Project

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.

The project restored over 100 km^2 of river and associated floodplain wetlands. It was started in 1999 and completed in 2015. It benefits over 320 fish and wildlife species, including the endangered bald eagle, wood stork and snail kite. It has created over 11 000 hectares of wetlands. Seasonal rains and flows now inundate the floodplain in the restored areas.

Restoration of the river and its associated natural resources required **dechannelisation**. This entailed backfilling approximately half of the flood-control channel and re-establishing the flow of water through the natural river channel. In residential areas, the flood-control channel will remain in place.

The costs of restoration

It is estimated that the project cost over $400 million (initial channelisation cost $20 million), a bill being shared by the state of Florida and the federal government.

Restoration of the river's floodplain could result in higher losses of water due to evapotranspiration during wet periods. In extremely dry spells, navigation may be impeded in some sections of the restored river. It is, however, expected that navigable depths will be maintained at least 90 per cent of the time.

Benefits of restoration

- Higher water levels should ultimately support a natural river ecosystem again.
- Re-establishment of floodplain wetlands and the associated nutrient filtration function is expected to result in decreased nutrient loads to Lake Okeechobee.
- Populations of key avian 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.

Section 1.4 Activities

1 Outline the natural and human causes of floods.
2 Compare and contrast methods of flood management.
3 To what extent can flood frequency and magnitude be predicted?
4 Outline the disadvantages of channelisation as shown in Figure 1.36.
5 Outline the benefits of wetlands.
6 What is meant by *river restoration*? What are the benefits of river restoration?

Case Study: Flooding in Bangladesh

Figure 1.39 Satellite image of the 1998 floods

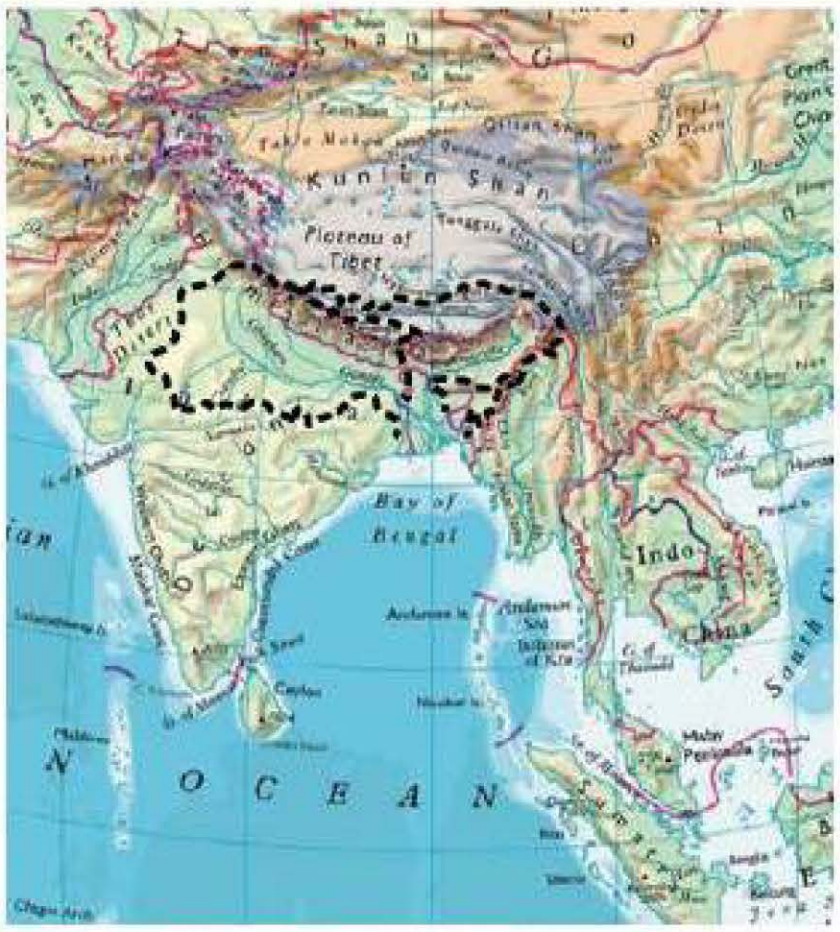
Bangladesh is a small, flat and low-lying country: 60 per cent is less than 6 metres above sea level. For this reason, tides affect one-third of land area. Banglasdesh is located where the Ganga, Brahmaputra (called *Jamuna* in Bangladesh) and Meghna rivers meet. The average gradient of the rivers is 6 cm/km. The country drains an area 12 times its own size. It has a high frequency of floods and cyclones.

Table 1.5 Bangladesh factfile

Area	143 998 km^2
Population	166 million (2014)
Age structure	51% under 25 years of age
Population density	1161/km^2
Annual growth rate	0.6%
Literacy	58.8%
PPP	$3400
Life expectancy	70.65 years
Employment	Agriculture: 47% Industry: 13% Services: 40%

Source: CIA World Factbook

Bangladesh has a high population density, low human development index (HDI) and a majority of the population is dependent on agriculture. An area of about 150 000 km^2 is shared by 123 million people.



Source: Philip's Interactive Modern School Atlas by G. Nagle (Hodder Education, 2006) © Philip's

Figure 1.40 The Ganges drainage basin

Several regions affect conditions within Bangladesh:

- **high plateau of Tibet** – the source of the Brahmaputra, where most of the river flow derives from snow melt and glacier melt
- **Himalayas** – source of the Ganga and many of the springs that feed into the Brahmaputra
- **Ganga Plain** – one of the largest lowland areas in the world, and a region of intense cultivation
- **Meghalaya Hills** – located between the floodplain of north-east Bangladesh and the Indian lowlands of Assam; rise to a height of 2500 m and act as a barrier to the monsoon winds from the Indian Ocean; Cherrapungee has an annual rainfall of over 11 000 mm.

Table 1.6 Watershed characteristics of the Ganga and the Brahmaputra/Meghna (Br/M) rivers and a comparison with the Nile, the Amazon and the Mississippi

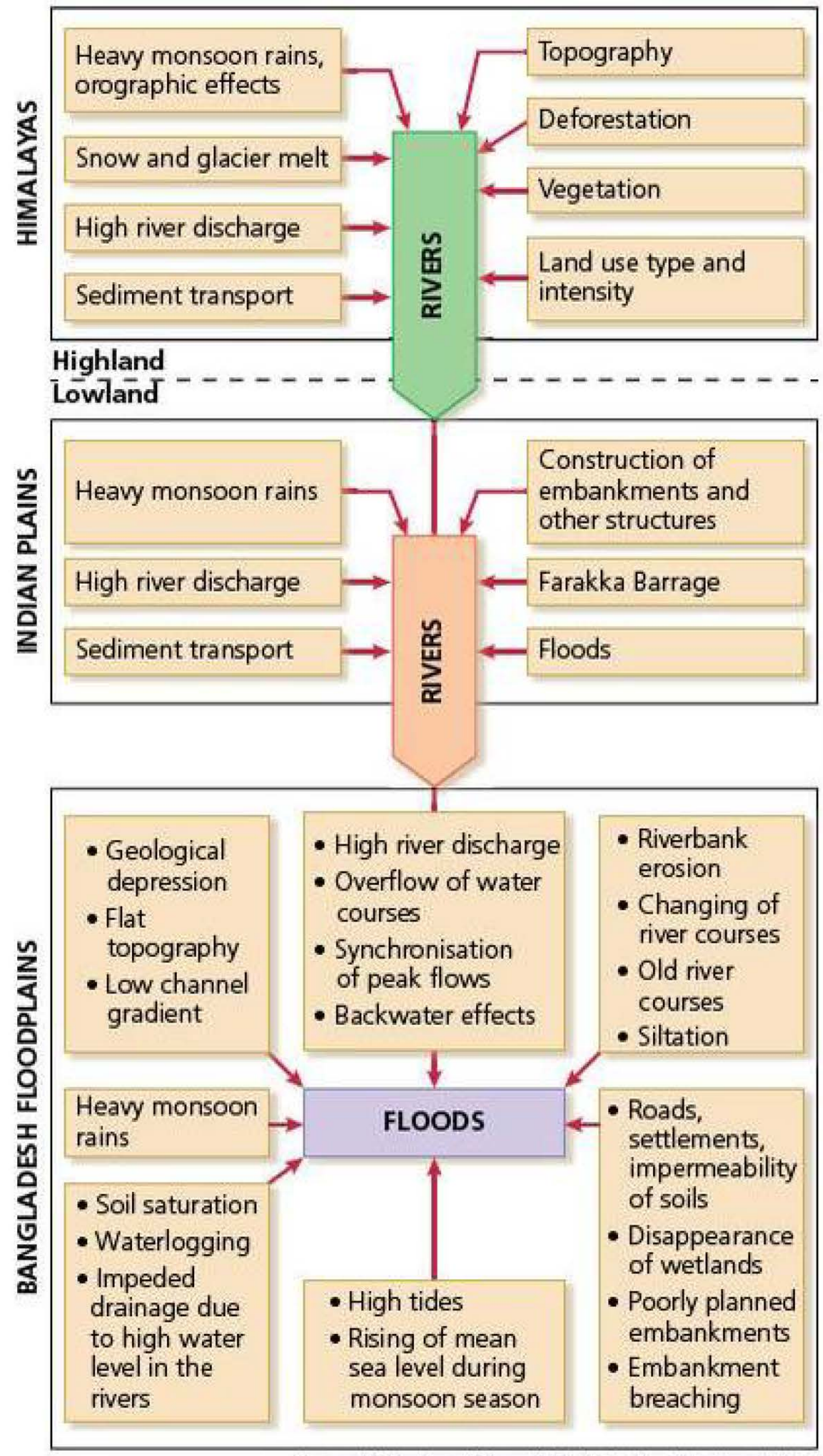
Characteristics	Ganga	Br/M	Nile	Amazon	Mississippi
Basin area (km^2)	1016104	651334	3254555	6144727	3202230
Length (km)	2296	2772	5964	4406	4240
Average annual discharge (m^3/s)	11365	19772	2760	176177	17600
Forest (%)	4	19	2	73	22
Cropland (%)	7	29	10	15	35
Cropland irrigated (%)	15	47	5	0	4
Grassland (%)	7	29	52	8	22
Large dams	6	0	7	2	2091

Source: Hofer, T. and Messerli, B, 2006, Floods in Bangladesh, *United Nations University Press, Table 2.2*

The Ganges and the Brahmaputra are two of the world's largest rivers by catchment size, length, amount of flow, sediment discharge (the Brahmaputra carries 540 million tons of sediment per year, the Ganges 520 million tons) and lateral shifting.

Causes of flooding

There are many causes of flooding in Bangladesh (Figure 1.41), which originate in three areas – the highlands (Himalayas); the Indian Plains of the Ganges and the Brahmaputra; and the floodplains of Bangladesh.



Source: Hofer, T and Messerli, B, 2006, *Floods in Bangladesh*, United Nations University Press

Figure 1.41 The causes of floods in the Ganges

Flooding in Bangladesh alternates between periods of high flood frequency and low flood frequency.

- Floods in the western part of Bangladesh were more intensive in the eighteenth and nineteenth centuries than in the twentieth or twenty-first centuries.
- Massive floods occurred regularly long before human impact on the watershed began; there is no evidence that flood frequency is increasing.
- The variation in the extent of flooding year by year has been increasing since the 1950s.

- There is increasing monsoon rain, particularly in the Brahmaputra–Meghna system.
- There is a worsening impact on the Bangladeshi people, but human influence in the Himalayas is not thought to be increasing flooding in Bangladesh.

Flooding is viewed very differently by rural people and by politicians and engineers. For many rural people, flooding is a short-term necessity for their crops; engineers and politicians see the damage it causes to infrastructure and the economy.

The 1998 floods

These were the longest lasting and most devastating floods in 100 years; 1998 was a La Niña year, in which normal circulatory patterns are intensified. The most-affected areas of Bangladesh included the capital Dhaka and other areas close to the main rivers; 53 of the 64 districts of the country – that is, about 50 per cent – were affected, by up to 3 metres of water for up to 67 days. The flooding on 7 September was probably the worst of the twentieth century.

The main causes were:

- the high peaks on all three main rivers occurring at the same time
- high tides causing the river floods to back up
- a strong monsoon that caused excessive flooding, and obstructions by man-made infrastructure.

Table 1.7 Major impacts of the 1998 floods

Number of people affected	c.30 million
Number of deaths	c.780–1500
Number facing malnutrition	25 million
Rice production loss	2.2 million tons
Damage to cultivated area	1.5 million ha
Loss of livestock sector	$500 million
Roads damaged	15 000 km
Embankments damaged	c.4500 km
Bridges/culverts damaged	>20 000
Villages damaged	30 000
Houses damaged	550 000–900 000

Source: Hofer, T. and Messerli, B, 2006, Floods in Bangladesh, *United Nations University Press, Table 2.2*

Coping with flooding in Bangladesh

- Many houses, and also many roads, are built on raised platforms, above the level of the average flood. People who live on islands mainly use bamboo and reeds for their houses, which can be dismantled in about an hour in an emergency.
- Rural people cultivate different varieties of rice, some of which can grow in floodwaters of 1 metre and grow up to 20 centimetres a day to keep up with the rising water level; jute and sugar cane can also withstand submergence.
- It takes up to three days for floodwaters to rise, giving people some time to prepare, such as raising platforms in their homes so that they can sleep on dry ground.
- Levees can prevent overflow but may cause deposition in the channel, which raises the river bed and reduces the capacity of the river.
- Levees can give a false sense of security – they protect against minor floods but not against major ones.
- The Flood Action Plan 1989–95 led to the development of the Bangladesh Water and Flood Management Strategy Report, which stated that there are three main water-resource development options:
  Minimum intervention – improve forecasting and improve existing flood schemes but do not create new ones
  Selective intervention – protect densely populated areas, key infrastructure and water supplies
  Major intervention – build large-scale engineering works on all main rivers.
- In terms of existing measures, there are currently over 10 000 kilometres of levees and a number of raised flood and cyclone shelters.
- Groynes in rivers protect important townships.
- Non-structural measures include flood forecasting, preparation and relief. The Flood Forecasting Warning Centre issues five-day forecasts during the monsoon season.
- Up to 20 per cent of the population is at risk from lateral erosion, which is more predictable on the Ganga than on the braided Brahmaputra. Many families may be forced to move 10 to 15 times during their lifetime.

Social problems

- **Loss of land**, leading to loss of social status and poverty, which can prevent a family's children from being able to marry.
- **Food shortages**, leading to reliance on relatives and neighbours.

Section 1.4 Activities

1. Study Table 1.6. Outline the main differences in watershed characteristics of the rivers. Suggest how these differences may affect the flood hazard.
2. Study Figure 1.41. Outline the main physical and human causes of flooding in Bangladesh.
3. Describe the main impacts of the 1998 floods in Bangladesh. Why were the impacts so great?
4. Evaluate the opportunities for flood control in Bangladesh.