Opposite: Volunteers try to clear water that is full of discarded plastic bottles and other garbage, blocking the Vacha Dam near the town of Krichim, Bulgaria

4.1 Introduction to water systems

Significant ideas

The hydrological cycle is a system of stores and flows that can be easily disrupted by human activities.

The ocean circulatory system influences global climates by transporting water and energy around the Earth.

Big questions

As you read this section, consider the following big questions:

- What strengths and weaknesses of the systems approach and the use of models have been revealed through this topic?
- To what extent have the solutions emerging from this topic been directed at *preventing* environmental impacts, *limiting* the extent of the environmental impacts, or *restoring* systems in which environmental impacts have already occurred?
- How are the issues addressed in this topic of relevance to sustainability or sustainable development?
- In what ways might the solutions explored in this topic alter your predictions for the state of human societies and the biosphere some decades from now?

Knowledge and understanding

- Solar radiation drives the hydrological cycle.
- Only a small fraction (approximately 2.6 per cent by volume) of the Earth's water storages are fresh water.
- Storages in the hydrological cycle include the atmosphere, organisms, soil, and various water bodies such as oceans, groundwater (aquifers), lakes, rivers, glaciers, and ice caps.
- Flows in the hydrological cycle include evapotranspiration, sublimation, evaporation, condensation, advection (wind-blown movement), precipitation, melting, freezing, flooding, surface run-off, infiltration, percolation and stream-flow/currents.
- Human impacts such as agriculture, deforestation and urbanization have a significant impact on surface run-off and infiltration.
- Ocean circulation systems are driven by differences in temperature and salinity that affect water density. The resulting differences in water density drive the ocean conveyor belt which distributes heat around the world, so affecting climate.

The hydrological cycle

Solar radiation drives the hydrological cycle.

SYSTEMS APPROACH

The global hydrological cycle refers to the movement of water between atmosphere, lithosphere, biosphere, and pedosphere (Figure 4.1). At a global scale, it can be thought of as a closed system with no losses. In contrast, at a local scale, the cycle generally has a single input – *precipitation* (PPT) – and two major losses (outputs) – *evapotranspiration* (EVT) and *run-off*. Exotic rivers are an exception – they bring water into a region from a different climate zone (e.g. the Nile flowing through the Sahara desert brings water from the Ethiopian Highlands).

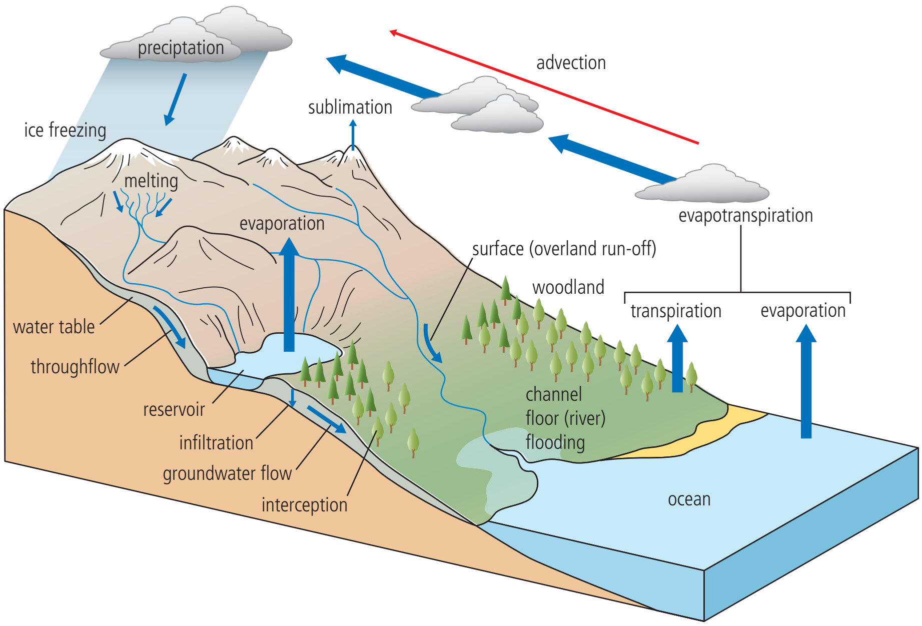

Figure 4.1 The global hydrological cycle

TOK

The global hydrological cycle is complex. To enable our understanding of how the cycle works, scientists use a systems model. This is a simplified structuring of reality which shows just a few parts of the system. Many parts of the cycle cannot be observed. Hence, scientists use the drainage basin hydrological cycle (Figure 4.2). The drainage basin is taken as the unit of study rather than the global system, as it is easier to observe and measure more parts of the cycle. The basin cycle is an open system: the main input is precipitation which is regulated by various means of storage.

Water can be stored at a number of places within the cycle. These stores include organisms, depressions on the Earth's surface, soil moisture, groundwater and water bodies such as rivers and lakes, and bodies of ice such as glaciers and ice caps. The global hydrological cycle also includes stores in the oceans and the atmosphere.

Solar radiation drives the hydrological cycle. This is because the main source of energy available to the Earth is the Sun. In some places, there are important local sources of heat; for example, geothermal heat in Iceland and human-related (anthropogenic) sources in large-scale urban-industrial zones. However, solar heating is the main cause of variations in the hydrological cycle, as well as the main cause of global temperature patterns and global wind patterns.

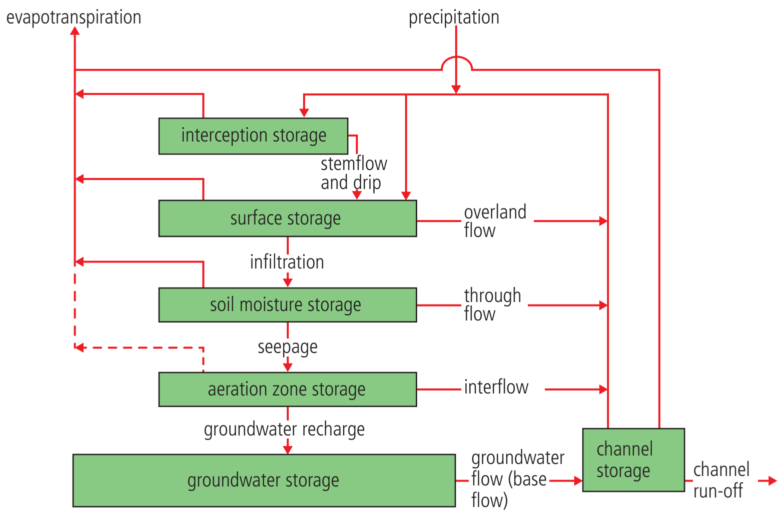

Figure 4.2 Systems diagram of the hydrological cycle

Only a small fraction (approximately 2.5 per cent by volume) of the Earth's water storages is fresh water.

Global water stores

Table 4.1 summarizes the Earth's water stores. Of the fresh water, around 70 per cent is in the form of ice caps and glaciers, around 30 per cent is groundwater. The

Reservoir		Thousands of cubic kilometres	% of total
ocean		1 350 000	97.403
atmosphere		13.0	0.000 94
land		35 977.8	2.596
of which	in rivers	1.7	0.000 12
	in freshwater lakes	100.0	0.007 2
	in inland seas	105.0	0.007 6
	in soil water	70.0	0.005 1
	in groundwater	8 200.0	0.592
	in ice caps/glaciers	27 500.0	1.984
	in biota	1.1	0.000 88

Table 4.1 Global water reservoirs

water in lakes, rivers and biota, soil water, and atmospheric water vapour is a very tiny percentage of the whole. Fresh water on the surface of the Earth to which we have direct access (lakes and rivers) is around 0.3 per cent of the total. Atmospheric water vapour contains around 0.001 per cent of the Earth's total water volume. Taken together, all the forms in which the Earth's water can exist are called the hydrosphere.

Storages in the hydrological cycle include organisms, soil water and the atmosphere, and various water bodies such as oceans, groundwater (aquifers), lakes, rivers, glaciers, and ice caps.

The different forms of water in the Earth's water budget are fully recycled during the hydrological cycle but at very different rates. The time for a water molecule enter and leave a part of the system (i.e. the time taken for water to completely replace itself in part of the system) is called the **turnover time**. Turnover time varies enormously between different parts of the system (Table 4.2).

The degree to which water can be seen as a renewable or non-renewable resource depends on where it is found in the hydrological cycle. Renewable water resources

Water location	Turnover time
polar ice caps	10 000 years
ice in the permafrost	10 000 years
oceans	2 500 years
groundwater	1 500 years
mountain glaciers	1 500 years
large lakes	17 years
bogs	5 years
upper soil moisture	1 year
atmospheric moisture	12 days
rivers	16 days
biological water	a few hours

Table 4.2 Turnover time for different parts of the hydrosphere

are waters that are recycled yearly or more frequently in the Earth's water turnover processes. Thus, groundwater is a non-renewable source of water as turnover time is very long. An aquifer is an underground formation of permeable rock or loose material which stores groundwater. Aquifers can produce useful quantities of water when tapped by wells. Aquifers come in all sizes, from small (a few hectares in area) to very large (covering thousands of square kilometres). They may be only a few metres thick, or they may measure hundreds of metres from top to bottom. Unsustainable use of aquifers results in depleting the storage and has unfavourable consequences: it depletes the natural resource and disturbs the natural equilibrium established over centuries. Restoration requires tens to hundreds of years.

Flows in the hydrological cycle include evapotranspiration (EVT), sublimation, evaporation, condensation, advection (wind-blown movement), precipitation, melting, freezing, flooding, surface run-off, infiltration, percolation, and stream-flow/ currents.

Flows

The hydrological cycle comprises evaporation from oceans, water vapour, condensation, precipitation, run-off, groundwater and EVT (Table 4.3). If 100 units represents global precipitation (on average 860 mm per year), 77 per cent falls over the oceans and 23 per cent on land. A total of 84 units enter the atmosphere by evaporation via the oceans, thus there is a horizontal transfer of 7 units from the land to the sea. Of precipitation over the land, 16 units are evaporated or transpired and 7 units run off to the oceans. There may be some time lag between precipitation and eventual run-off. About 98 per cent of all free water on the globe is stored in the oceans.

Precipitation includes all forms of rainfall, snow, frost, hail and dew. It is the conversion and transfer of moisture in the atmosphere to the land. *Interception* refers to water that is caught and stored by vegetation. It has three main components:

- *interception loss* – water which is retained by plant surfaces and which is later evaporated away or absorbed by the plant
- *throughfall* – water which either falls through gaps in the vegetation or which drops from leaves, twigs or stems
- *stemflow* – water which trickles along twigs and branches and finally down the main trunk.

Table 4.3 Global water exchanges

Annual exchange		Thousands of cubic kilometres	
Evaporation		496.0	
of which	from oceans		425.0
	from land		71.0
Precipitation		496.0	
of which	to oceans		385.0
	to land		111.0
Run-off to oceans		41.5	
of which	from rivers		27.0
	from groundwater		12.0
	from glacial meltwater		2.5

Interception loss varies with different types of vegetation. Interception is less from grasses than from deciduous woodland owing to the smaller surface area of the grass shoots. From agricultural crops, and from cereals in particular, interception increases with crop density. Coniferous trees intercept more than deciduous trees in winter, but the reverse is true in summer.

Evaporation is the process by which a liquid or a solid is changed into a gas. It is the conversion of solid and liquid precipitation (snow, ice, and water) to water vapour in the atmosphere. It is most important from oceans and seas. Evaporation increases under warm, dry, and windy conditions and decreases under cold, calm conditions. Evaporation losses will be greater in arid and semi-arid climates than they will be in polar regions. Factors affecting evaporation include meteorological factors such as temperature, humidity, and windspeed. Of these, temperature is the most important factor. Other factors include the amount of water available, vegetation cover, and colour of the surface (*albedo* or reflectivity of the surface).

Transpiration is the process by which water vapour escapes from living plants, mainly from the leaves, and enters the atmosphere. The combined effects of evaporation and transpiration are normally referred to as evapotranspiration (EVT). EVT represents the most important aspect of water loss, accounting for the loss of nearly 100 per cent of the annual precipitation in arid areas and 75 per cent in humid areas. Only over ice and snow fields, bare rock slopes, desert areas, water surfaces, and bare soil will purely evaporative losses occur.

Infiltration is the process by which water soaks into or is absorbed by the soil. The *infiltration capacity* is the maximum rate at which rain can be absorbed by a soil in a given condition. Infiltration capacity decreases with time through a period of rainfall until a more or less constant value is reached. Infiltration rates of 0–4 mm h^{-1} are common on clays whereas 3–12 mm h^{-1} are common on sands. Vegetation also increases infiltration. This is because it intercepts some rainfall and slows down the speed at which it arrives at the surface. For example, on bare soils where rainsplash impact occurs, infiltration rates may reach 10 mm h^{-1}. On similar soils covered by vegetation rates of between 50 and 100 mm h^{-1} have been recorded. Infiltrated water is chemically rich as it picks up minerals and organic acids from vegetation and soil.

Infiltration is inversely related to overland run-off and is influenced by a variety of factors such as duration of rainfall, antecedent soil moisture (i.e. pre-existing levels of soil moisture), soil porosity, vegetation cover, raindrop size and slope angle. In contrast *overland flow* (surface run-off) is water that flows over the land's surface. It occurs in two main circumstances:

- when precipitation exceeds the infiltration rate
- when the soil is saturated (all the pore spaces are filled with water).

In areas of high precipitation intensity and low infiltration capacity, overland run-off is common. This is clearly seen in semi-arid areas and in cultivated fields. By contrast, where precipitation intensity is low and infiltration is high, most overland flow occurs close to streams and river channels.

Condensation is the process by which vapour passes into a liquid form. It occurs when air is cooled to its dew point or becomes saturated by evaporation into it. Further cooling leads to condensation on surfaces to form water droplets or frost.

Sublimation refers to the conversion of a solid into a vapour with no intermediate liquid state. Under conditions of low humidity, snow can be evaporated directly into water vapour without entering the liquid water state. Sublimation is also used to describe the direct deposition of water vapour onto ice.

▲ Condensation is easily observable on a window.

Advection is the horizontal transfer of energy or matter. It refers particularly to the movement of air in the atmosphere which results in the redistribution of such elements as warm or cold air, moisture and pollutants.

Freezing refers to the change of liquid water into a solid ice, once temperatures fall below 0 °C. *Melting* is the change from a solid ice to a liquid water when the air temperature rises above 0 °C.

Stream-flow or *currents* refers to the movement of water is channels, such as streams and rivers. The water may enter the stream as direct channel precipitation (it falls on the channel), or it may reach the channel by surface run-off, groundwater flow (baseflow), or throughflow (water flowing through the soil).

You should be able to construct and analyse a hydrological cycle diagram.

Flooding refers to the covering (inundation) of normally dry land by water. It occurs when the river channel is unable to contain the amount of water added to it. Flooding may occur for a variety of reasons (e.g. heavy rainfall, prolonged rain, snowmelt, tidal surges, dam failure). Human activities in the drainage basin may intensify flood conditions and increase flood frequency.

Human impacts such as agriculture, deforestation, and urbanization have a significant impact on surface run-off and infiltration.

Human influences on the hydrological cycle

Human modifications are made at every scale. Good examples include large-scale changes of channel flow, irrigation and drainage, and abstraction of groundwater and surface water for domestic and industrial use.

Eutrophication and dead zones are discussed on pages 255–61 and 262, respectively.

The impact of agriculture on water systems

Irrigation

Irrigation is the addition of water to areas where there is insufficient 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 spray and drip irrigation, where precise amounts are measured out to each individual plant (Figure 4.3).

Drip irrigation.

Centre pivot irrigation.

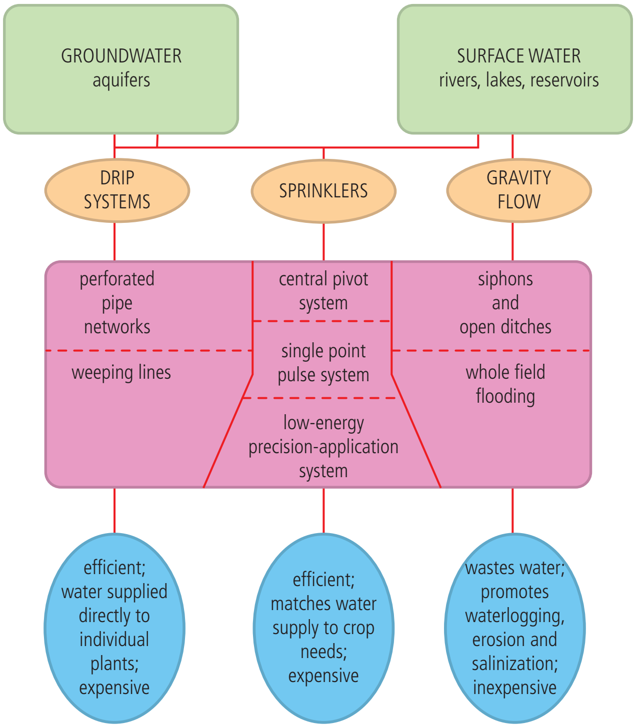

Figure 4.3 Types of irrigation

Irrigation occurs in MEDCs and LEDCs. For example, large parts of the USA and Australia are irrigated. In Texas, irrigation has lowered 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 in the last 100 years and caused widespread *salinization*. 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. Some irrigation, especially for growing rice crops in paddies, requires huge amounts of water. As water evaporates in the hot sun, the salinity levels of the remaining water increase. This could lead to the promotion of salt-tolerant organisms.

Irrigation can reduce the Earth's albedo (reflectivity) by as much as 10 per cent. 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, hail storms, 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 a complete vegetation cover. EVT rates increase and result in increases in the amount of summer rainfall, as has been seen in Kansas, Nebraska, Colorado, and Texas. In addition, hail storms and tornadoes are more common over irrigated areas compared with non-irrigated areas.

Farming can also have a major impact on interception and infiltration. Interception is determined by vegetation type and density. In farmland areas, cereals intercept less than broad leaf crops. Row crops leave a lot of soil bare. Infiltration is up to five times greater under forests compared with grassland. This is because the forest channels water down tree trunks and roots.

Land use practices are also important (Table 4.4). Grazing leads to a decline in infiltration due to compaction of the soil. Ploughing increases infiltration because it loosens soils. Waterlogging and salinization are common if there is poor drainage.

Table 4.4 Influence of ground cover on infiltration rates

Ground cover	Infiltration rates / mm h^{-1}
old permanent pasture	57
permanent pasture: moderately grazed	19
permanent pasture: heavily grazed	13
strip-cropped	10
weeds or grain	9
clean tilled	7
bare, crusted ground	6

Deforestation is also linked with increases in the sediment and chemical loads of streams as nitrates are lost from soil and erosion occurs (Table 4.6). In an extreme case of deforestation in the north-east of the USA, sediment loads increased 15-fold and nitrate loads increased by almost 50 times! Other examples are not so extreme - much depends on how the forest is managed. If deforestation is only partial, there is less sediment load. If replanting takes place quickly the effects of deforestation are reduced.

The impact of deforestation on water systems

Deforestation has a large impact on water systems: after deforestation, flood levels in rivers increase. Changes in run-off and erosion following deforestation are shown in Table 4.5.

Following forest regeneration, flood levels and water quality return to pre-removal levels. But this may take decades to occur. The return to pre-removal levels after regeneration include:

- higher interception rates of mature forests
- decreased overland run-off beneath a mature forest
- higher infiltration rates beneath forests
- deeper soils beneath a cover of trees.

The replacement of natural vegetation by crops needs to be carefully managed. The use of shade trees and cover crops is a useful way of reducing soil erosion following deforestation. Grazing tends to increase overland run-off because of surface compaction and vegetation removal.

Deforestation, agriculture and flooding at Batang Ai, Sarawak, Malaysia

Table 4.5 Changes in run-off and erosion following deforestation

Locality	Average annual rainfall / mm	Slope / %	Annual run-off / %			Erosion / t ha^{-1} yr^{-1}		
			A	B	C	A	B	C
Ougadougou (Burkina Faso)	850	0.5	2.5	2–32	40–60	0.1	0.6–0.8	10–20
Sefa (Senegal)	1300	1.2	1.0	21.2	39.5	0.2	7.3	21.3
Bouake (Ivory Coast)	1200	4.0	0.3	0.1–26	15–30	0.1	1–26	18–30
Abidjan (Ivory Coast)	2100	7.0	0.4	0.5–20	38	0.03	0.1–90	108–170
Mbapwa (Tanzania)	approx. 570	6.0	0.4	26.0	50.4	0	78	146

A = forest or ungrazed thicket; B = crop; C = barren soil

Table 4.6 Changes in nitrate–nitrogen levels after deforestation

Site	Nature of disturbance	Nitrate–nitrogen loss / kg ha^{-1} yr^{-1} Control	Nitrate–nitrogen loss / kg ha^{-1} yr^{-1} Disturbed
Hubbard Brook (New Hampshire)	clear-cutting without vegetation removal, herbicide inhibition of re-growth	2.0	97
Gale River (New Hampshire)	commercial clear-cutting	2.0	38
Fernow (West Virginia)	commercial clear-cutting	0.6	3.0
Coweeta (North Carolina)	complex	0.05	7.3*
HJ Andrews forest (Oregon)	clear-cutting with slash burning	0.08	0.26
Alsea River (Oregon)	clear-cutting with slash burning	3.9	15.4
	Mean	1.44	26.83

* Second year of recovery after a long-term disturbance: all other values are for first year of recovery

Indeed, young plants that are growing rapidly take up large amounts of water and nutrients from the soil, thereby reducing the rate of overland run-off and the chemical load of streams. Much depends on the type of vegetation, its relative density, size and rates of growth.

Deforestation can also have an important effect on local climate. The removal of trees leads to an increase in light intensity, temperature, wind speed, and moisture at ground level. This has a number of consequences, including:

- organic matter is decomposed at a faster rate
- raindrop impact increases
- EVT rates decrease
- overland run-off increases.

The reduced forest traps less rain; the litter layer is reduced and this, in turn, intercepts less rainfall; the proportion of bare ground increases, and raindrop impact compacts the soil. As forests are cut down, more light gets through to the ground so new vegetation can grow there. This encourages grazing animals which eat the buds of growing trees. Consequently, vegetation that grows from the base (e.g. grasses) is favoured over vegetation that grows from buds (e.g. trees). In addition, the grazers compact the soil and increase its density. This leads to decreasing infiltration, and increased overland flow, which increases soil erosion.

Thinner soils store and transport less moisture. Consequently, there is increased surface run-off and sediment discharge. Moreover, the removal of some trees may lead to a reduction in the amount of groundwater. This happens because the thin soils of the cut forest are more exposed to direct sunlight and lose more moisture through evaporation. Soils under a complete forest canopy are shaded, thus evaporation losses are less, and they provide more water to groundwater stores.

Deforestation is, therefore, associated with reduced infiltration rates, reduced soil water storage, and increased rates of surface run-off and soil erosion (Table 4.7). There are also changes in stream morphology (shape and size), increases in the mean annual flood, and an increase in the frequency of landslides. This is because on a forested slope, tree roots bind the soil, whereas on deforested slopes there is less anchorage of soil and an increase in landslides.

As a result of the intense surface run-off and soil erosion, rivers have a higher *flood peak* and a shorter time lag. However, in the dry season, river levels are lower, and rivers have greater turbidity (murkiness due to more sediment) as they carry more silt and clay in suspension.

Other changes relate to *climate*. As deforestation progresses, there is a reduction in the amount of water that is transpired from the vegetation, hence the recycling of water slows down. EVT rates from savannah grasslands are estimated to be about a third of that of tropical rainforest. Thus, mean annual rainfall is reduced, and the seasonality of rainfall increases.

Table 4.7 Soil erosion and deforestation in the Himalayas

Rainfall intensity / mm hr^{-1}	Average soil losses / kg ha^{-1} by percentage of area forested			
	20–30%	40–50%	60–70%	80–90%
0–9	6.1	4.0	2.9	2.6
10–19	19.1	19.2	9.8	10.6
>20	43.6	25.2	28.1	16.9

Urban development in Seoul, South Korea – notice the relative lack of vegetation and the large amount of impermeable surfaces.

The effect of urbanization on water systems

There are many changes to the water cycle that occur in urban areas (Table 4.8). The changes depend, in part, on the size of the urban area and the nature of land use. Due to the increase in impermeable surfaces (Table 4.9), there is more overland run-off. In most cities, due to the many storm sewers and drainage channels, water is diverted into underground channels very quickly. Due to the relative lack of vegetation in some parts, temperatures become quite high, increasing evaporation. Flash floods may occur owing to rapid run-off, little absorption, and a lack of storage.

Table 4.8 The potential impact of urbanization on water systems

The result of urbanization	Potential hydrological response
removal of trees and vegetation	• decreased EVT and interception
initial construction of houses, streets, and culverts	• decreased infiltration and lowered groundwater table • increased storm flows and decreased base flows during dry periods • increased stream sedimentation
development of residential, commercial and industrial areas	• 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 increase flood problems downstream
drainage density	• basins with a high drainage density (e.g. urban basins with a network of sewers and drains) respond very quickly • networks with a low drainage density have a very long time lag
land use	• land uses which create impermeable surfaces, or reduce vegetation cover, decrease interception and increase overland flow
porosity and impermeability of 'artificial surface' rocks and soils	• urban areas contain large areas of impermeable surfaces which cause more water to flow overland; this causes greater peak flows • rocks such as chalk and gravel are permeable and allow water to infiltrate and percolate; this reduces peak flow and increases the time lag • sandy soils allow water to infiltrate, whereas clay is much more impermeable and causes water to pass overland

Type of surface	Impermeability / %
water-tight roof surfaces	70–95
asphalt paving in good order	85–90
stone, brick and wooden block pavements: with tightly cemented joints with open or uncertain joints	 75–85 50–70
inferior block pavements with open joints	40–50
tarmacadam roads and paths	25–60
gravel roads and paths	15–30
unpaved surfaces, railway yards, vacant land	10–30
parks, gardens, lawns, meadows – depending on the surface slope and character of the sub-soil	5–25

Table 4.9 Impermeability of urban surfaces

You should be able to discuss the human impact on the hydrological cycle.

CHALLENGE YOURSELF

Thinking skills ATL

To what extent can the hydrological cycle be considered an open or closed system?

Ocean circulation

The distribution of the oceans and ocean currents

The oceans cover approximately 70 per cent of the Earth's surface, and are of great importance to humans. Particularly important is through the atmosphere–ocean link, by which oceans regulate climatic conditions. Warm ocean currents move

Ocean circulation systems are driven by differences in temperature and salinity that affect water density. The resulting difference in water density drives the ocean conveyor belt which distributes heat around the world, so affecting climate.

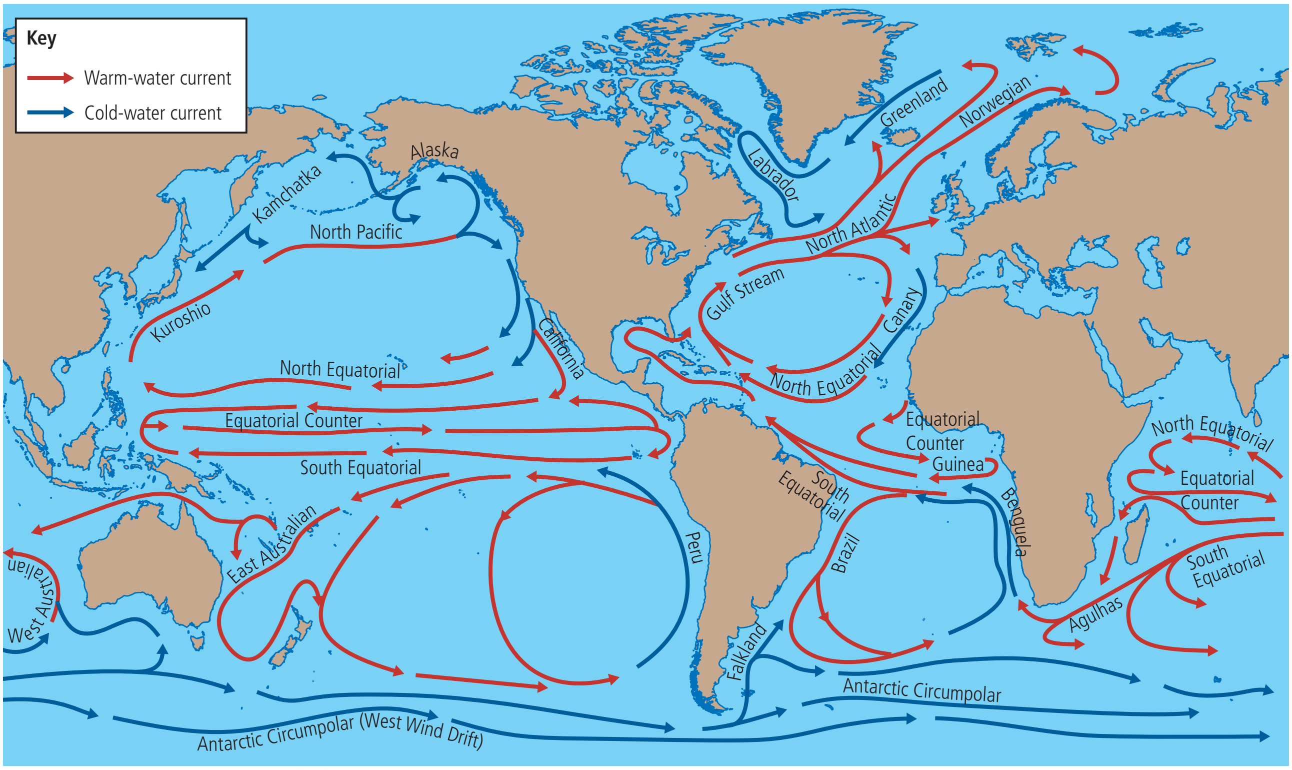

Figure 4.4 The world's main ocean currents

water away from the equator towards the poles, whereas cold ocean currents move water away from the cold regions towards the equator (Figure 4.4). The warm Gulf Stream, for instance, transports 55 million cubic metres per second from the Gulf of Mexico towards north-west Europe. Without it, the temperate lands of north-west Europe would be more like the sub-Arctic. The cold Peru current brings nutrient-rich waters dragged to the surface by offshore winds. In addition, there is the Great Ocean Conveyor Belt (page 224). This deep, global-scale circulation of the ocean's waters effectively transfers heat from the tropics to colder regions.

Salinity

Oceanic water varies in salinity (Figure 4.5). Average salinity is about 35 parts per thousand (ppt). Concentrations of salt are higher in warm seas, because of the high evaporation rates of the water. In tropical seas, salinity decreases sharply with depth. The run-off from most rivers is quickly mixed with ocean water by the currents, and has little effect on reducing salinity. However, a large river such as the Amazon in South America may result in the ocean having little or no salt content for over a kilometre or more out to sea.

The freezing and thawing of ice also affects salinity. The thawing of large icebergs (made of frozen fresh water and lacking any salt) decreases salinity, while freezing of seawater increases the salinity temporarily. Salinity levels increase with depth.

The predominant mineral ions in seawater are chloride (54.3 per cent) and sodium (30.2 per cent), which combine to form salt. Other important minerals in the sea include magnesium and sulfate ions.

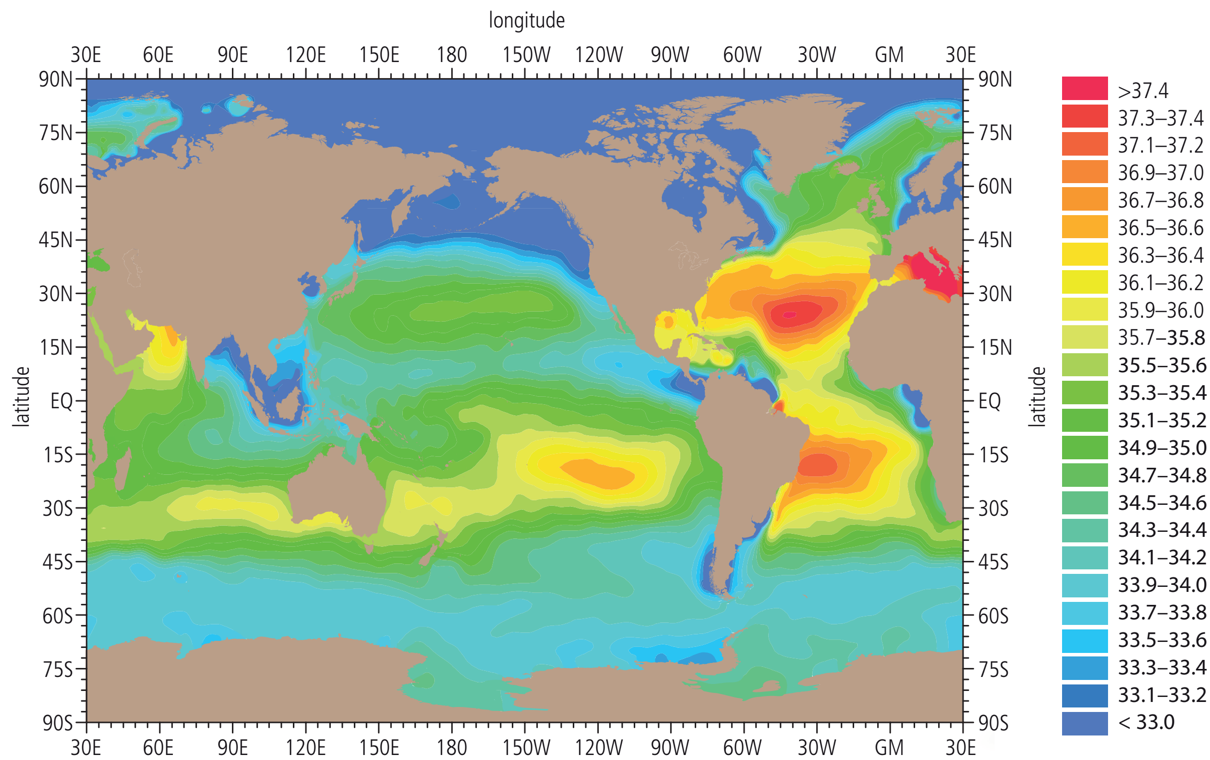

Figure 4.5 Global variations in oceanic salinity

Temperature

Temperature varies considerably at the surface of the ocean, but there is little variation at depth (Figure 4.6). In tropical and subtropical areas, sea surface temperatures in excess of 25 °C are caused by insolation. From about 300 to 1000 m, the temperature declines steeply to about 8–10 °C. Below 1000 m, the temperature decreases to a more uniform 2 °C in the ocean depths.

The temperature profile is similar in the mid-latitudes (40–50° N and S), although there are clear seasonal variations. Summer temperatures may reach 17 °C, whereas winter sea temperatures are closer to 10 °C. There is a more gradual decrease in temperature with depth (thermocline).

Density

Temperature, salinity, and pressure affect the density of seawater. Large water masses of different densities are important in the layering of the ocean water (denser water sinks). As temperature increases, water becomes less dense. As salinity increases, water becomes more dense. As pressure increases, water becomes more dense. A cold, highly saline, deep mass of water is very dense, whereas a warm, less saline, surface water mass is less dense. When large water masses with different densities meet, the denser water mass slips under the less dense mass. These responses to density are the reason for some of the deep ocean circulation patterns.

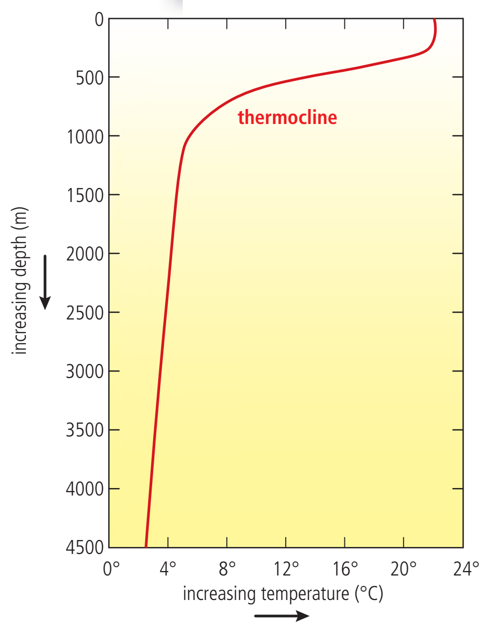

Figure 4.6 Ocean temperature and depth

The Great Ocean Conveyor Belt

The oceanic conveyor belt is a global thermohaline circulation, driven by the formation and sinking of deep water and responsible for the large flow of upper ocean water (Figure 4.7). In addition to the transfer of energy by wind and the transfer of energy by ocean currents, there is also a transfer of energy by deep-sea currents. In polar regions, cold, salty water sinks to the depths and makes its way towards the equator. It then spreads into the deep basins of the Atlantic, the Pacific, and the Indian Oceans. Surface currents bring warm water to the North Atlantic from the Indian and Pacific Oceans. These waters give up their heat to cold winds which blow from Canada across the North Atlantic. This water then sinks and starts the reverse convection of the deep ocean current. The amount of heat given up is about a third of the energy received from the Sun.

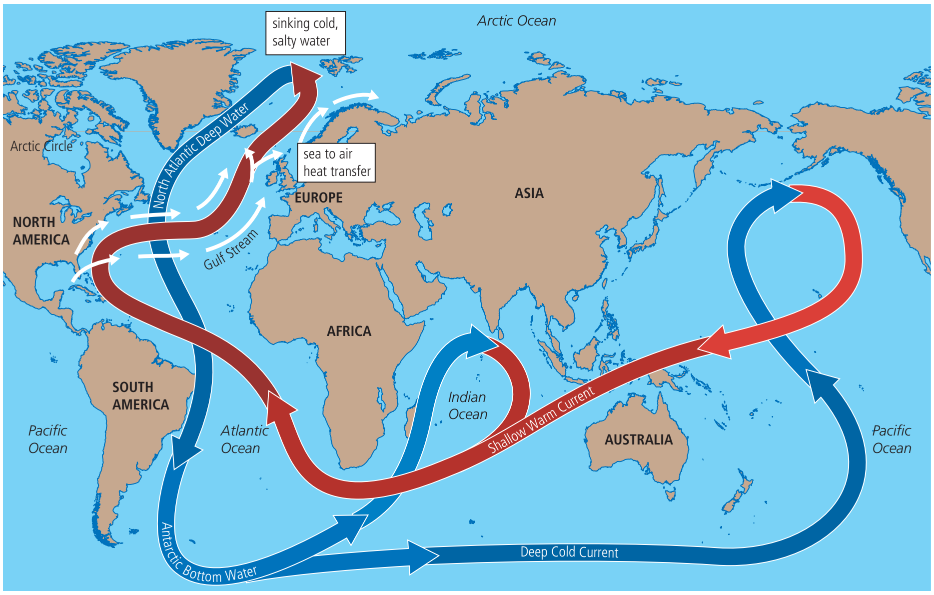

Figure 4.7 The Great Ocean Conveyor Belt

Because the conveyor operates in this way, the North Atlantic is warmer than the North Pacific, so there is proportionally more evaporation there. The water left behind by evaporation is saltier and therefore much denser, which causes it to sink. Eventually the water is transported into the Pacific where it mixes with warmer water and its density is reduced.

Specific heat capacity

The specific heat capacity is the amount of energy it takes to raise the temperature of a body. It takes more energy to heat up water than it does to heat land. However, it takes longer for water to lose heat. This is why the land is hotter than the sea by day, but colder than the sea by night. Places close to the sea are cool by day, but mild by night. With increasing distance from the sea this effect is reduced.

Exercises

1. Define the term *hydrological cycle*.
2. Study the photograph opposite of a mountainous scene from the European Alps. Identify two visible stores of fresh water.

Mountainous scene, the Alps

3. Study the photograph opposite of part of the River Thames, UK. Identify three stores in the hydrological cycle that are visible in the photograph.
4. Use the data in Table 4.1 to construct a pie chart to show the main components of the global hydrological cycle.
5. Define the terms *transpiration* and *sublimation*.
6. Outline the factors that increase the rate of evaporation.
7. Construct a flow diagram to show the main characteristics of the global water exchanges (Table 4.3)
8. Study Figure 4.3. Identify the least efficient method of irrigation.
9. Which two forms of irrigation are most efficient?
10. Explain why drip irrigation systems are more efficient than whole field flooding (gravity flow) types of irrigation.
11. Study Table 4.4.
    a. Define the term *infiltration*.
    b. Suggest why pastoral farming (pasture) allows more infiltration than arable farming (cropped or grain).
    c. Suggest why farmed land has a higher infiltration than bare earth.
12. Using Table 4.5 describe how erosion varies with annual run-off. How do rates of erosion and run-off vary with average annual rainfall?
13. Compare annual run-off under forest or ungrazed thicket, crop, and barren soil.
14. Table 4.6 shows changes in nitrate–nitrogen levels after deforestation. How do nitrate–nitrogen losses differ between disturbed (deforested) plots and control plots? Use evidence to support your answer.
15. Table 4.7 shows data for soil loss, rainfall intensity and percentage forest cover in part of the Himalayas.
    a. Describe how average soil loss varies with (i) forest cover and (ii) rainfall intensity.
    b. Suggest reasons for your answers to part A.
16. Study Table 4.8. In what ways does the drainage of cities differ from natural drainage systems? In what ways does this influence the hydrological cycle within urban areas?
17. Study Table 4.9. In which parts of a city would you expect there to be:
    a. most impermeable surfaces
    b. least impermeable surfaces?
18. Explain briefly how different land uses may influence the hydrological cycle within urban areas.
19. Describe the global variations in oceanic salinity as shown in Figure 4.5.
20. Briefly explain the operation of the Great Ocean Conveyor Belt (Figure 4.7).

River Thames, UK

Big questions

Having read this section, you can now discuss the following big questions:

- What strengths and weaknesses of the systems approach and the use of models have been revealed through this topic?
- To what extent have the solutions emerging from this topic been directed at *preventing* environmental impacts, *limiting* the extent of the environmental impacts, or *restoring* systems in which environmental impacts have already occurred?
- How are the issues addressed in this topic of relevance to sustainability or sustainable development?
- In what ways might the solutions explored in this topic alter your predictions for the state of human societies and the biosphere some decades from now?

Points you may want to consider in your discussions:

- Many hydrological cycles cross international boundaries. How does this affect the management of water?
- Identify the solutions to the impacts of agriculture, deforestation, and urbanization on the hydrological cycle.
- Can agriculture, deforestation, and urbanization allow for the natural functioning of the hydrological cycle?
- In what ways may population growth and human activities have an impact on the hydrological cycles of the future?