1.2 The water cycle

Key terms

Atmospheric water – Water found in the atmosphere; mainly water vapour with some liquid water (cloud and rain droplets) and ice crystals.

Cryospheric water – The water locked up on the Earth's surface as ice.

Discharge – The amount of water in a river flowing past a particular point expressed as m^3s^{-1} (cumecs).

Greenhouse gas – Any gaseous compound in the atmosphere that allows short wave ultraviolet radiation from the Sun to pass through the atmosphere, but then prevents outgoing terrestrial infrared radiation from escaping to space.

Hydrosphere – A discontinuous layer of water at or near the Earth's surface. It includes all liquid and frozen surface waters, groundwater held in soil and rock and atmospheric water vapour.

Oceanic water – The water contained in the Earth's oceans and seas but not including such inland seas as the Caspian Sea.

Terrestrial water – This consists of groundwater, soil moisture, lakes, wetlands and rivers.

'Water is life's matter, mother and medium.'
Albert Szent-Gyorgyi, 1937 Nobel Prize acceptance speech

The major stores of water

Water on or close to the Earth's surface is called the **hydrosphere**. Scientists have attempted many times to estimate the total amount of water in the hydrosphere. There is general agreement that it amounts to some 1.338×10^9 km^3. It is thought that approximately 97 per cent of this is **oceanic water** (Figure 1.5). Fresh water, which makes up the remaining 3 per cent, is locked up in land ice, glaciers and permafrost (**cryospheric water**), groundwater, lakes, soil, wetland, rivers, biomass (**terrestrial water**) and **atmospheric water**.

12,900 km^3 of water vapour are found in the atmosphere. This amounts to a global average of 26 kg/m^2 of water for each column of air on the surface of the Earth. There are large variations in this, however. Although atmospheric water only makes up 0.4 per cent of all water, it has a profound effect on our lives at present.

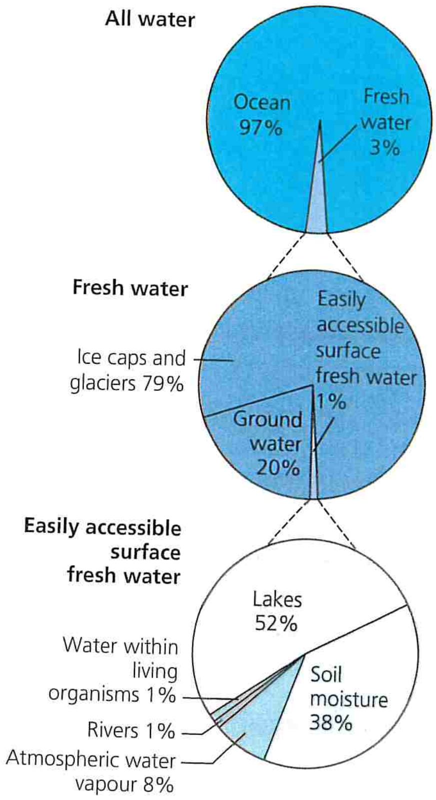

Figure 1.5 The distribution of the world's water

The amount of water in these stores is in a state of dynamic equilibrium with changes at a range of timescales from diurnal to geological. Changing amounts of atmospheric water in the future could be a major cause and/or important effect of climate change.

Oceanic water

The oceans dominate the amount of available water. Its exact amount is unknown with figures varying from 1,320,000,000 to 1,370,000,000 km³ with an average depth of 3,682 m. That difference is greater than the sum of all the rest of the water put together. They cover approximately 72 per cent of the planet's surface (3.6×10^8 km^2). They are customarily divided into several principal oceans and smaller seas. Although the ocean contains 97 per cent of the Earth's water, oceanographers have stated that only 5 per cent has been explored.

Oceanic water tastes salty because it contains dissolved salts. These salts allow it to stay as liquid water below 0°C. They are alkaline with an average pH of about 8.14. The pH has fallen from about 8.25 in the last 250 years and it seems destined to continue falling. This change in the pH is linked to the increase in atmospheric carbon and may have a profound influence on marine ecosystems.

The cryosphere

The cryosphere is those portions of the Earth's surface where water is in solid form. Figure 1.6 shows the five locations of cryospheric water.

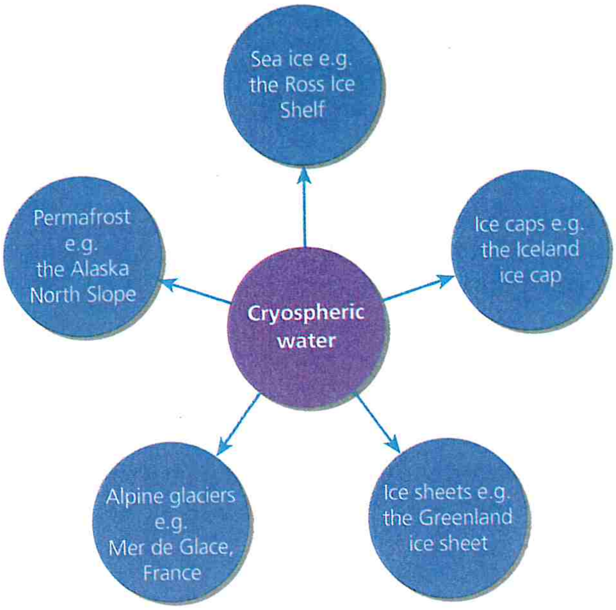

Figure 1.6 The locations of cryospheric water

Sea ice

Much of the Arctic Ocean is frozen; the amount of which grows in winter and shrinks in summer. The same is true of the waters surrounding Antarctica. Sea ice forms when water in the oceans is cooled to temperatures below freezing. Sea ice does not raise sea level when it melts, because it forms from ocean water. It is closely linked with our planet's climate, so scientists are concerned about its recent decline.

Figure 1.7 Chunks of broken sea ice in Yelverton Bay, Ellesmere Island, Canada

Ice shelves are platforms of ice that form where ice sheets and glaciers move out into the oceans. Ice shelves exist mostly in Antarctica and Greenland, as well as in the Arctic near Canada and Alaska. Icebergs are chunks of ice that break off glaciers and ice shelves and drift in the oceans. They raise sea level only when they first leave land and push into the water, but not when they melt in the water.

Ice sheets

An ice sheet is a mass of glacial land ice extending more than 50,000 km^2. The two major ice sheets on Earth today cover most of Greenland and Antarctica. During the last ice advance, ice sheets also covered much of North America, northern Europe and Argentina.

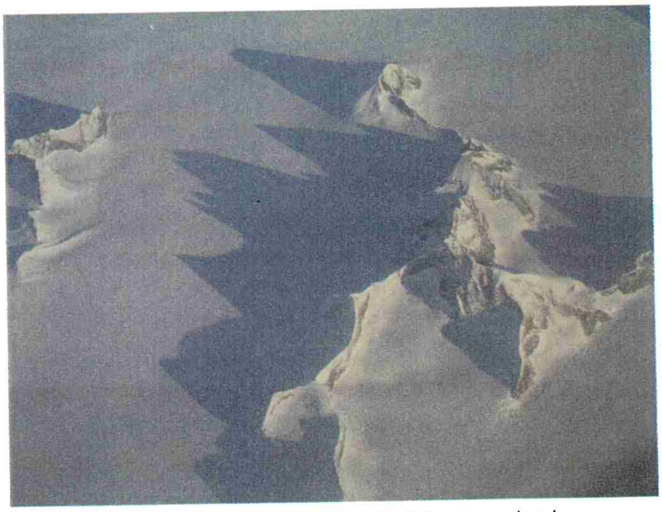

Figure 1.8 Mountains rising out of part of the Greenland ice sheet

Together, the Antarctic and Greenland ice sheets contain more than 99 per cent of the freshwater ice on Earth. The Antarctic Ice Sheet extends almost 14 million km^2, roughly the area of the United States and Mexico combined. It contains 30 million km^3 of ice. The Greenland Ice Sheet extends about 1.7 million km^2, covering most of the island of Greenland.

Ice sheets form in areas where snow that falls in winter does not melt entirely over the summer. Over thousands of years, the layers of snow pile up into thick masses of ice, growing thicker and denser as the weight of new snow and ice layers compresses the older layers. Ice sheets are constantly in motion, slowly flowing downhill under their own weight. Near the coast, most of the ice moves through relatively fast-moving outlets called ice streams. This type of glacier is significant in the Antarctic where they can be up to 50 km wide, 2 km thick and hundreds of kilometres long. As long as an ice sheet accumulates the same mass of snow as it loses to the sea, it remains stable.

Ice sheets contain enormous quantities of frozen water. If the Greenland Ice Sheet melted, scientists estimate that sea level would rise about six metres. If the Antarctic Ice Sheet melted, sea level would rise by about 60 m.

Ice caps

Ice caps are thick layers of ice on land that are smaller than 50,000 km². They are usually found in mountainous areas. Ice caps tend to be dome-shaped and are centred over the highest point of an upland area. They flow outwards, covering almost everything in their path and becoming the major source for many glaciers.

Ice caps occur all over the world, from the polar regions to mountainous areas such as the Himalayas, the Rockies, the Andes and the Southern Alps of New Zealand. The Furtwangler Glacier on Kilimanjaro, at 60,000 m², is Africa's only remaining ice cap. It is melting rapidly and may soon disappear.

Figure 1.9 The Furtwangler ice cap. The last ice cap in Africa

Alpine glaciers

Alpine glaciers are thick masses of ice found in deep valleys or in upland hollows. Most valley glaciers are fed by ice from ice caps or smaller corrie glaciers. These glaciers are particularly important in the Himalayas where about 15,000 Himalayan glaciers form a unique reservoir which supports perennial rivers such as the Indus, Ganges and Brahmaputra which, in turn, are the lifeline of millions of people in South Asian countries (Pakistan, Nepal, Bhutan, India and Bangladesh).

Permafrost

Permafrost is defined as ground (soil or rock and included ice or organic material) that remains at or below 0°C for at least two consecutive years. The thickness of permafrost varies from less than one metre to more than 1,500 m. Most of the permafrost existing today formed during cold glacial periods and has persisted through warmer interglacial periods, including the Holocene (the last 10,000 years). Some relatively shallow permafrost (30 to 70 m) formed during the second part of the Holocene (the last 6,000 years) and some during the Little Ice Age (from 400 to 150 years ago). Subsea permafrost occurs at close to 0°C over large areas of the Arctic continental shelf, where it formed during the last glacial period on the exposed shelf landscapes when sea levels were lower. Permafrost is found beneath the ice-free regions of the Antarctic continent and also occurs beneath areas in which the ice sheet is frozen to its bed.

The permafrost has begun to melt as climate warms. This melting is releasing large amounts of carbon dioxide and methane, potentially affecting global climates.

Terrestrial water

Terrestrial water falls into four broad classes:

- surface water
- groundwater
- soil water
- biological water.

Surface water

Surface water is the free-flowing water of rivers as well as the water of ponds and lakes.

- **Rivers** act as both a store and a transfer of water; they are streams of water within a defined channel. They transfer water from the ground, from soils and from the atmosphere to a store. That store may be wetlands, lakes or the oceans. Rivers make up only a small percentage (0.0002 per cent) of all water, covering just 1,000,000 km² with a volume of 2,120 km³. One river alone, the Amazon in South America, is the largest river in the world by **discharge** of water, averaging a discharge of about 209,000 m^3/s, greater than the next seven largest independent rivers combined. It drains an area of about 7,050,000 km^2 and accounts for approximately one-fifth of the world's total river flow. The portion of the river's drainage basin in Brazil alone is larger than any other river's basin. The Amazon enters Brazil with only one-fifth of the flow it finally discharges into the Atlantic Ocean, yet already has a greater flow at this point than the discharge of any other river.

- **Lakes** are collections of fresh water found in hollows on the land surface. They are generally deemed a lake if they are greater than two hectares in area. Any standing body of water smaller than this is termed a pond.

The majority of lakes on Earth are freshwater, and most lie in the Northern Hemisphere at higher latitudes. Canada has an estimated 31,752 lakes larger than 3 km^2 and an estimated total number of at least 2 million. Finland has 187,888 lakes 500 m^2 or larger, of which 56,000 are large (10,000 m^2).

The largest lake is the Caspian Sea at 78,200 km^3. It is a remnant of an ancient ocean and is about 5.5 million years old. It is generally fresh water, though becomes more saline in the south where there are few rivers flowing into it. The deepest lake in the world is Lake Baikal in Siberia with a mean depth of 749 m and a deepest point at 1,637 m.

- **Wetlands**: The **Ramsar Convention** defines wetlands as 'areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing where there is a dominance by vegetation'.

They are areas where water covers the soil, or is present either at or near the surface of the soil all year or for varying periods of time during the year, including during the growing season. Water saturation determines how the soil develops and the types of plant and animal communities living in and on the soil. Wetlands may support both aquatic and terrestrial species. The prolonged presence of water creates conditions that favour the growth of specially adapted plants and promotes the development of characteristic wetland soils.

Wetlands vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation and other factors, including human disturbance. They are found from the polar regions to the tropics and on every continent except Antarctica.

The Pantanal wetlands

The Pantanal of South America is often referred to as the world's largest freshwater wetland system. It extends through millions of hectares of central western Brazil, eastern Bolivia and eastern Paraguay (Figure 1.10).

It is a complex system of marshlands, flood plains, lagoons and interconnected drainage lines. It also provides economic benefits by being a huge area for water purification and groundwater discharge and recharge, climate stabilisation, water supply, flood abatement, and an extensive, transport system, among numerous other important functions.

Figure 1.10 The location of the Pantanal wetlands (shown in dark green)

Wetlands are the main ecosystem in the Arctic. These peatlands, rivers, lakes, and shallow bays cover nearly 60 per cent of the total surface area. Arctic wetlands store enormous amounts of **greenhouse gases** and are critical for global biodiversity.

Groundwater (lithosphere)

Groundwater is water that collects underground in the pore spaces of rock (Figure 1.11, page 8). Scientists have set a lower level for groundwater at a depth of 4,000 m but it is known that there are large quantities of water below that. A very deep borehole in the Kola Peninsula in Northern Russia found huge quantities of hot mineralised water at a depth of 13 km.

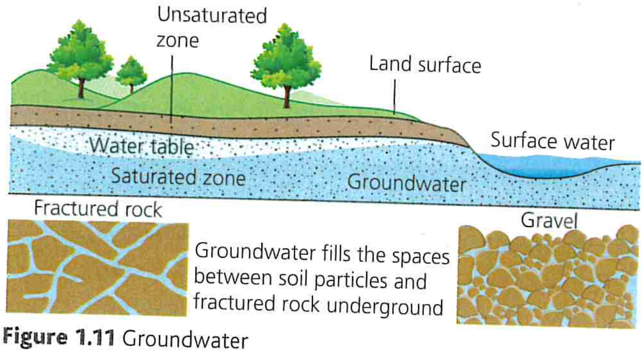

Figure 1.11 Groundwater

The depth at which soil pore spaces or fractures and voids in rock become completely **saturated** with water is called the water table. Groundwater is recharged from, and eventually flows to, the surface. Natural discharge often occurs at springs and seeps, and can form oases or wetlands. The amount of groundwater is reducing rapidly due to extensive extraction for use in irrigating agricultural land in dry areas.

Soil water

Soil water is that which is held, together with air, in unsaturated upper weathered layers of the Earth. It is of fundamental importance to many hydrological, biological and biogeochemical processes. It affects weather and climate, **run-off** potential and flood control, soil erosion and slope failure, reservoir management, geotechnical engineering and water quality. Soil moisture is a key variable in controlling the exchange of water and heat energy between the land surface and the atmosphere through **evaporation** and plant **transpiration**. As a result, soil moisture plays an important role in the development of weather patterns and the production of precipitation.

Biological water

Biological water constitutes the water stored in all the biomass. It varies widely around the globe depending on the vegetation cover and type. Areas of dense rainforest store much more water than deserts. The role of animals as a water store is minimal.

Trees take in water via their roots. This is either transported or stored in the trunk and branches of the tree. The water is lost by the process of transpiration through stomata in the leaves. This storage provides a reservoir of water that helps maintain some climatic environments. If the vegetation is destroyed, this store is lost to the atmosphere and the climate can become more desert-like. Many plants are adapted to store water in large quantities. Cacti are able to gather water via their extensive root system and then use it very slowly until the next rainstorm. The baobab tree stores water, but it is thought that this is to strengthen the structure of the tree rather than to be used in tree growth.

The atmosphere

Atmospheric water exists in three states. The most common atmospheric water exists as a gas: water vapour. This is clear, colourless and odourless and so we take its presence for granted. This atmospheric water vapour is important as it absorbs, reflects and scatters incoming solar radiation, keeping the atmosphere at a temperature that can maintain life. The amount of water vapour that can be held by air depends upon its temperature. Cold air cannot hold as much water vapour as warm air. This results in air over the poles being quite dry, whereas air over the tropics is very humid.

A small increase in water vapour will lead to an increase in atmospheric temperatures. This becomes positive feedback as a small increase in global temperature would lead to a rise in global water vapour levels, thus further enhancing the atmospheric warming.

Cloud is a visible mass of water droplets or ice crystals suspended in the atmosphere. Cloud formation is the result of air in the lower layers of Earth's atmosphere becoming saturated due to either or both of two processes: cooling of the air and an increase in water vapour. When the cloud droplets grow they can eventually fall as rain.

Factors driving the change in magnitude of water stores

Water exists on Earth in three forms: liquid water, solid ice and gaseous water vapour. Figure 1.12 shows the processes that occur as water changes from one state to another. Energy, in the form of latent heat, is either absorbed or released depending on the process. This is particularly important in atmospheric processes such as cloud or precipitation formation.