VCE ENVIRONMENTAL SCIENCE | UNITS 1 & 2

5TH EDITION
fully revised and updated

Monitoring environmental systems

ENVIRONMENT EDUCATION VICTORIA

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Please be aware that this publication may contain images and names of Aboriginal and Torres Strait Islander people now deceased.

Foreword

Environment Education Victoria acknowledges the generous support from the many contributors to this fifth edition of *Monitoring Environmental Systems*. VCE Environmental Science continues to expand as a subject, and as we head towards 2030 there is no more important time to shape the careers of young people aspiring to become environmental practitioners. The broad career options for young people studying Environmental Science, like the subject matter itself, will evolve, and the work taken on by students who continue along this path will be world changing.

We trust that this new edition provides teachers and students with the tools to go from awareness to deeper understanding to be able to improve local ecosystems and delve into the diverse opportunities to become part of the solution for global issues and climate change.

Committee of Management
Environment Education Victoria

ENVIRONMENT EDUCATION VICTORIA

Acknowledgement of Country

Environment Education Victoria acknowledges the Traditional Custodians and Elders of the lands on which we live and work. We extend our respect to Elders past, present and emerging of all First Nations peoples. We respect and uphold Aboriginal and Torres Strait Islander peoples' vital and continuing connection to the land, air, waters, culture and all living things.

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UNIT 7

How are Earth's dynamic systems interconnected to support life?

Living organisms are able to survive in ecosystems as diverse as deserts, sea beds, the tropics and Antarctica, as well as in backyard gardens and ponds. In this area of study students analyse the range of components and processes that contribute to ecosystem functioning, and examine how events occurring in one of Earth's four interrelated systems can affect all systems to support life on Earth.

The selection of learning contexts should allow students to develop practical techniques and undertake fieldwork to monitor and/or assess ecological integrity and to examine the inputs, processes and outputs of ecosystems. Students develop their skills in the use of scientific equipment and apparatus. They simulate or model population changes such as the effects of introduced species on predator–prey relationships, and develop their skills in selecting appropriate sampling methods to determine the number and proportion of different species present, such as transects and quadrats in fieldwork.

Outcome 1

On completion of this unit the student should be able to describe the movement of energy and nutrients across Earth's four interrelated systems, and analyse how dynamic interactions among biotic and abiotic components of selected local and regional ecosystems contribute to their capacity to support life and sustain ecological integrity.

AREA OF STUDY 1

How are Earth's systems organised and connected?

Key knowledge

Area	Section
Investigation of local ecosystems	
• the range of biotic and abiotic components that determine the environmental conditions of varied habitats within aquatic and terrestrial ecosystems	1.1
• interrelationships within ecological communities as represented by food chains, food webs, energy and biomass pyramids	1.2
Earth systems thinking	
• natural interactions between Earth's four systems – the atmosphere, biosphere, hydrosphere and lithosphere – that support and are affected by the movement of energy and matter within and between local and global ecosystems	2.1
• systems thinking as a way of exploring relationships in environmental systems by identifying inputs, outputs, components and processes that may be visible or invisible to the human eye, including representation of a local and regional environmental system	2.2

CHAPTER

1

Investigation of local ecosystems

CASE STUDY 1.1
Fires fuelled by climate change are damaging Earth's fundamental systems

Our planet consists of four interconnected spheres that make up all life on Earth. These spheres are the:

- lithosphere – solid ground
- atmosphere – all gases
- hydrosphere – all water
- biosphere – all life.

Natural disturbances, including earthquakes, bushfires, floods and drought, affect the components of individual spheres and can also change the way Earth's spheres interact with each other. As our climate warms, some natural disturbances, such as bushfires, are becoming more extreme and having a damaging impact on components of the interrelated spheres, such as wildlife, plants and soil.

Black Summer fires

In the Australian summer of 2019–20, known as Black Summer, the country saw possibly its worst bushfire season in history. Fires burnt on the east coast of Australia from June 2019 to May 2020, burning 18,636,077 hectares (ha) of land.

Thirty-four people died in the fires, and another 417 deaths were attributed to indirect effects, such as smoke inhalation and heat. Around 3,500 homes and 5,850 outbuildings were burnt, and the costs of the fires are estimated at approximately $103 billion.

Ecologists from the University of Sydney estimated more than one billion mammals, birds, and reptiles were lost, and scientists are concerned that entire species of plants and animals may have been wiped out by bushfire. The fires are estimated to have released around 306 million tonnes (t) of carbon dioxide into the atmosphere.

What caused the fires?

While the individual fires were largely caused by lightning strikes, the huge scale of the fires came about because of the dry forest environments. Large areas of forests were particularly dry because of widespread drought and record-breaking heat brought about by climate factors including:

- in the shorter term – weather patterns caused by a positive Indian Ocean Dipole (see p 91)
- in the longer term – climate change.

How climate change affects bushfires

Climate change intensifies both the size and frequency of bushfires. Researchers from Murdoch University, University of Tasmania, University of Wollongong and CSIRO are working to understand accurately the impacts of more frequent and larger ecological disturbances caused by bushfire. They have proposed a model, called the 'interval squeeze', to explain the effects of altered bushfire patterns (Enright et al. 2015). The model describes the challenges faced by fire-intolerant woody plant species in fire-affected ecosystems globally.

The interval squeeze model shows that warmer and drier conditions and more frequent fires give plants fewer opportunities for new plant growth. If the climate continues to get warmer and drier, woody plant species will on average produce fewer seeds, and fewer seedlings will survive. As areas become more fire-prone, these woody plants may not have long enough periods between fires to grow to maturity and produce enough seeds to sustain the population (Figures 1.1 and 1.2).

The 2019–20 bushfires posed similar threats to the biosphere. Such intense bushfires will ultimately drive some plant species to extinction, as populations will be limited in their means of reproduction and survival. These fires also had a devastating impact on wildlife, and some endangered species may have become extinct.

The carbon dioxide emitted by the fires would usually be reabsorbed by forest regrowth, but this might not be possible if some plants and forests can't regenerate in the time between fires. The air we breathe and the water we drink after a bushfire can damage our health, highlighting the importance of lessening the amount and intensity of bushfires.

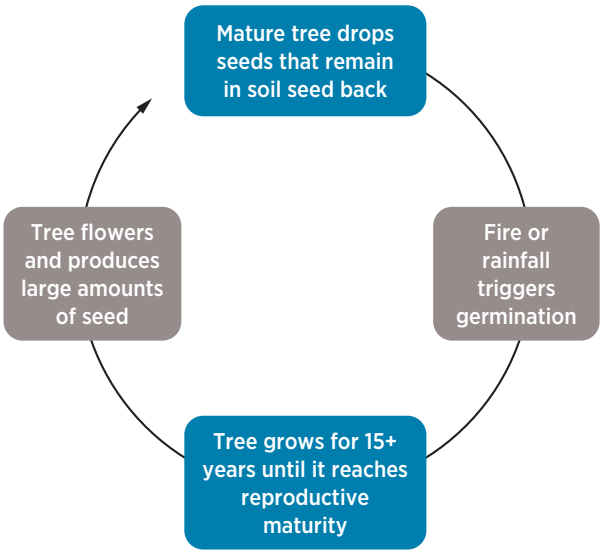


Figure 1.1. Forests regenerate when trees produce seeds that can grow to maturity

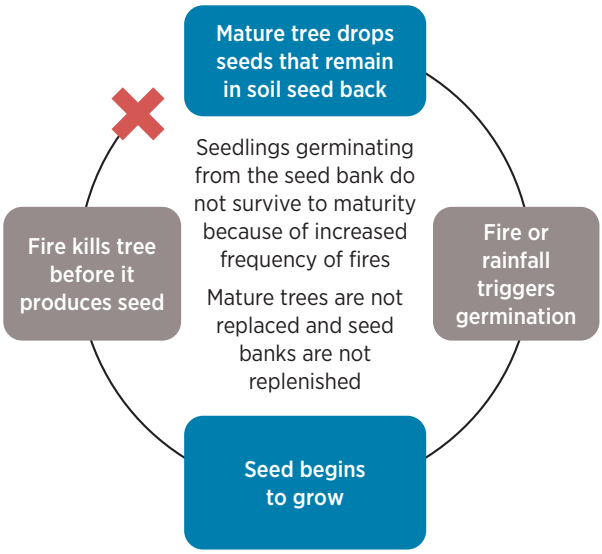


Figure 1.2. Fire-intolerant species can't regenerate when fires are frequent

The lithosphere, in particular the fertility of soil, altered considerably due to the fires as the soil was deprived of nitrogen, which is essential for plant growth. Poor soil quality can also have a negative impact on the hydrosphere, as the top layer of soil after the fires had burned and could be eroded by rain and wind into waterways such as streams or reservoirs. Sediment would accumulate in the waterways, which would result in siltation.

In all these ways, the fires affected all four of Earth's spheres.

Reference

Enright NJ, Fontaine JB, Bowman DMJS, Bradstock RA, & Williams RJ, 2015, Interval squeeze: altered fire regimes and demographic responses interact to threaten woody species persistence as climate changes, *Frontiers in Ecology and the Environment*, vol. 13(5), pp. 265–72.

Questions

1. **Determine** the science required to understand this case study.
2. **Describe** the types of technology that would assist with understanding or solving issues in this case study.
3. **List** the many stakeholders involved in this case study.
4. Using the definitions presented in 'Stakeholder values' (p 82), **describe** the values and priorities of the stakeholders involved. **Justify** your choice/s.
5. **Identify** the regulatory frameworks used to protect the environment that is described this case study.

CASE STUDY 1.2
EcoCheck: the Grampians are struggling with drought and deluge

John White, Associate Professor in Wildlife and Conservation Biology, Deakin University; Dale Nimmo, Lecturer in Ecology, Charles Sturt University; and Susannah Hale, PhD Candidate in ecology, Deakin University

This article was originally published in The Conversation, *9 September 2016.*
https://theconversation.com/ecocheck-the-grampians-are-struggling-with-drought-and-deluge-65097

The Grampians National Park is a large conservation reserve, sprawling across 168,000 ha embedded in western Victoria's agricultural landscape. With a rich cultural heritage and regionally important flora and fauna, it is a hugely significant area for conservation. But in recent years it has been subjected to a series of major wildfire events, a flood, and long periods of low rainfall.

Our research shows that this has sent small mammal populations on the kind of boom-and-bust rollercoaster ride usually seen in arid places, not temperate forests.

The fire and the flood

We began studying the Grampians in 2008, investigating how small mammals had responded to a catastrophic wildfire that burned half of the national park in 2006. What started as a 1-year study has turned into a long-term research program to investigate how the past few years of hypervariable rainfall and heightened bushfire activity have affected the animals that live in the park.

Fortunately (for our study, at least), the beginning of our research in 2008 was in the middle of a long run of very poor rainfall years, as the Millennium Drought reached its height. The drought was broken at the end of 2010 by the Big Wet, which led to well-above-average rainfall and floods in the Grampians.

But soon after, rainfall rapidly dipped back to below average. It has stayed there ever since. We also saw two more major fire events, in 2013 and 2014, which together with the 2006 fire burned some 90% of the Grampians landscape.

The reason this is fortunate from a scientific point of view is that this sequence of events has mimicked almost exactly the predictions of what climate change will bring.

We believe the Grampians is offering us a lens through which to look at future climate conditions and at how ecosystems will respond.

Animals on the wane

We have monitored small mammal communities at 36 sites throughout the Grampians each year since 2008. The system exhibited extremely slow recovery after the 2006 wildfires, with the mammal community dominated by the introduced house mouse.

Then all of a sudden, in 2011 and particularly 2012, the system went boom. Mammal numbers almost trebled. We were seeing species in areas where we had never found them before, and populations were flourishing.

It was amazing. But almost as fast as the system went up, it crashed back to low numbers again by 2013 and has stayed that way since. This boom and bust is not something we would expect to see in a temperate forest ecosystem such as the Grampians. It is more like what you would expect to see in arid ecosystems.

It is clear that rainfall is incredibly important for the region's small mammal communities. If the rain turns off, mammal numbers decline and they retreat to areas that offer enough resources for them to survive.

The rain is a critical bottom-up driver of this ecosystem, because it sparks plant growth, which in turn encourages invertebrates. Mammals depend on both for food.

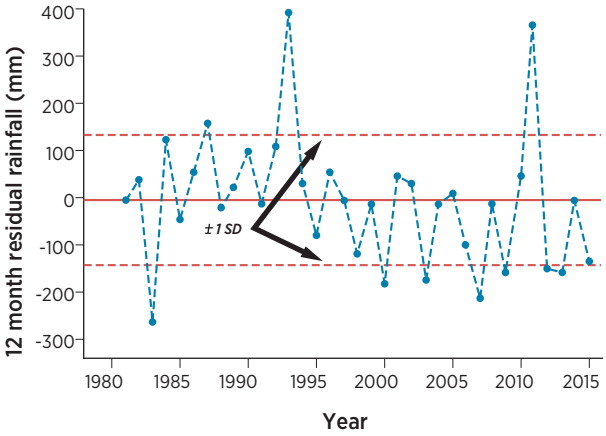


Figure 1.3. Rainfall relative to the long-term average in the Grampians region. Since the mid-1990s rainfall has rarely been above average, with the exception of 2011. Author provided

Figure 1.4. The Grampians' mammals, such as this heath mouse, ultimately depend on reliable rainfall. Author provided

The climate question

How can these findings inform us about the potential impacts of climate change? Maybe we need to look at what the broad predictions are for future climate conditions in south-east Australia. What we can expect is a general reduction in rainfall, with rainfall in many years falling well below long-term averages, punctuated by extreme rainfall events and floods.

We can also expect to see much more fire activity, with more frequent, bigger and more intense bushfires.

Our research suggests that places like the Grampians, which we thought would be fairly resilient to climate change, may be in far more trouble than we thought. We could potentially lose species entirely if the dry periods continue for too long.

Possibly more troubling is the potential interplay between flood events and subsequent fires.

Effectively, the flood events could be promoting fires. While this sounds counterintuitive, floods drive rapid vegetation growth and recovery, effectively priming the landscape for severe fires once rainfall dwindles again.

We saw this in 2013 and 2014, with major fires following on the heels of the 2011 floods. While fire is not a bad thing for ecosystems, our research has highlighted the critical importance of having a lot of long-unburnt vegetation in the system to promote the best conditions for mammal communities.

Unfortunately, the system has extremely limited long-unburnt vegetation. If climate change pans out in a similar way to what we have seen in the Grampians, the capacity for ecosystems to maintain such vegetation will be compromised, with worrying implications for native wildlife.

At this stage, the long-term prognosis for the health of the Grampians ecosystem is mixed. With very little long-unburnt vegetation, many small mammals will struggle until the vegetation ages. They may be waiting a long time if future rainfall and bushfire projections are accurate.

We commented earlier on how lucky we have been in getting such hypervariable rainfall conditions across the duration of our research. We could not have shown that a system like the Grampians is acting like an arid boom-bust system if we had not decided to take a long-term approach.

Long-term studies like this, however, are rare in Australia and most of our knowledge is thus limited to mere snapshots. If we had conducted typical short-term studies looking at the response of mammals to fire in 2009 versus 2012, we would have missed the intervening boom.

In the face of emerging climate change, we need to foster more long-term ecological research programs around Australia in different landscape types.

You can follow this research project on Twitter at @Wild_Gramps.

Questions

1. **Determine** the science required to understand this case study.
2. **Describe** the types of technology that would assist with understanding or solving issues in this case study.
3. **List** the many stakeholders involved in this case study.
4. Using the definitions presented in 'Stakeholder values' (p 82), **describe** the values and priorities of the stakeholders involved. **Justify** your choice/s.
5. **Identify** the regulatory frameworks used to protect the environment that is described this case study.

1.1. Components of the environment

The range of biotic and abiotic components that determine the environmental conditions of varied habitats within aquatic and terrestrial ecosystems

All organisms on Earth depend on and interact with a variety of **biotic** (living or once living) and **abiotic** (non-living) factors in the particular area or ecosystems where they are found.

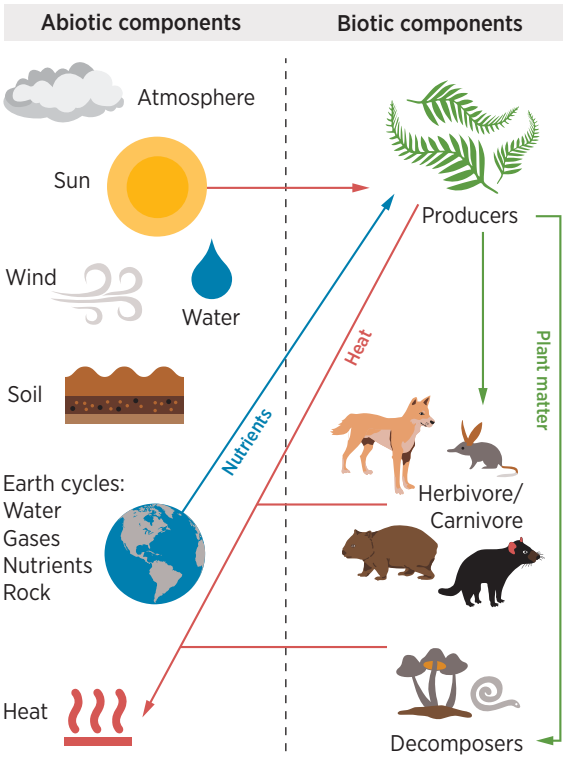


Figure 1.5. Interactions of biotic and abiotic ecosystem components

Ecology

The scientific study of ecosystems is called **ecology**. Ecologists study the interactions between living things and between living things and their environment. For instance, ecologists interested in why population sizes of a species may be increasing or decreasing can investigate biotic and abiotic factors such as the climate, numbers of predators, loss of habitat and food availability.

To understand these interactions it is important to identify the ecological levels within living systems on Earth, from the largest and most varied, to the smallest.

From biomes to individuals

The biosphere (all living things) can be broken down into components called **biomes**. Biomes contain many ecosystems. They are influenced by global weather and climate patterns, which determine the organisms that can survive in an area. Figure 1.6 shows a generalised map of the biomes around the globe.

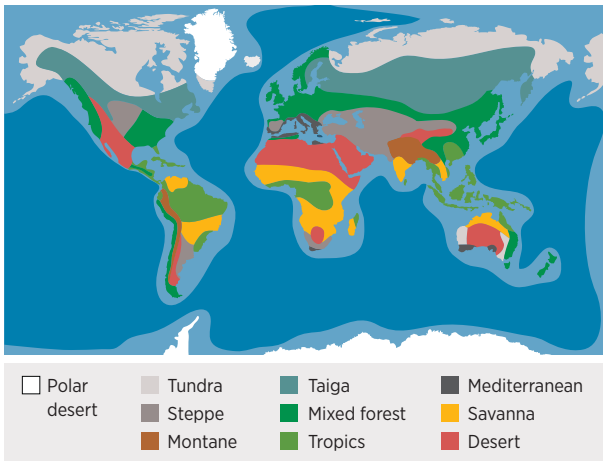


Figure 1.6. Map of general global biomes

An **ecosystem** is the total of all the different organisms that depend upon, and interact with, each other in a specific location, plus the abiotic factors that affect them such as wind, rain and tides. Ecosystems are made up of many **habitats** which are home to a variety of organisms (see Figure 1.7).

An ecosystem contains a number of communities. An ecological **community** is made up of the different **species** that interact at a specific location (habitat). Members of a species are all the organisms of the same kind that can breed together to produce fertile offspring. Groups of organisms belonging to a particular species and living in one area are called **populations**; populations are made up of **individuals** (Figure 1.7).

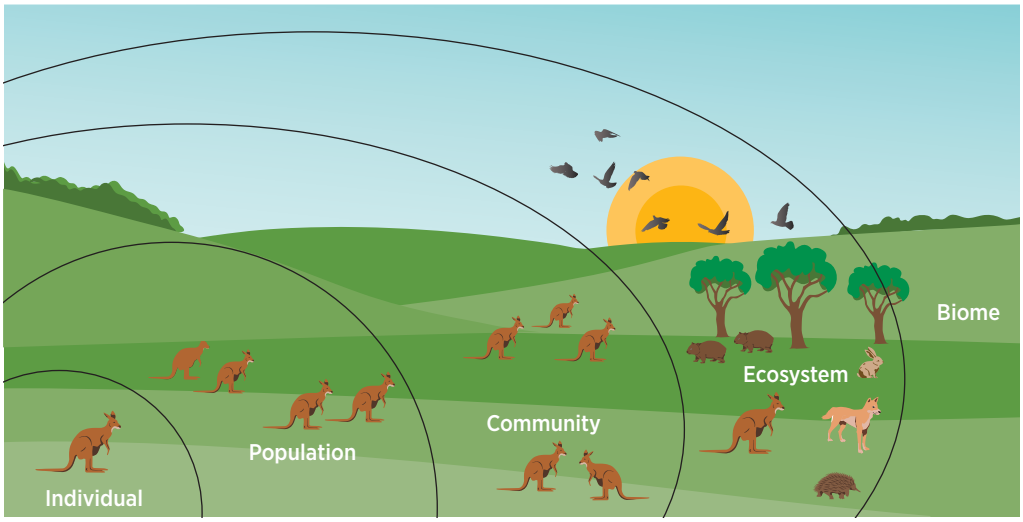


Figure 1.7. Levels of organisation within the biosphere

Ecosystem boundaries are not always well defined, and ecosystems often blend into one another along their borders. For example, a woodland forest can blend into a coastal heathland, the difference becoming more distinct as you get further from the boundary. A large region dominated by a particular type of vegetation can be viewed as an ecosystem, but ecosystems can also be smaller areas with more restricted interactions between organisms. For example, an ecosystem can be a rainforest, a creek or a log on the rainforest floor beside a creek. Land-based ecosystems are called **terrestrial**, and those in bodies of water are called **aquatic**.

Ecosystem processes

The **processes** operating within a system result in change to the **system**. A process is any movement, interaction or energy transfer occurring between the components of a system, whether physical, chemical or biological. Within a forest ecosystem, the following processes are likely to occur: erosion, deposition, growth, decomposition, condensation, evaporation, cell division, reproduction and death. Our basic ecosystem model can now be represented in Figure 1.8.

Figure 1.8. A basic ecosystem model

Figure 1.9 shows a forest ecosystem represented in the basic ecosystem model. You can see there are many abiotic and biotic processes that affect the system. For example, matter such as oxygen and carbon dioxide are abiotic components that determine the presence or absence of biotic ecosystem components.

Inputs	Components	Outputs
Matter – fauna – oxygen – carbon dioxide – humans	– fauna – flora – water – soils – rocks – climate	**Matter** – oxygen – water – wind-blown seed – timber
Energy – solar	**Processes** – respiration – photosynthesis – transpiration – translocation – reproduction – succession – cycling – decomposition	**Energy** – heat

Figure 1.9. A forest ecosystem (note the lists are not exhaustive)

Student activity 1.1
Science skills: Classification

1. Using your classroom as an example ecosystem, complete the following table by **classifying** abiotic and biotic components.

Abiotic	Biotic

2. Looking at the abiotic and biotic components, **describe** how you interact with each component. That is, how do you affect those components and how do they affect you?

3. **Justify** your answers to Question 2 by completing the following table, classifying your ideas according to the column headings.

Opinion	Evidence	Theory/explanation

4. **Explain** how you define the boundaries in your classroom ecosystem and justify your answer.

5. Answer the above questions (1–4) for an ecosystem of your choice from the classification of the Victorian ecosystems shown in Table 1.1 (p 12).

Victorian ecosystems

Ecosystems in Victoria are characterised by the type of vegetation they support. This vegetation is determined by abiotic factors such as temperature, soil type, rainfall, terrain, altitude and energy (such as wind or wave activity).

Broadly, Victorian ecosystems, as used by Parks Victoria in their conservation action plans, include alps, mallee, grassland, dry forest and woodland, wet forest and rainforest, heathland, inland water and wetlands, marine, and coastal.

Table 1.1 Victorian ecosystems and their characteristics

Type of ecosystem	Biotic and abiotic characteristics
Alps	Harsh climatic conditions; low temperatures; high winds; long periods of snow cover; short growing season
Mallee	Low and unreliable rainfall; poor soil fertility; sandy soil; high summer temperatures
Grassland	Waterlogged soil in winter; dry, cracked soil in summer; occurs in volcanic and alluvial plains
Dry forest and woodland	Widely known as dry sclerophyll forest; supports a wide variety of plant and animal species; small amount of rainfall; largely cleared for agriculture and timber
Wet forest and rainforest	Highly sensitive to fire; found in sheltered gullies **Cool temperate rainforests** typically in highland areas with higher rainfall, fertile soil, cooler temperatures **Warm temperate rainforests** typically in low-lying areas with lower rainfall, slightly warmer temperatures
Heathland	Widespread; low soil nutrients; poor soil drainage; occurs in regularly burnt areas in rocky landscapes and sand plains; experiences wide range of rainfall and temperatures; often occurs in areas with high wind and sun exposure; soil moisture periodically high
Inland waters and wetlands	Includes creeks, streams, rivers and lakes; can be permanent or ephemeral (short term); wetlands support natural processes that purify water

Type of ecosystem	Biotic and abiotic characteristics
Marine Includes estuaries, rocky reefs (subtidal and intertidal), seagrass beds, mangroves and saltmarsh, mudflats, and open water	High salt content **Estuaries** are a stretch of brackish (slightly salty) water where a fresh water river terminates at the sea. The brackish water is caused by the fresh water from upstream mixing with the marine water flushing into the open mouth of the river **Intertidal rocky reefs** are exposed at low tides; experience storm waves and extreme temperature changes; hypersaline in evaporating rockpools **Subtidal rocky reefs** are always submerged; can occur in deep and shallow water; sponge gardens in deep reefs and shaded areas cycle nutrients in oceans; kelp forests attach to rocks and provide an 'underwater forest' canopy **Seagrass beds** occur in sheltered water on silt or sand; trap soil and other materials **Mangroves and saltmarshes** occur on the margins of estuaries; experience regular inundation by seawater with varying influx of terrestrial fresh water; low wave action, intertidal zones, mostly muddy sediments; provide protection from erosion **Mudflats** (soft sediments) grow little vegetation; muddy sediments exposed to air at low tide; little oxygen below surface **Open water** is exposed to strong winds, large waves and powerful tidal currents
Coastal	Exposed to lots of salt spray and high winds; unstable sand; unstable soil with low nutrients; sandy soil holds little to no water; can be exposed to large waves; some coasts experience lots of erosion

Open, closed and semipermeable systems

One way to understand environmental systems is to look at the flow of energy and matter within and between different systems. Systems can be open, closed or semipermeable.

An **open system** exchanges matter and energy with other systems; it is not isolated from other systems. For example, ecosystems are open systems. Ecosystems are constantly exchanging inputs and outputs with other systems through the processes of biogeochemical cycles, individual organisms and food chains.

A **closed system** is isolated from other systems in the environment. A closed system does not exchange matter with its external environment, but even closed systems exchange energy. Closed systems don't occur naturally in the environment, although some people argue that Earth is a closed system. While Earth absorbs electromagnetic energy from the Sun, very little matter enters or departs Earth's system.

A **semipermeable system** is somewhere between a closed and open system: it permits some movement of energy and matter into and out of the system but does not freely exchange materials with its surrounding environment. A biological cell is an example of a semipermeable system.

Student activity 1.2
Science skills: Graphic organiser

Figure 1.10. What makes up an ecosystem?
Credit: designed by Freepik

Being able to organise your ideas is an important science skill. It helps you focus on important ideas and evaluate those ideas. One way of organising ideas is to use graphic tools such as brainstorming, SWOT charts, Venn diagrams and concept maps.

Concept map

A concept map is a series of words that are linked to one another to show relationships. To create a concept map:

1. Make a list of words for a given topic or idea.
2. Decide which of those words are the most important or highest priority.
3. Organise those key words on paper around the central topic or idea.
4. Link the key words to one another via a line with a connecting statement that explain why the words have a connection.

Now you will create a concept map.

1. Select and investigate an organism that is of interest to you.
2. Draw a concept map that represents your organism's place within each of the following elements of its environment: species, population, community, ecosystem. To display a comprehensive understanding of environments using a systems approach, include definitions and explanations of biotic and abiotic features in your concept map. This is done via the linking statements.

Critical and creative thinking and discussion 1.1

1. Opinions differ on how many biomes Earth has.

a) **Explain** why this is the case, including the key factors that characterise a biome.

b) **List** the five major biomes including the ecosystems they could support.

c) **List** the biomes found in Australia.

2. Using the example of an intertidal rocky shore:

a) **Explain** how changes to a biotic factor can affect this ecosystem.

b) **Explain** how changes to an abiotic factor can affect an ecosystem.

3. Choose an animal. Considering specific ecosystems, **design** a habitat that would suit your chosen animal.

4. Take a walk and photograph as many different ecosystems that you can. **Justify** why the areas in your photos can be considered ecosystems.

1.2. Ecological relationships and energy transfer

Interrelationships within ecological communities as represented by food chains, food webs, energy and biomass pyramids

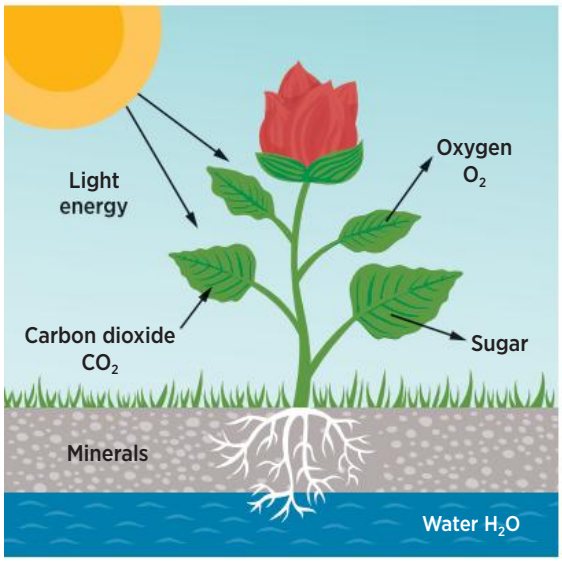


Figure 1.11. Simplified diagram of photosynthesis
Credit: designed by Freepik

Ecosystems rely on the transfer of energy to support life. **Organisms** require chemical energy for life-supporting processes such as growth, reproduction and movement. This energy originates from the solar energy (light) given off by the sun.

Organisms, such as plants, that can convert solar energy into chemical energy are called **autotrophs.** These organisms absorb solar energy and convert it into glucose (sugars with high energy stored in atomic bonds) during **photosynthesis.** Any organism that must obtain this chemical energy by eating another organism is known as a **heterotroph**. Animals are heterotrophs.

Food chains

Single feeding pathways within ecosystems can shown in a **food chain** (Figure 1.12). Energy flow is represented by the arrows in the diagram. Each feeding level in the food chain above is known as a **trophic level**, and each organism plays a particular role within a trophic level.

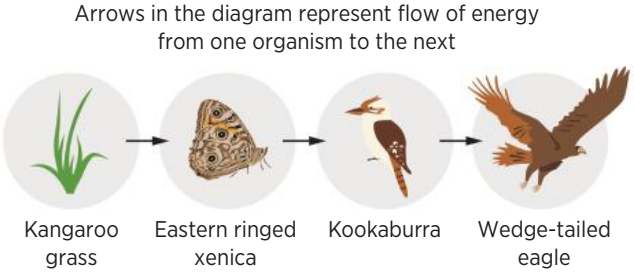


Figure 1.12. Food chain in an Australian native ecosystem

At the beginning of this food chain (**first trophic level**) is an autotroph, the kangaroo grass. Kangaroo grass produces its own chemical energy via photosynthesis and therefore can be called a **producer**.

An eastern ringed xenica butterfly eats the kangaroo grass, so energy is passed along the food chain. The butterfly needs to eat glucose as a source of chemical energy, so it is called a **consumer**. As the butterfly is the first consumer in this food chain, it is the **primary consumer**. The primary consumer in any ecosystem feeds on producers, and therefore occupies the **second trophic level** in the food chain.

As you go up trophic levels, you also get to higher levels of consumer. Figure 1.13 shows the relationship between trophic levels, levels of consumer and the Australian native species shown in Figure 1.12.

Flow of energy ↑

Role in the food chain	Trophic level	Producer/ consumer level	Example
Heterotroph	Fourth trophic level	Tertiary consumer	Wedge-tailed eagle
	Third trophic level	Secondary consumer	Kookaburra
	Second trophic level	Primary consumer	Eastern ringed xenica
Autotroph	First trophic level	Producer	Kangaroo grass

Figure 1.13. Relationship between trophic levels and roles within ecosystems

Food webs

In healthy ecosystems, organisms will usually have more than one food source, and will be eaten by more than one consumer, so food chains don't fully represent the way energy moves through an ecosystem. More complex feeding relationships between producers and consumers, involving multiple organisms at each level, can be shown in a **food web**. They show us that a particular organism can fit into multiple trophic levels, depending on its food source in that particular ecosystem.

In Figure 1.14, the dingo is a secondary consumer (third trophic level) when it is preying on the rabbit, wombat or kangaroo, but a tertiary consumer (fourth trophic level) when it is preying on the frill-necked lizard or the echidna.

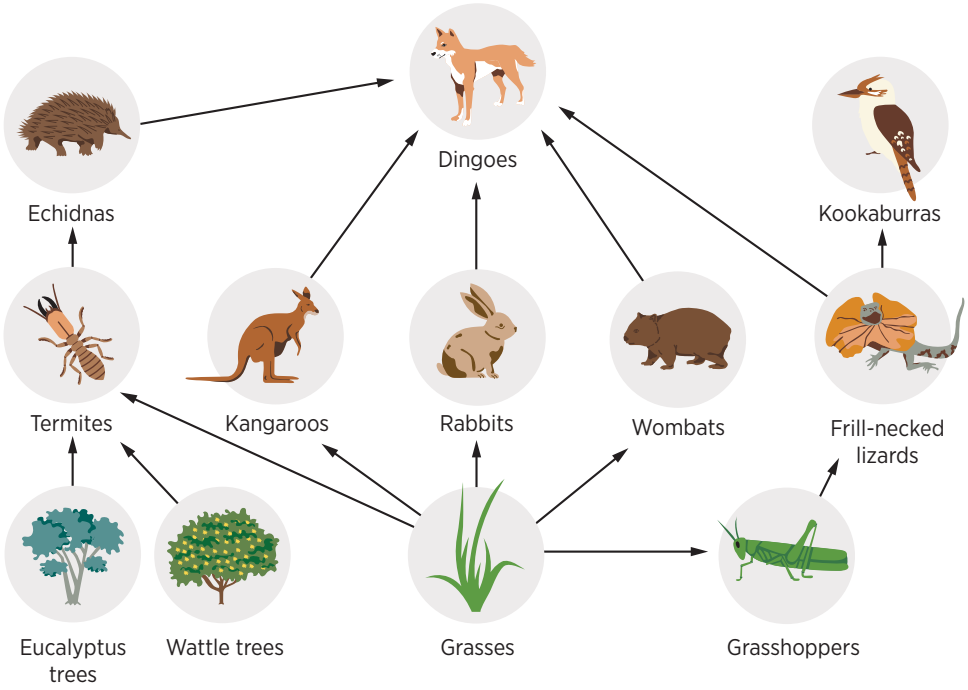


Figure 1.14. Food web showing complex feeding relationships in an Australian ecosystem

Biomass and energy-flow pyramids

Both food chains and food webs show the flow of energy in the particular ecosystem. At the base of every food web are the autotrophs (producers), who get their energy through photosynthesis. At each higher **trophic** level, consumers gain **energy** by feeding on organisms in the level below.

The second law of thermodynamics tells us that no energy conversion is 100% efficient. In food chains, an estimated 90% of energy is lost with each transfer to the next trophic level. In other words, only approximately 10% of the energy in any one trophic level is available as food for the organisms in the next level.

At each trophic level, some of the energy consumed is used for growth and other life processes (collectively called **metabolism**), but most is lost as heat to the environment. That explains why large areas of pasture are required to feed livestock, and why there are usually fewer predators than prey in an ecosystem.

The decreasing amount of energy available in each successive trophic level can be illustrated in an energy pyramid, which shows that each trophic level contains less energy than the one below it (see Figure 1.17, p 18).

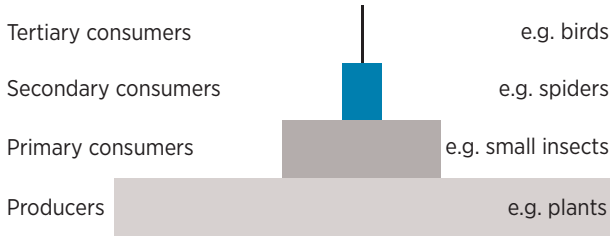


Figure 1.15. A biomass pyramid

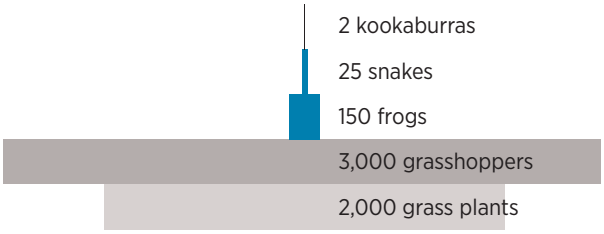


Figure 1.16. A pyramid of numbers

You can also look at an ecosystem's biomass pyramid, where biomass is measured as the total dry weight of living organic matter in a given area (Figure 1.15).

A **pyramid of numbers** (Figure 1.16) shows the number of organisms at each trophic level. This doesn't give an accurate picture of the amount of energy or biomass at each level. For instance, a single large tree (producer) can support many caterpillars (primary consumers) – the relative number of organisms at each trophic level will vary depending on their size and growth rates.

The basic concepts of food webs and energy flow can be applied to almost all ecosystems. Understanding the interactions between different levels of a hierarchy like the biomass pyramid can help you understand why observed changes may be occurring to an overall system (the **supra-system**).

For example, if you see a decline in the population of one species, you could explore its relationship with both the trophic level above (to see if predator numbers have increased) and the trophic level below (to see if food is in short supply). Exploring the levels above and below an organism (including changes in its habitat and ecosystem changes) will provide a better understanding of issues causing decline than looking at the system as a whole. This is an important process in environmental science because if we ignore changes on an individual level or system, we may be missing a much bigger piece of the puzzle that could have detrimental effects on the supra-system.

Decomposers

Food chains and food webs often leave out the decomposers. **Decomposers** are heterotrophic organisms that break down, and then consume, organic waste and dead organisms. Bacteria, fungi and some protozoans are all decomposers.

Decomposers are critical to the functioning of a healthy ecosystem. They play an important role in cycling nutrients, such as nitrogen and carbon, through the ecosystem. Decomposers ensure nutrients are available to autotrophs, which in turn produce sugars by photosynthesis.

Decomposers also ensure that dead matter doesn't over accumulate and cause an imbalance in the ecosystem. Decomposers are put into their own trophic level because they consume all other trophic levels.

Ecosystem productivity

Ecosystems that produce a large **biomass** are described as highly productive ecosystems. One example is a warm, shallow, sheltered estuary. There, the rich supply of nutrients carried by streams can support a vigorous seagrass community, where many fish, shellfish and birds feed and breed.

The productivity of an ecosystem depends on the amount of available nutrients and energy.

It is influenced by abiotic factors such as temperature, soil fertility and rainfall. Productivity is defined as the rate at which biomass is produced by an ecosystem. It can be measured by the biomass produced by an area per unit of time (for example, the amount of living material produced on a square metre of surface in 1 year). It can also be measured in terms of the amount of energy (kilojoules, kJ) that is locked up within the organisms per unit of time, for example, grams per cubic metre per year ($g/m^3/year$).

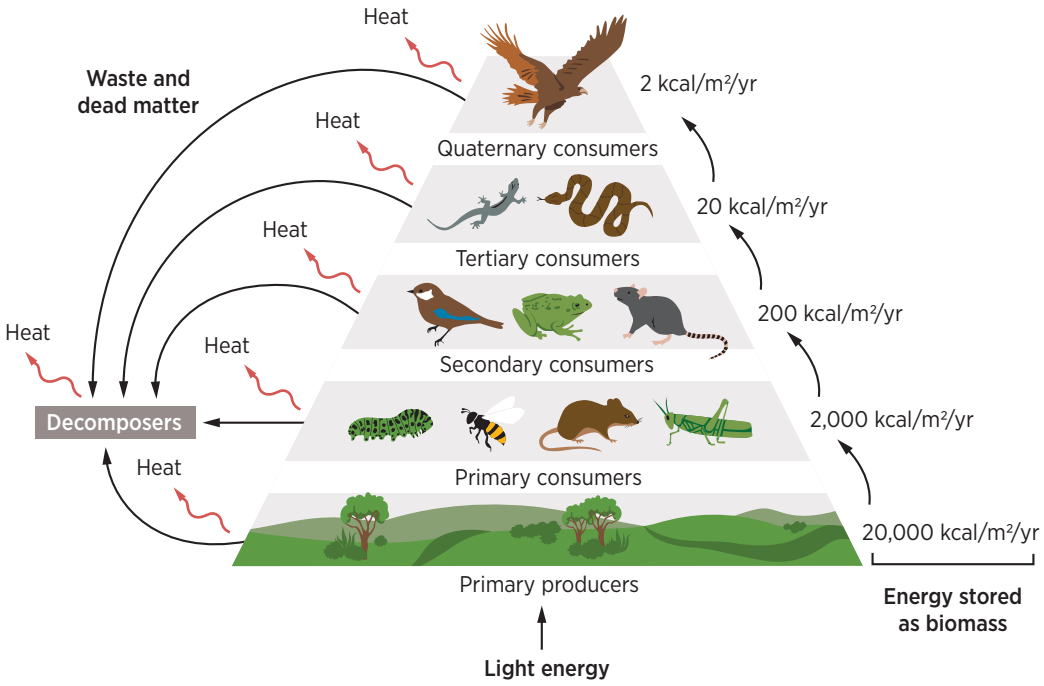


Figure 1.17. Energy pyramid showing movement and loss of energy at each trophic level

Practical 1.1 Field study: Creating a food web of a local ecosystem

Aim

To explore and collect data from a local ecosystem and collate your data into a food web.

Materials

- phone or camera to document images of species that you may not be able to identify
- field guide or similar resources to look up species feeding habits
- small square for observing small or fixed species such as those on a rocky platform

Procedure

1. Observe the species found in your ecosystem and list them in your results table. Document images if needed for further research.
2. Copy the results table.
3. Record in your table how each each organism interacts with the trophic levels above.
4. Back in the classroom, use your data to build a food web of your local ecosystem.

Results

Organism	Energy sources	Preyed upon by

Analysis

Consider the following as part of your data analysis.

1. **Identify** the producers in your food web.
2. **List** the consumers in your food web and identify their level (for example, primary consumer, secondary consumer).
3. **State** how many trophic levels there are in your food web.
4. **Explain** how the number of trophic levels relates to loss of energy in this particular ecosystem.
5. **List** any organisms that fit into more than one trophic level and explain how this is possible.
6. **Describe** how this food web may change in the coming years as the human population increases.

Discussion

1. **Describe** the relationship between photosynthesis and energy production in a food web.
2. **List** examples of decomposers in an ecosystem and explain the importance of decomposers.
3. **Compare** the movement of energy through an ecosystem with the movement of biomass through an ecosystem.
4. **Explain** this statement: 'Organisms can occupy various trophic levels in a food web'.
5. **Discuss** why most food chains and food webs are limited to four or five trophic levels.

Data analysis 1.1
Food webs

Figure 1.18 shows part of the food web for an Antarctic ecosystem.

1. **Identify** the primary consumer in this food web.
2. **Discuss** why the fur seal is described as a tertiary consumer.

Figure 1.19 shows a basic energy pyramid for the Antarctic ecosystem.

3. **Explain** the shape of the energy pyramid in Figure 1.19.
4. **State** two reasons for the decrease in energy available to higher level consumers.
5. If the phytoplankton produce 26,500 kJ of energy, **calculate** how much energy will be transferred to humpback whales?
6. **Predict** the effect overfishing the squid population would have on this ecosystem.

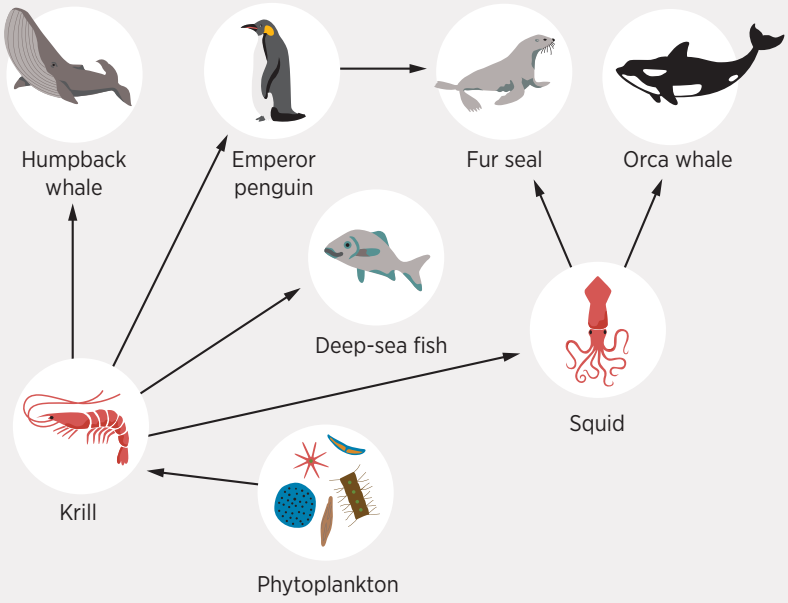


Figure 1.18. Marine Antarctic food web

Figure 1.19. Marine Antarctic energy pyramid

CHAPTER

2

Earth systems thinking

2.1. Earth's four systems

Natural interactions between Earth's four systems – the atmosphere, biosphere, hydrosphere and lithosphere – that support and are affected by the movement of energy and matter within and between local and global ecosystems

Earth as a system

Earth can be viewed as a series of interconnecting systems and subsystems. The three major non-living systems – the **hydrosphere** (water), **lithosphere** (land) and **atmosphere** (air) – determine the conditions under which organisms (living things – the **biosphere**) evolved and now live on Earth.

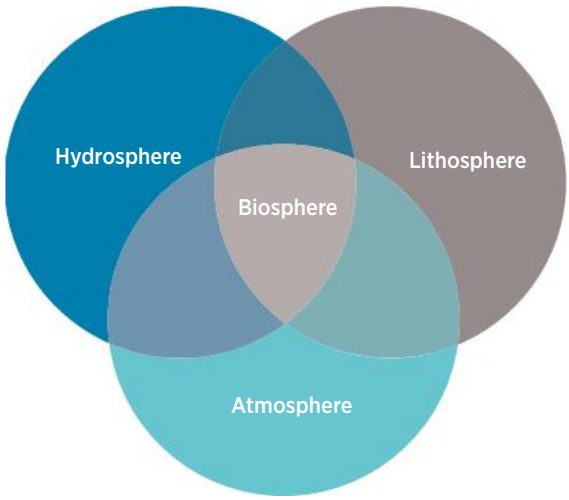


Figure 2.1. Interactions between Earth's systems

The biosphere

Together, all Earth's ecosystems form the **biosphere** – a band around the planet about 20 km thick, from the floor of the deepest ocean (11,000 m below sea level) to the tops of the tallest peaks (9,000 m above sea level). The biosphere is the region in which all organisms on Earth are found. Our knowledge of the limits of the biosphere is still being extended; for example, scientists have recently discovered bacteria deep in underground rocks and oil.

Plants, animals, microorganisms and other living things are referred to collectively as **biota**. The biosphere is also where the biota interact with the three other major systems.

An environment may be described as everything external to an organism. An organism's environment includes:

- biotic (living) components – other organisms
- abiotic (non-living) components – the air, water, light, oxygen, climate, soil and other physical factors.

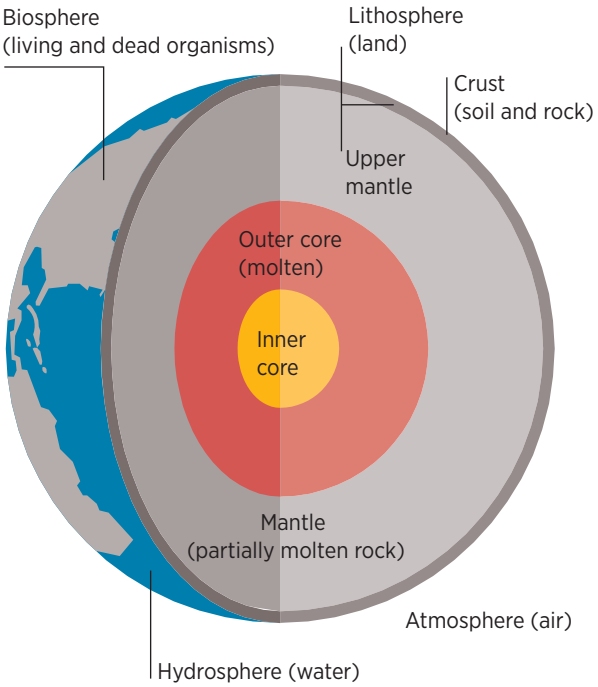


Figure 2.2. Our life-support systems: the general structure of Earth

The hydrosphere

The hydrosphere encompasses all the water found on Earth. Water is by far the most abundant liquid and is essential for all life. About 60% of human body weight is water. All organisms depend on water for their metabolism and many live only in aquatic (water) environments. The oceans and large lakes, together with the atmosphere, have a major effect on our climate. Water is constantly moving between the atmosphere, the soil, rocks, plants, animals and the water bodies on the planet.

Structure of the hydrosphere

Water is incredibly abundant, covering about 70% of Earth's surface. The hydrosphere includes oceans, lakes, ponds, streams, glaciers, groundwater and water vapour in the air.

The hydrosphere contains about 1.5 billion km^3 of water. Of this, about 97% is in the oceans and 0.6% is groundwater. Only about 2.5% is fresh water, and over two-thirds of that is frozen in glaciers and the ice caps of Antarctica and Greenland.

Groundwater

Groundwater is located below Earth's surface. Over time, water from rain and rivers infiltrates the ground and becomes stored in the spaces between grains of porous soils and rocks. Groundwater exists in vast quantities, flowing slowly through aquifers, connecting with rivers, streams, lakes and wetlands, and watering trees and vegetation.

Australia is a very old continent and much of its groundwater is tens of thousands, even hundreds of thousands of years old. The Great Artesian Basin (Figure 2.3) is the largest aquifer of its kind in the world, underlying 22% of the continent and containing water that is more than a million years old.

Figure 2.3. The Great Artesian Basin

In Australia, around a third of our total water consumption comes from groundwater, although the proportion varies from location to location. In the Northern Territory, 90% of water is sourced from aquifers, while the greatest groundwater use is in the Murray–Darling Basin. In many regions of Australia, particularly in the outback, groundwater is the only available source of water – numerous townships, farms and mines are totally reliant on groundwater. Farmers sink bores to bring water to the surface from artesian basins, and windmills use wind energy to pump water from hidden aquifers. In irrigation areas, vast quantities of bore water supply thousands of hectares of crops and pastures.

Even large cities depend on groundwater. For example, about 70–90% of Perth's water supply (excluding from their desalination plant) typically comes from groundwater, including the Gnangara Mound, where vast natural storages of groundwater occur in a large mound of sandy soil. In many places groundwater discharges naturally to the surface, bubbling into natural springs or flowing into rivers and wetlands.

Groundwater often plays a crucial role in sustaining rivers and streams, particularly during droughts when it becomes a valuable buffer against low rainfall. Australia is Earth's driest inhabited continent and has vast areas with limited surface water resources.

Many Australian ecosystems, including some of the most iconic, depend on groundwater. Groundwater is a finite resource, and aquifers can become depleted when extraction rates exceed replenishment, or **recharge**, rates. Like surface water, groundwater can become polluted or contaminated.

Processes in the hydrosphere

The properties of water have profound implications for living organisms. Water can dissolve many substances, and most of the chemical reactions within living things require water. Water in the environment may be **fresh**, **brackish** or **salt water**. Water cycles continuously through Earth's systems (see 'Water cycle', p 34).

Water can store large amounts of heat energy (it has a high specific heat capacity). Frozen water is less dense than liquid water and floats, insulating the water below and making it less likely to freeze. Since light can only pass through water to a limited depth, water cannot support plant growth below 200 m; less if the water is not clear.

The number and kinds of life forms found in aquatic environments are determined by the depth of the water, its temperature and its salinity. For instance, some organisms can live only in fresh water and others only in seawater. Relatively few species can tolerate a wide range of salinity.

The lithosphere

The lithosphere forms the outermost solid layer of Earth. It includes the crust and upper mantle (see Figure 2.2). This part of Earth's crust includes rocks and the rock cycle (see p 55) as well as soil.

The lithosphere is about 100 km thick and made of rigid rock. The outer layer of the lithosphere is Earth's crust, which is made up mainly of slabs of igneous rocks and soil. The crust is about 40 km thick under the continents but only 10 km thick under the oceans.

The lithosphere also includes the outer mantle. In some places, the top of the mantle is partly molten. This is where magma (molten rock) forms. At the centre of the Earth (below the lithosphere) is the core. The outer core is also molten and composed mainly of the metals nickel and iron. The inner core, composed of iron, is solid due to the intense pressure exerted by the weight of the planet pressing down on it.

The lithosphere is made up of large, mobile plates that fit together like a giant jigsaw puzzle. The continents and oceans resting on these plates are carried around with the plates as they move. This movement and the processes that occur at the margins of the plates is explored in more depth in 'Plate tectonics' (p 53).

Student activity 2.1
Science skills: Observation and inferences

Scientists make **observations** to discover explanations for certain occurrences in the natural world. Careful observations are the basis for conclusions of scientific investigations. Scientists can also infer. **Inferences** are conclusions drawn without direct observations but on the basis of evidence and reasoning. For example, I did not see the sun rise this morning but it is reasonable to infer that it has because I can see it in the sky. To be able to accurately infer takes skill. You should only infer with caution to ensure you don't make untrue claims.

Volcanoes of Victoria

Observations

Research and identify a region in Victoria that has been volcanically active. Describe the general physical, chemical and biotic characteristics of the area.

1. Print a map of Victoria on an A3 piece of paper and mark all the volcanoes that have existed in Victoria, as well as the time period each was active. You will need to research this to complete the task.
2. Choose one of the volcanoes you have noted on your map and describe how the ecosystem around the volcano would have changed over time.

Inference

Over time, Victoria has had a number of dormant and active volcanoes.

3. What can you infer about why Victoria had active volcanoes in the past and why we do not have any today?

Figure 2.4. Mount Noorat is a dormant volcano in Victoria. Credit: Peterdownunder CC BY-SA 4.0

Soil

Soil is a mixture of particles formed over long periods of time by the weathering of rocks and the remains of dead organisms. Rocks eventually break down into minerals, yielding mineral salts essential to the growth of plants. Dead organisms decay to form a dark organic material called **humus**. Soil containing large amounts of humus is fertile and retains moisture. Soil contains vast numbers of worms and other invertebrates (animals without backbones), microorganisms, fungi and other biota.

Soil types and structure

Soil particles range in size from gravel (particles more than 2 millimetres (mm) across), sand, then silt, to clay (less than 0.002 mm across). The proportion of these particle sizes determines the texture of the soil. The texture is a guide to the properties of the soil, including density, aeration, drainage and the soil's capacity to hold water and nutrients. Sandy soils allow water to pass through rapidly, while clay soils retain water for long periods. The best soils for growing most crops are loams, which contain roughly equal amounts of sand, silt and clay. Soils high in clay can become waterlogged, which reduces oxygen availability to the roots of plants because water has a limited capacity to dissolve oxygen.

The **porosity**, which is the number and size of the spaces (pores) between the particles, also determines the **structure** of the soil. The pores allow air and water to penetrate the soil. Productive soils have a variety of particle sizes and plenty of pores of various sizes. Large pores allow the soil to drain rapidly when wet, while fine pores retain water in dry periods. The structure of soil can be damaged by being repeatedly compressed by heavy machinery, vehicles and the feet of livestock and humans, a process known as **soil compaction**.

The availability of nutrients for plants is a measure of **soil fertility**, and depends largely on the type of parent rock and the climate. For example, soils formed on volcanic rocks, such as basalt, in areas with a good rainfall are highly fertile.

Fertility also depends on **soil pH**: most plants grow best in almost **neutral** soil (around pH 7), although some prefer **acid** soil (pH <7) and others do better in **alkaline** soil (pH >7).

Soil profiles

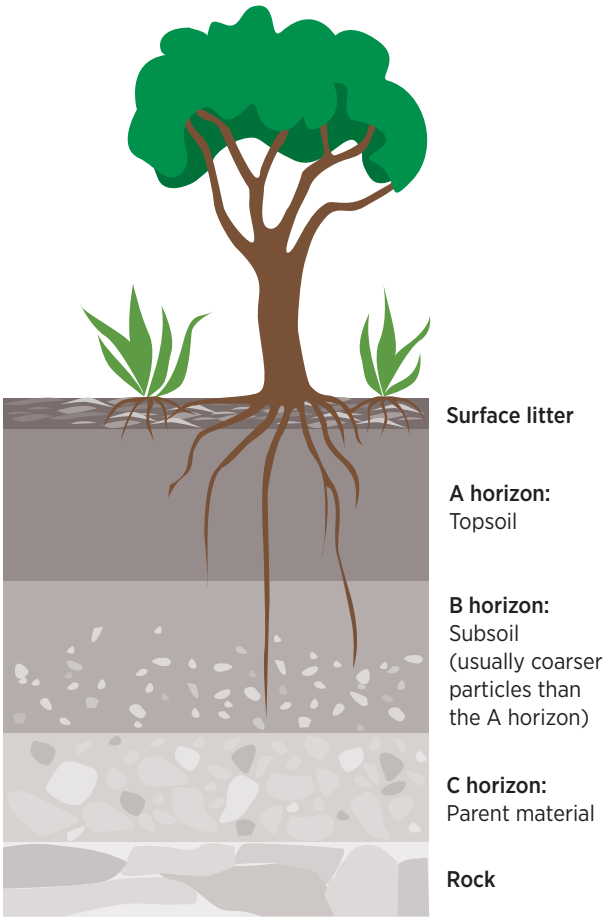


Figure 2.5. Soil horizons

Soil profiles consist of layers called **horizons** (Figure 2.5). You can see soil profiles in roadside cuttings or quarries. The A horizon (topsoil) is fertile. The B horizon (subsoil) receives clay particles and soluble particles washed down from the A horizon. The C horizon is the parent material. On top of the A horizon may be plant litter, such as leaves, twigs and bark. This decays to form humus, which becomes part of the A horizon. The depth and structure of the A horizon is important because most soil organisms live in this zone.

Student activity 2.2
Science skills: Stakeholder perspectives

Much of the way science is presented has humans as the central object. If we consider Earth as a system, it is clear that humans are not the only living organisms, so humans are not the only stakeholders. Stakeholders are all the organisms included in a process. In some environmental decision-making processes, non-human stakeholders are not adequately represented. As environmental scientists, we have a duty to consider all stakeholder values, human and non-human. This is summed up very well by Dr Suess in *The Lorax*: "I am the Lorax – I speak for the trees".

I am the Lorax – I speak for the earthworms!!!

Find out how earthworms affect the structure and fertility of soil. Make a list of all the stakeholders. Present research findings from the point of view of the earthworm along with an illustrated poster with a catchy title or slogan.

Practical 2.1
Soil investigations

NOTE: This practical has a range of parts to it and can be undertaken in its entirety or as individual activities.

Part 1 Soil pH

Aim

To determine the pH of soil samples.

Equipment

- soil samples from several sites
- soil pH test kit or barium sulfate and universal indicator
- white container or Petri dish placed over a white tile
- spatula

Procedure

1. Place a small sample of soil in the white container.
2. Follow the instructions on the pH test kit OR add barium sulfate and a few drops of universal indicator.
3. Leave sample for about 30 seconds.
4. Compare the colour with the test kit colour chart or the universal indicator colour chart to determine the pH.

Results

Record your results in a table.

Discussion

1. **Suggest** any reasons why the pH of your soil sample varied.
2. The acidity of the soil influences the plant species that can grow in an area. Which of the soil samples that you tested would be suitable for the greatest variety of plants? **Explain** your answer.

Part 2 Soil water content

Aim

To calculate soil water content.

Equipment

- balance
- crucible or dish
- incubator or hotplate
- soil sample

Procedure

1. Weigh the crucible. Add 100 g soil to crucible.
2. Place the soil and crucible in an incubator or heat on a hotplate. Heat for approximately 1 hour at 110 °C.
3. Weigh the dried soil and crucible.

4. Calculate the amount of water in the soil by using this formula:

$$\% \text{ water content} = \frac{(C - D) \times 100\%}{B}$$

Where:
A = crucible weight
B = soil weight = 100 g
C = crucible + soil = A + 100 g
D = weight of dried soil + crucible = dried soil + A

Results

Record the final result.

Discussion

1. Were you surprised by the amount of water in the soil? **Explain** why.
2. Water is needed by plants for photosynthesis and for the replacement of water lost through transpiration. **Explain** how water enters the plants so it can be used.

Part 3 Soil texture

Aim

To determine the texture of a variety of soil samples.

Equipment

- a variety of soils ranging from sand to clay
- water

Procedure

1. Take a sample of soil (about the size of a golf ball) and break up any clods.
2. Moisten the soil with water to form a ball, knead it for a minute.
3. Test the texture by pressing the ball between your thumb and forefinger to make a ribbon. Observe whether and how the soil ball holds together, the length of the ribbon, and whether it feels gritty, silky or like plasticine. To decide the soil's texture refer to Table 2.1.

Results

Record your results in a table.

Discussion

1. Is there a relationship between soil texture and water content? **Explain**.
2. **Suggest** ways in which soil texture might influence the distribution of plant species.

Table 2.1 Soil texture categories

Ball	Ribbon length	Feel	Texture
Will not ball		Single grains of sand sticking to fingers	Sand
Ball only just holds together	0.5 cm	Gritty	Loamy sand
Ball just holds together	0.5–1.3 cm	Sticky, sand grains stick to the fingers	Clayey sand
Ball just holds together	1.3–2.5 cm	Very sandy to touch, visible sand grains	Sandy loam
Ball holds together	1.3–2.5 cm	Fine sand can be felt	Fine sandy loam
Ball holds together strongly	2–2.5 cm	Sandy to touch, sand grains visible	Light sandy loam
Ball holds together	2.5 cm	Spongy smooth, but not gritty or silky	Loam
Ball holds together	2.5 cm	Slightly spongy, fine sand can be felt	Loam
Ball holds together	2.5 cm	Very smooth to silky	Loam, fine sandy
Ball holds together strongly	2.5 cm	Sandy to touch, medium sand grains visible	Silt loam, sandy clay loam
Ball holds together	3.5–5 cm	Plastic, smooth to manipulate	Clay loam
Ball holds together	7.5 cm	Plastic, smooth handles like plasticine and can be moulded into rods	Clay

Source: McGuinness, S, 1991, Soil structure assessment kit: a guide to assessing the structure of red duplex soil, Department of Conservation and Environment: Bendigo, Victoria.

The atmosphere

The **atmosphere** is the gaseous envelope of air that is held close to Earth's surface by gravity. The atmosphere is the very air that we breathe, and higher layers of atmosphere protect life on Earth from harmful radiation and cosmic debris.

Close to Earth, the atmosphere consists mainly of gases in the proportions shown in Table 2.2. Some other gases are found in even smaller amounts.

Student activity 2.3
Science skills: Communication

Many people try to climb to the summit of Mount Everest. Using your knowledge of the structure of the atmosphere, design an information flyer for what climbers might expect when climbing Mount Everest. Include a description of the biotic and abiotic factors that will affect climbers as well as a list of equipment and your rationale for that equipment.

Structure of the atmosphere

The atmosphere is made up of four major layers: the **troposphere**, **stratosphere**, **mesosphere** and the **thermosphere** (see Figure 2.6). The boundaries between these layers are, in order of increasing altitude, called the **tropopause**, **stratopause** and **mesopause**. Beyond the thermosphere is a fifth layer, the **exosphere**, where Earth's atmosphere fades away into space.

Because of gravity, air is most dense near Earth's surface, and three-quarters of the mass of the atmosphere is found in the troposphere. This lowest layer of the atmosphere extends to an altitude of about 15 km, and it is the region where visible clouds form and where all our weather takes place.

A total of 99% of the atmosphere's mass is within 30 km of Earth's surface. In the troposphere, the principal components of the atmosphere are the gases nitrogen, oxygen, argon (an inert gas) and carbon dioxide.

Table 2.2 Gases in the atmosphere near sea level

Atmospheric gases	% of the atmosphere
Nitrogen (N_2)	78.09
Oxygen (O_2)	20.94
Argon (Ar)	0.933
Carbon dioxide (CO_2)	0.035
Water vapour (H_2O)	About 1
Neon (Ne)	0.0018
Helium (He)	0.00052
Methane (CH_4)	0.00015
Krypton (Kr)	0.0001

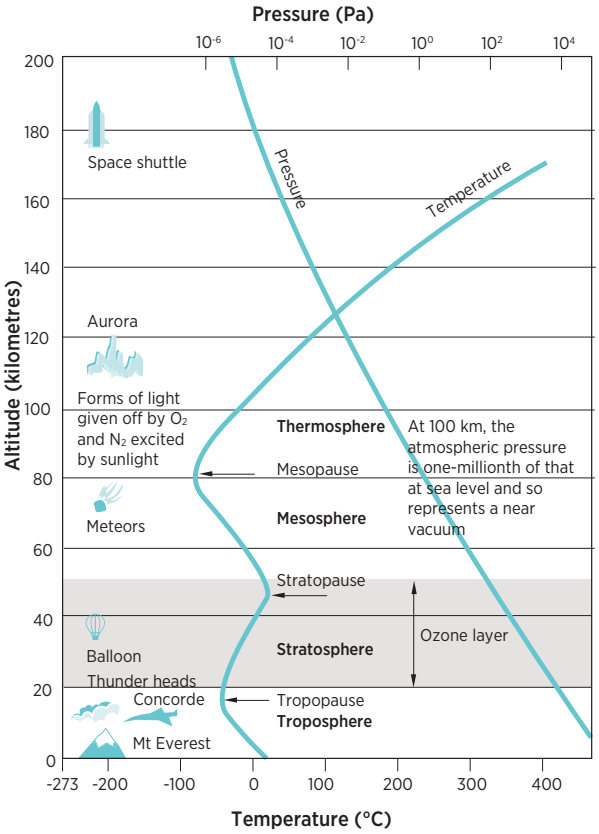


Figure 2.6. The vertical structure and temperature of layers in the atmosphere

The stratosphere lies between 15 and 50 km above Earth's surface. The mesosphere extends to an altitude of about 80 km. The lower part of the thermosphere extends from 80 km above the surface of Earth to 550 km. The thermosphere includes the ionosphere – not technically an atmospheric layer, the ionosphere is a layer of ionised air in the atmosphere.

Student activity 2.4
Science skills: Representing data

Investigating the composition of the atmosphere

1. Using the data in Table 2.2, draw a pie chart to visually represent the proportions of the principal components of the atmosphere near sea level.
2. Research the composition of the atmosphere in the stratosphere, mesosphere and thermosphere. Compare your findings to your pie chart and discuss possible reasons for similarities and differences.

Processes in the atmosphere

The atmosphere warms up in layers where incoming **solar radiation** is absorbed. Figure 2.6 shows that the temperature decreases from Earth's surface to the top of the troposphere, increases in the stratosphere, decreases again in the mesosphere and then increases in the thermosphere.

At ground level in the troposphere, solar radiation takes the form of **visible light** and **infrared radiation** (which you feel as heat). Most of the energy of the Sun passes through the atmosphere unimpeded and heats Earth's surface. Earth then emits heat, which warms the air just above the surface. The warm air rises and, because of the decrease in air pressure with altitude, the air expands. This expansion cools the air, which stops rising when it reaches the same temperature as the surrounding air.

This process explains why the air is colder the higher it is in the troposphere. At the top of the troposphere, the average temperature is about −60 °C. This is cooler than the layer above.

The convection currents set up by this process carry gases released from Earth and mix them throughout the troposphere. The mixing can take as little as a few days or as long as a few months.

On cold, clear nights, the rising of warm air, and hence the mixing of gases, may be prevented by a layer of cold air trapped near the ground. This happens when the air at ground level cools faster than the air higher up. Because cold air does not rise, the lower layer fails to mix with the warmer air above. This situation, where the air temperature increases with height, is called a **temperature inversion** (see Figure 2.7). The inversion remains until the Sun rises and heats the ground. This heats the layer of cold air, which rises once it is warmer than the air above. Inversions can cause serious air quality problems in cities when exhaust fumes and other pollutants cannot escape into the upper troposphere.

In the stratosphere, energy in the form of **ultraviolet (UV) radiation** from the Sun is absorbed, so the temperature of the air increases with the distance from Earth's surface. As a result, gases released from Earth can take years to mix evenly to the top of this layer. The stratosphere acts like a lid on the atmosphere. The upper stratosphere contains the ozone layer. The temperature at the top of the stratosphere maintains temperatures close to 0 °C.

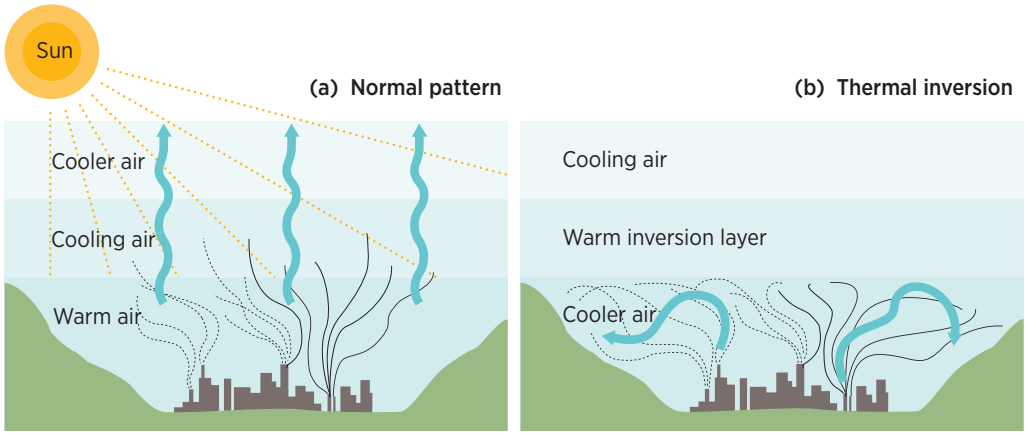


Figure 2.7. A temperature inversion

In the mesosphere, the temperature decreases sharply to −100 °C before it begins to rise at the top of this layer, where ozone and oxygen molecules absorb energy from UV rays.

In the top layer (the thermosphere), the temperature increases as the air molecules absorb energy from gamma rays and X-rays from the Sun and other stars. The temperature is lowest at the bottom of this layer because most radiation is absorbed at the top.

The lower part of the thermosphere includes a layer of ionised air called the **ionosphere** (which is technically not another atmospheric layer). There are relatively few air molecules in the ionosphere, but the energy they absorb produces large numbers of ions. An ion is an electrically charged particle produced when an atom loses or gains one or more electrons in a process called ionisation.

The ions in this layer produce the spectacular displays of the aurora australis (southern lights) and aurora borealis (northern lights) that can be seen near the poles. The free electrons in this layer reflect long-wavelength radio waves back into space. Usefully for us, they also reflect short-wave radio signals, like those used in radio broadcasts, back down to Earth where they can be received thousands of kilometres away.

Beyond the ionosphere, extending out to around 10,000 km, is the **exosphere** or outer thermosphere, which gradually merges into space.

The ozone layer

Ozone is a molecule of three atoms of oxygen (O_3). Ozone is found only in tiny amounts at ground level. A relatively high concentration occurs in the ozone layer in the middle stratosphere, 19–50 km above Earth.

Ozone forms when ultraviolet light strikes oxygen (O_2) molecules, forming individual oxygen atoms.

$$O_2 \xrightarrow{\text{UV radiation}} 2O$$

These oxygen atoms are then free to combine with another molecule of O_2 to form ozone (O_3). In this reaction, heat is released and another molecule must be present to absorb the heat.

$$O + O_2 \rightarrow O_3 + \text{heat}$$

This ozone layer is important to the survival of life on Earth because ozone absorbs ultraviolet radiation from the Sun. Skin cancer, genetic damage and immune system suppression in humans, as well as reduced productivity in the food chain, have all been linked to the short wavelengths of UV radiation. The ozone layer protects life on Earth from this damage.

Ozone is broken down by visible light. The ozone concentration depends on the balance between the action of ultraviolet light and bright light. This balance has been altered by human-produced chemicals, such as chlorofluorocarbons (CFCs).

Interaction of components of Earth's systems

The hydrosphere, lithosphere, atmosphere and biosphere interact in many ways and affect our weather and climate. **Weather** is the day-to-day changes in conditions of the atmosphere, such as temperature, humidity, precipitation (rain, hail and snow), solar radiation, air pressure, wind speed, wind direction and cloud cover, at a particular location. **Climate** describes the average weather conditions of a place over many years. Climate is determined by such factors as latitude, position relative to oceans or continents, and altitude.

Oceans act as a huge heat sink. They are much slower to heat up and slower to cool down than the air above, so they delay any changes to the air temperature. People who live on the coast are well aware of the moderating effect the ocean has on the climate, cooling the air by day and warming it at night.

Ocean currents and winds are set up by the uneven heating of the globe, caused by more heat being received at the equator than at the poles. This imbalance sets up convection currents in the atmosphere and oceans, which transfer heat away from the equator. For example, Australia is warmed by ocean currents moving southwards from the equatorial region. Small changes in the temperature of these currents have major effects on our climate. The El Niño droughts caused by such changes are described in 'Changes over years' (p 59).

The oceans are also a carbon sink; they take up far more carbon dioxide from the atmosphere than they release. The carbon dioxide dissolves in the uppermost layer of seawater, where it is dispersed by waves and currents and taken up in the ocean by tiny algae (called phytoplankton) for photosynthesis. Over time, through the death of the plankton and its consumers, the carbon ends up in sediments at the bottom of the ocean. It may be locked up there for millions of years. Eventually, the sediments form rock, which may reappear as land when changes in sea level or movements of Earth's crust cause the sea floor to rise.

Water shapes the landscape in many ways. The amount of rainfall in a region has a major effect on the extent of rivers and lakes and the abundance and types of vegetation. This, in turn, influences the kinds of animals that can live in an area and the populations it can support.

Vegetation cover influences climate by increasing the amount of water evaporating from the soil. Water is taken up from the soil by plants for use in photosynthesis and evaporated through transpiration from the leaves. Transpiration is the reason clouds form more readily over vegetated areas than over desert regions. The rate of evaporation of water from the sea and other parts of the hydrosphere determines the amount of water vapour in the air. This, in turn, influences the amount of precipitation, mist or fog that forms when the water vapour cools and condenses.

Student activity 2.5
Science skills: Graphic organiser – lotus diagram

A lotus diagram is a type of graphic organiser that is useful for complex ideas. You begin with a 3 × 3 grid in the centre that holds the main idea and up to eight sub-ideas.

From each identified sub-idea, a further eight ideas radiate with more detail about the sub-idea (Figure 2.8).

Draw a detailed and informative lotus diagram of Earth's four systems. Consider important aspects of their interactions as well as their individual components and processes.

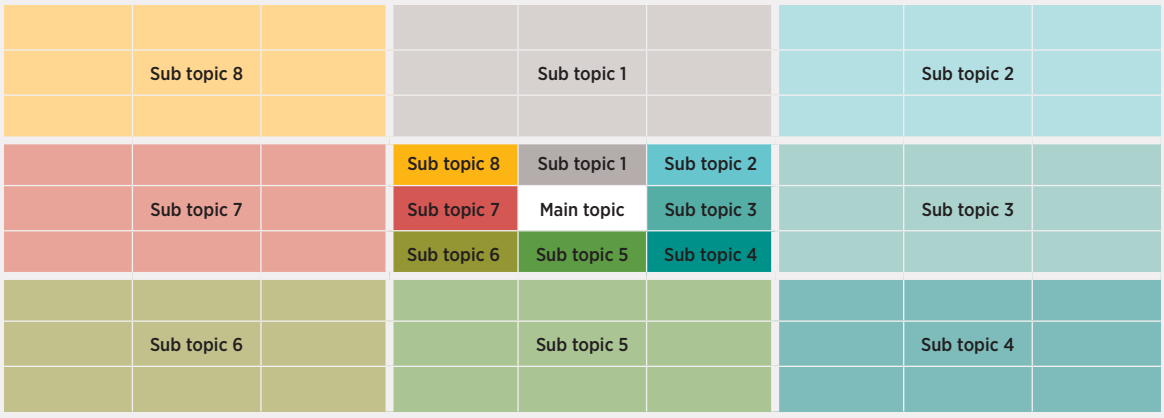


Figure 2.8. A lotus diagram

2.2. Environmental systems

Systems thinking as a way of exploring relationships in environmental systems by identifying inputs, outputs, components and processes that may be visible or invisible to the human eye, including representation of a local and regional environmental system

What is a system?

A system is a thing or process that functions as a complex and unified whole through the interacting, interrelated or independent parts. These interactions are affected by feedback loops; therefore, the status of one component affects the status of another component. Exploring relationships using **biogeochemical cycles** shows how biologically important elements and molecules flow through the biosphere, atmosphere, hydrosphere and lithosphere.

Biogeochemical cycles

Nearly 40 of the naturally occurring elements on Earth are essential for living organisms. **Carbon**, **oxygen**, **sulfur**, **phosphorus** and **nitrogen** are the most important of these critical nutrients.

Unlike the unlimited supply of energy that Earth continously receives from the Sun, Earth's supply of elements needed for life is limited. Elements are not continually produced, instead they are withdrawn from global atmospheric and geological stores, used in various ways and then eventually returned to the stores in continuing cycles. These cycles are called **biogeochemical cycles** or **nutrient cycles**.

Biogeochemical cycles are driven directly or indirectly by solar energy and gravity. All rely on the actions of the biotic and abiotic components of ecosystems. Nutrients cycle through the atmosphere, water, soil and organisms. Nutrients are released by the weathering of rocks and deposited in sediments at the bottom of seas or lakes, eventually forming new rocks. Here the nutrients remain, perhaps for millions of years, until the rocks are uplifted and eroded and the cycle begins again.

Carbon–oxygen cycle

The carbon–oxygen cycle (see Figure 2.9) is driven largely by Earth's biosphere. It depends on the capacity of plants to photosynthesise, thereby absorbing carbon dioxide from the air and incorporating the carbon into glucose, starch and other molecules. The carbon moves up the food chain when animals eat the plants and are, in turn, eaten by other animals.

At each stage in the food chain, some carbon is released back into the atmosphere as carbon dioxide through respiration. Aerobic respiration is the process by which animals, fungi, microorganisms and plants break down glucose to produce energy. In the process, they consume oxygen and produce carbon dioxide. Aerobic respiration can be described by this equation:

$C_6H_{12}O_6$	+	$6O_2$	→	$6H_2O$	+	$6CO_2$	+	energy
glucose		oxygen		water		carbon dioxide		

In the absence of oxygen, a process known as anaerobic respiration occurs. During anaerobic respiration, glucose ($C_6H_{12}O_6$) breaks down in the presence of a suitable catalyst to ethanol (C_2H_5OH) and carbon dioxide (CO_2), releasing energy in the process.

The balance of oxygen and carbon dioxide in the atmosphere is maintained by the organisms on our planet. Scientists estimate that the plants on Earth contain about 6×10^{11} t of carbon, and the soil another 16×10^{11} t. This balance, with the processes of photosynthesis and aerobic respiration working in parallel, is critical to sustaining life on Earth.

Higher levels of atmospheric carbon dioxide have led the ocean to absorb increasing amounts.

Carbon dioxide dissolves in water to form a weak acid called carbonic acid (H_2CO_3), and the extra input from the atmosphere is causing ocean acidification. Carbonic acid slowly breaks down rocks containing calcium silicate, releasing ions once part of living creatures, such as molluscs, corals and certain phytoplankton. These marine organisms build protective skeletons or coverings of calcium carbonate, and as the ocean's pH drops, their shells can dissolve in the acidic water. The decomposition of organisms and the weathering of limestone (calcium carbonate) rocks returns carbon into the system. Volcanic eruptions are another source of carbon dioxide.

Since the Industrial Revolution, humans have increased the amount of carbon released into the atmosphere by burning fossil fuels (such as coal, oil and gas) and by deforestation. The fossil fuels were formed by the accumulation of dead plants in waterlogged soils, where lack of oxygen prevented their decay, over thousands to millions of years. Burning fossil fuels adds significantly to the concentration of carbon dioxide in the atmosphere. Combined with deforestation, this significantly affects the carbon–oxygen balance: plants are no longer able to absorb and process carbon dioxide at the rate in which it is being produced.

The average global release of carbon dioxide is around 35 billion tonnes annually. Of that, oceans absorb approximately 26% while plants absorb 28%; tropical forests have the highest rate of carbon dioxide absorption with approximately 1.5 billion tonnes absorbed by rainforests alone. This means 46% of the carbon dioxide released each year ends up in the atmosphere. Earth is experiencing the negative effects of this in the form of global warming leading to climate change, which you'll investigate further in 'The greenhouse effect' (p 67).

Student activity 2.6 Creative thinking

Select an organism that plays an important role in the carbon–oxygen cycle. Write a story that displays a complete cycle of processes that your organism is a part of. You may wish to tell your story by writing a script for a play, or by using a flowchart with visual diagrams. Include detailed explanations of each contributing process throughout your story. Be creative and use your imagination!

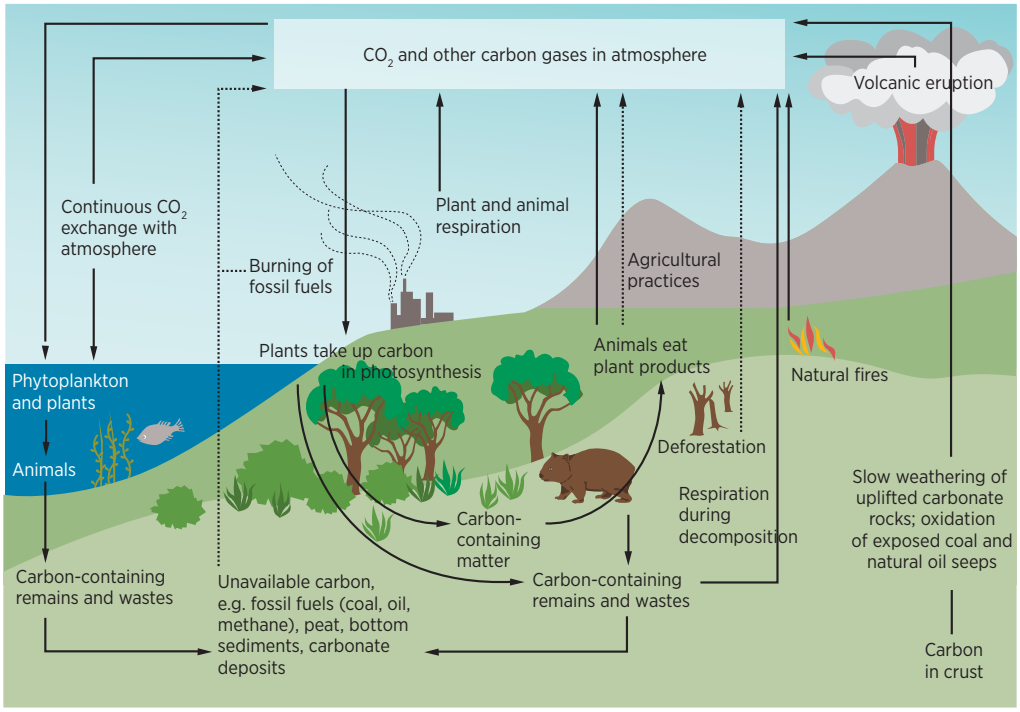


Figure 2.9. The carbon–oxygen cycle

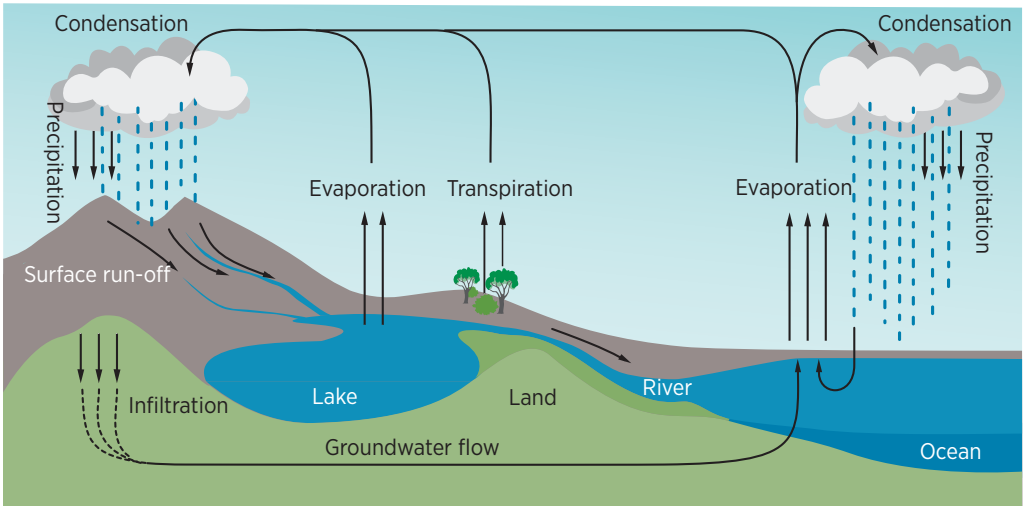


Figure 2.10. The water cycle

Water cycle

The natural water cycle, also known as the hydrologic cycle, describes the continuous movement of water on, above and below Earth's surface. Water is always changing states between liquid, vapour and ice, with these processes happening both in the blink of an eye and over millions of years. The whole water cycle is powered by the Sun. The Sun's energy **evaporates** water from the surface of oceans, lakes and rivers. Plants **transpire** moisture through their leaves into the atmosphere. **Condensation** occurs in the clouds and the water molecules fall to the ground in a variety of forms of **precipitation**. This water may fall into oceans, **infiltrate** into the ground, run over the surface into rivers or lakes or be absorbed by plants (Figure 2.10).

Only 1% of the water on Earth is easily accessible for plants and animals to use, and the world's ever-growing population is putting more and more strain on the fresh water supply. Water is a finite resource, as the amount of available water today is the same amount available thousands of years ago, always continually cycling through the water cycle.

Evaporation

Evaporation is the process of changing water from liquid to gas. When the sun heats water in rivers, lakes or oceans, it provides enough energy to break the hydrogen bonds between water molecules.

The individual molecules rise through the air into the atmosphere, in the form of water vapour or steam. Only fresh water makes its way up to the clouds; the salts, minerals and metals in ocean water are left behind when it evaporates.

Condensation

Condensation is the process of changing water from gas to liquid. As water vapour rises, it becomes cooler and changes back into tiny liquid water droplets. These merge together to form clouds.

Precipitation is when rain, snow, sleet or hail falls from the sky. When so much water has condensed that the air cannot support its weight, water falls from the clouds back to the ground. Depending on the air temperature, water can take a liquid form (rain), or a solid form (snow, sleet or hail).

Infiltration

Infiltration occurs when water that falls back to the surface soaks into the ground. This underground water collects in layers of rock, sand or gravel called aquifers, and is known as groundwater. Groundwater eventually seeps to the bottom of rivers, providing a steady flow of water even after the rain has stopped.

Transpiration

Water in the ground can also be absorbed by plant roots. This water travels up through the plant to its leaves where some of it is used in the process of photosynthesis. Transpiration occurs when water evaporates from plants, mainly through their leaves. This gets water vapour back into the air, and gives plants an important role in maintaining the water cycle.

Surface run-off

Run-off occurs when water does not soak into the ground, but flows across land instead. This water is called surface water, and collects in creeks which flow into larger rivers and eventually back into the oceans. Run-off can be associated with pollution as waste, fertilisers and other pollutants are swept up and carried into water systems from roads and land used for agriculture and other human activities.

Nitrogen cycle

All organisms need **nitrogen** to manufacture proteins, large molecules that perform many functions in the body. Within an ecosystem, nitrogen is present in a number of organic and inorganic forms. Inorganic forms of nitrogen include nitrogen gas (N_2) in the atmosphere and nitrate (NO_3^-), nitrite (NO_2^-) and ammonium (NH_4^+) ions in the soil and water. Nitrogen atoms are found in organic form in proteins in living and dead organisms and in waste products, such as uric acid or urea. The nitrogen cycle describes the various processes by which nitrogen is changed from one form to another as it is recycled through the biosphere (see Figure 2.11).

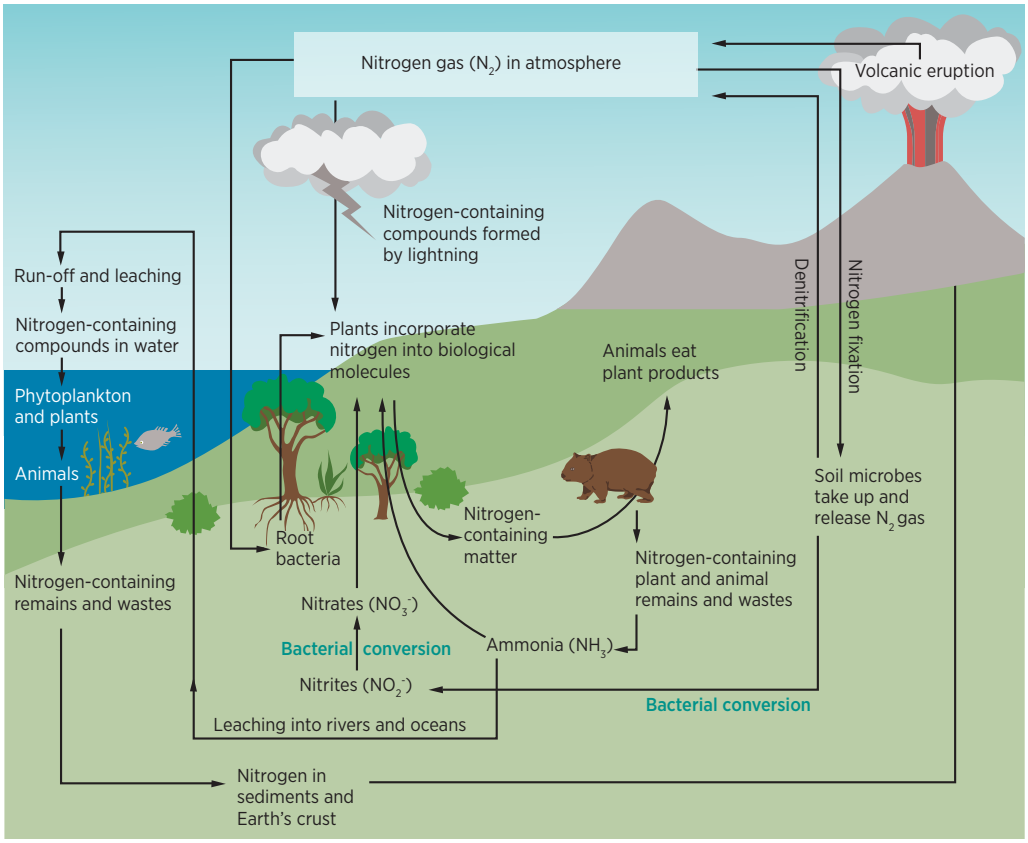


Figure 2.11. The nitrogen cycle

Nitrogen fixation

Gaseous nitrogen makes up 78% of the atmosphere, but plants can't take up nitrogen in this form. The only organisms that can take up nitrogen from the atmosphere are nitrogen-fixing bacteria, such as *Azotobacter* and *Rhizobium*, which are present either within the soil or in nodules on the roots of legume plants These bacteria convert gaseous nitrogen into ammonia (NH_3) and other forms that plants can use such as ammonium. Lightning can also fix nitrogen, forming ammonia and nitrate.

Nitrification

Nitrifying bacteria, found in well-aerated soils, convert ammonia to nitrite ions and then the nitrite ions to nitrate ions in a process called oxidation (in which one molecule is released to form another molecule). These two oxidation steps are carried out by different sets of bacteria.

Assimilation

Plants absorb nitrates, nitrites, and ammonium that is formed when ammonia dissolves in soil moisture, and use them to manufacture proteins. Consumers absorb the nitrogen present in this protein when they eat the plants.

Ammonification

Decomposers return nitrogen to the soil by converting nitrogen-rich compounds in dead bodies and wastes to ammonia.

Denitrification

Denitrifying bacteria work in anaerobic conditions (such as waterlogged soil) to convert nitrate and nitrites into gaseous nitrogen, which is released back into the atmosphere to continue the cycle again.

Human impacts on the nitrogen cycle

Many human activities have a significant impact on the nitrogen cycle. Burning fossil fuels, producing and applying nitrogen-based fertilisers, and other activities can dramatically increase the amount of biologically available nitrogen in an ecosystem.

Nitrogen availability limits the primary productivity of many ecosystems, so large increases in the availability of nitrogen can dramatically change the nitrogen cycle in both aquatic and terrestrial ecosystems. Additional nitrogen inputs to terrestrial ecosystems can increase plant growth but may also cause nutrient imbalances, reduce forest health and decrease biodiversity. Increased plant growth can be associated with increased carbon storage, so changes to the nitrogen cycle can also affect the carbon–oxygen cycle.

Production of synthetic fertilisers has increased significantly in recent decades and is now a major source of nitrogen input to the biosphere. Fertilisers are produced by reacting atmospheric nitrogen with hydrogen to form ammonia, known as the Haber–Bosch process. Today, nearly 80% of the nitrogen found in human tissues originated from the Haber–Bosch process.

Fertilisers are used extensively on farms to increase plant production, but much of the nitrogen applied to agricultural and urban areas ultimately enters rivers and near-shore coastal systems in the form of nitrate. In near-shore marine systems, increases in nitrogen can alter biodiversity and species composition, the structure of food webs and even overall ecosystem function. Excess nitrogen can lead to anoxic (no oxygen) or hypoxic (low oxygen) conditions, and it can also contribute to increased acidification of fresh water ecosystems. One common consequence of increased nitrogen in waterways is an increase in harmful algal blooms (caused by **eutrophication**) or an excess of nutrients. Toxic blooms of certain types of dinoflagellates have been associated with high mortality of fish and shellfish in some areas.

Student activity 2.7
Science skills: Communicating via a research report

A research report gives a scientist the opportunity to construct an evidence-based argument that uses appropriate theories and explanations to communicate scientific ideas. Your task is to take the role of an agronomist (plant and soil scientist) who has been approached by a local farmer because their crops are growing poorly. You take a soil sample to be tested and the results indicate the soil is very low in nitrogen as well as a number of other nutrients.

Research report challenge

Your task is to write a report to the farmer identifying why the soils may be low in nitrogen and how the soil quality can be improved to increase crop production.

Your report must refer to scientific theories and explanations, and you must keep a record of those sources. For two of those sources, provide an explanation as to why they were useful and how you determined if they were a credible source.

Phosphorus cycle

Phosphorus forms part of nucleic acids and other important molecules that control the flow of energy in cells. It is a component of cell membranes, bones and teeth.

Phosphorus is found in organisms, water, rocks, soil and sediments, but is not found in air in the gaseous state like most other compounds in biogeochemical cycles. Phosphorus mainly cycles through soil, sediments, organisms and water. Australian soils are generally very old and low in phosphorus. Although native plants are adapted to low-phosphorus soils, agricultural crops are often limited by the lack of available phosphorus in the soil.

The phosphorus cycle (see Figure 2.12) is the slowest of the biogeochemical cycles, occurring on a geological time scale of rock formation and weathering.

Weathering

Over time, rain and weathering cause rocks to release phosphate (PO_4^{3-}) ions and other minerals. This inorganic phosphate is then distributed in soils and water.

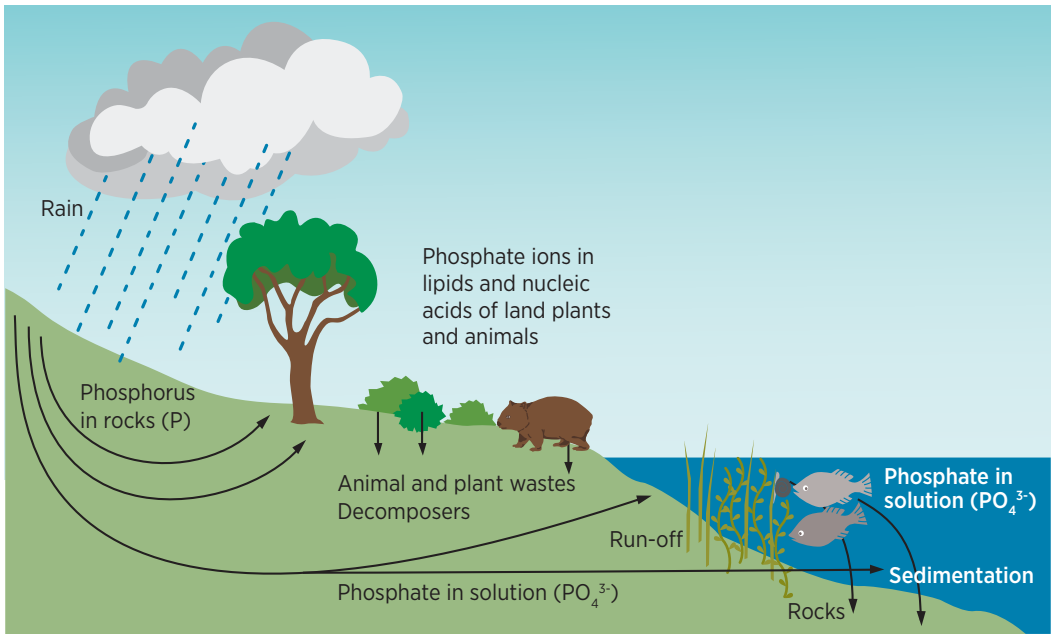


Figure 2.12. The phosphorus cycle

Assimilation

Plants take up inorganic phosphate from the soil through their roots. As plants are consumed by animals, phosphorus passes through the food chain. Once in the plant or animal, the phosphate is incorporated into organic molecules such as DNA.

Decomposition

Decomposition of dead plants and animals, and the waste of living organisms, returns organic phosphate the soil.

Mineralisation

Within the soil, organic forms of phosphate can be made available to plants by bacteria that break down organic matter to inorganic forms of phosphorus. This process is known as mineralisation.

Sedimentation

Phosphorus also ends up in sediments on the bottom of lakes and oceans, where dissolved phosphate is released, carried around by currents and used by phytoplankton. Some phosphorus is deposited in sediments that eventually form rocks. The most common phosphate rock (known as apatite) is used commercially in the production of phosphate fertilisers and in the pharmaceutical and chemical industries.

Human impacts on the phosphorus cycle

Human activity, related primarily to agriculture, has affected the phosphorus cycle. Human actions accelerate the natural phosphorus cycle at two key points: in the entry of phosphorus into the biosphere from rock, and in the movement from soil into aquatic ecosystems.

Phosphorus is mined in only a few locations around the world – primarily in Florida, west and north Africa, and Russia. Mined phosphorus is then made into fertilisers, animal feeds and other products, and transported to agricultural areas all over the world. On farms, phosphorus is incorporated into the soil, either directly as fertiliser or indirectly as excess phosphorus in the manure of animals fed a high-phosphate diet. Erosion of this phosphorus-laden soil, especially under poor land use practices, leads to the phosphorus running off into waterways.

By moving phosphorus from where it is mined to where it is used as fertiliser and animal feed, we radically alter the distribution of this element on the planet's surface. The effect of shifting large quantities of phosphorus to places where it would not naturally be found in high concentration has become a growing concern to aquatic ecologists and others who care about maintaining supplies of clean, fresh water. Phosphorus predominantly reaches surface waters via direct discharge and run-off from land application of fertilisers and animal manure. Once in receiving waters, the phosphorus becomes available to aquatic plants, which can lead to eutrophication and algal blooms in the same way as excess nitrogen can.

Student activity 2.8
Science skills: Using representations

Representations are used in science to illustrate a scientific phenomenon. Representations include diagrams, models, role plays, text, symbols and virtually anything that can be used to convey a scientific meaning.

Representations can be used by themselves or in combination. A combination of representations (for example, diagram and text) can help ensure you've provided a clear example and explanation.

Representation challenge

Your task is to create two representations of one of the biogeochemical cycles (carbon–oxygen, water, nitrogen or phosphorus):

1. First, construct a three-dimensional model to represent the cycle. Use materials such as plasticine, plastic animals, boxes, stickers, cotton wool, coloured paper, plants, tape, foil and glue.
2. Then, create a second representation in which you accompany the key processes in the cycle with an explanatory text to fully explain the phenomenon.

EXPLORING SCIENCE 1
Mixing iron into the north Pacific stirs geoengineering controversy

Peter Strutton, Associate Professor,
Institute for Marine and Antarctic Studies,
University of Tasmania

This article was originally published in The Conversation*, 8 November 2012.*
https://theconversation.com/mixing-iron-into-the-north-pacific-stirs-geo-engineering-controversy-10490

A British Columbian fishing community has drawn almost universal condemnation after dumping 100 tonnes of iron-rich dust into the ocean to stimulate a plankton bloom, in an effort to restore salmon numbers.

When the story broke in the *Guardian*, the *New York Times*, *CBC*, *Nature* and *Science*, many of the commentators claimed that ocean iron fertilisation on such a scale violated international protocols and had potentially dangerous impacts on the marine ecosystem.

But it is equally possible that the bloom was natural.

To understand why this may be the case and why the community took this approach to improving fish stocks, it is important to understand the science around iron fertilisation.

Oceanic iron fertilisation (OIF) has come to prominence as a potential geoengineering approach to global warming. The idea is that iron dissolved in the ocean could accelerate the growth of massive plankton blooms. This would increase the uptake of anthropogenic carbon dioxide from the atmosphere and sequester it deep in the ocean.

The natural process by which atmospheric carbon dioxide enters the ocean and is sequestered on the ocean floor is known as the biological pump. It relies on large numbers of plankton in massive blooms capturing carbon through photosynthesis.

When the blooms die, they sink to the bottom of the ocean, remaining there for thousands to millions of years and taking the carbon dioxide with them.

However, in vast areas of the global ocean – the north Pacific, tropical Pacific and Southern Ocean – the efficiency of the biological pump is limited by extremely low bioavailability of dissolved iron. Without sufficient dissolved iron, large plankton blooms cannot form.

At least nine OIF experiments have been performed since 1993 in each of the major iron-limited regions of the global ocean, mostly to understand changes in ocean productivity and atmospheric carbon dioxide concentrations over glacial–interglacial cycles (approx. 20,000 years).

Until recently, the export of carbon into the deep ocean had been confirmed in only two of these experiments. Even then, the efficiency of the transport was far less than expected.

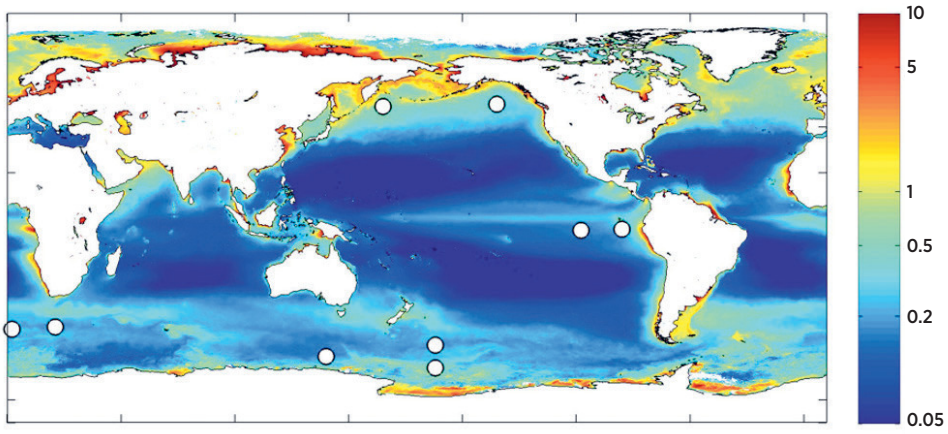


Figure 2.13. A map of satellite-derived mean annual chlorophyll concentration (units are mg chl m^{-3}). Phytoplankton contain chlorophyll, so these maps are used as an indicator of ocean productivity. The white circles are the locations of nine OIF experiments performed since 1993

But in 2004, an export efficiency (beyond 1,000 m depth) of greater than 50% was measured for an iron-fertilised bloom in a clockwise rotating eddy in the Southern Ocean. This result has to some extent revived the debate surrounding iron fertilisation as a geoengineering technique.

There are concerns about the impact of OIF on several aspects of ocean health. Fertilising with one nutrient will likely cause scarcity of the next least-available nutrient, probably phosphorus or nitrogen.

When the blooms die and decompose, they consume oxygen and may lead to larger oxygen-deficient zones. The phytoplankton favoured by iron addition could be the kind that produce potent neurotoxins, which accumulate up the food chain and cause illness in marine mammals and humans.

These concerns have led to moratoria on ocean iron fertilisation. But it's also important to realise that these are only potential impacts. With the possible exception of depletion of other nutrients, none of these processes have been observed in any experiments to date.

When the Haida Salmon Restoration Corporation (HSRC) announced it had dumped 100 tonnes of iron-rich dirt into the north Pacific from the fishing vessel Ocean Pearl during mid-2012, people suggested it had potentially violated the international moratoria. And there were worries about the scale of the experiment and the potential for unintended negative environmental impacts.

All of the earlier OIF experiments deployed about 1 tonne of iron as iron sulfate solution. If the dirt used by the HSRC was any more than 1% iron by weight (it was likely more than 5%), this would qualify as the largest deliberate iron addition ever performed.

Some news reports of the iron addition have shown a single satellite chlorophyll image indicating what appears to be a bloom. However, this region of the ocean is populated by eddies that move productive, high-iron coastal waters into the low-productivity open north Pacific.

Is it possible to determine whether the bloom in the satellite image in Figure 2.14 was due entirely to deliberate iron fertilisation by the HSRC?

Figure 2.14 is probably an average of about two weeks of satellite data. Individual daily images may be more useful for determining whether the circled bloom was natural or iron fertilised.

Many of the news reports say the iron fertilisation occurred in July this year [2012], but this does not seem to be true. The Ocean Pearl deployed 20 drifters provided by the National Oceanic and Atmospheric Administration (NOAA). The deployment information for these drifters gives an approximate location of the ship.

Figures 2.15 and 2.16 tell us a little about the pre-existing chlorophyll concentrations in this region of the North Pacific and the Ocean Pearl's expedition.

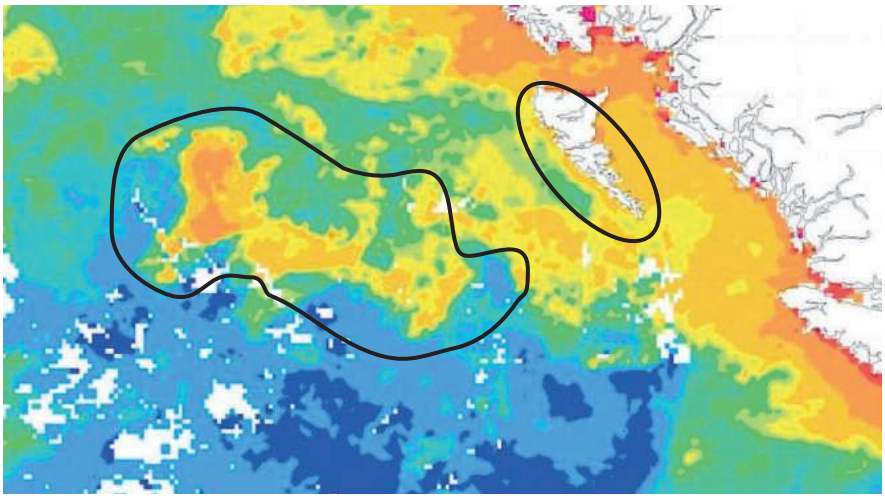


Figure 2.14. A satellite chlorophyll image from the Haida Gwaii region, purporting to show the bloom generated by the HSRC iron addition. Credit: Goddard Earth Sciences Data and Information Services Center/NASA

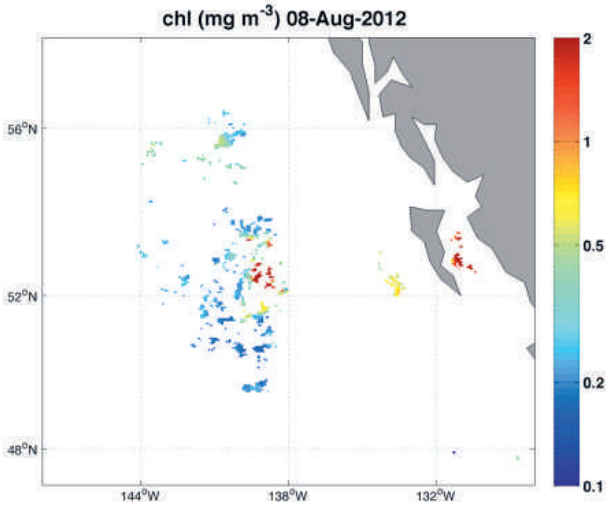


Figure 2.15. Chlorophyll concentrations, 8 August 2012. Credit: National Oceanic and Atmospheric Administration (NOAA)

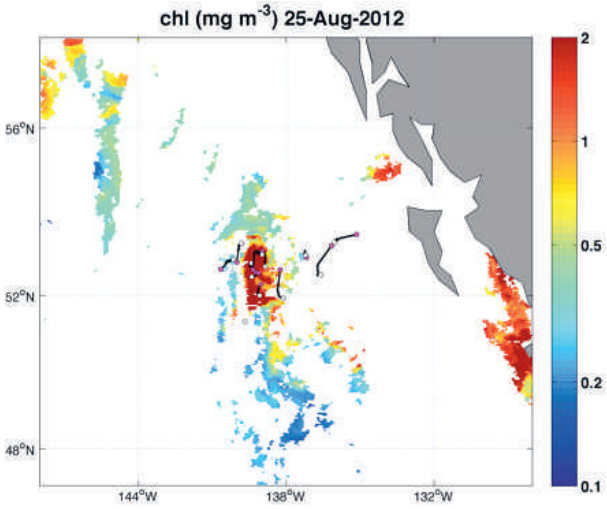


Figure 2.16. Chlorophyll concentrations, 25 August 2012. Credit: National Oceanic and Atmospheric Administration (NOAA)

Figure 2.15 is a snapshot from 8 August (before the ship left port). It shows some high chlorophyll near 139°W, 53°N, where the bloom was eventually seen in the first relatively clear satellite image.

In Figure 2.16, the magenta circles are the deployment locations of the drifters (indicating the ship's track). The white circles are the location of the drifters on 25 August and the black lines are the drifter trajectories.

Based on the drifter data and some images from 14 and 17 August (not shown here for brevity), the Ocean Pearl arrived in the location of the bloom on 14 August at the earliest but probably started fertilising no earlier than 16 or 17 August.

The high chlorophyll observed on 25 August (no more than 8 or 9 days after fertilisation) is approximately 4.5 mg m^{-3} and is probably an underestimate because of known problems with satellite chlorophyll retrievals at high latitudes.

In the Subarctic Ecosystem Response to Iron Enrichment Study (SERIES) experiment in 2002, chlorophyll concentrations of this magnitude were not observed until about 14 days after fertilisation.

All of this evidence strongly suggests the Ocean Pearl/HSRC did not solely generate the bloom observed on 25 August. At best they may have slightly enhanced an already high chlorophyll area, as suggested in an article in the *Vancouver Sun.* They did not create a bloom in an ocean desert.

If it is their intention to sell carbon credits to help offset the cost of the experiment, how will they document the amount of carbon sequestered? Measuring the amount of sequestered carbon has been one of the biggest challenges from every OIF experiment. How would they determine how much of that carbon sequestration was due to the addition of iron and how much was natural?

It is easy to understand why this experiment has drawn such heavy criticism. However, the over-emphasis on potentially negative but undocumented impacts does not help the debate. No deleterious impacts have been observed for any OIFs thus far. Risks may well be minimal and mitigated by good project design.

The scientific community, in its concern to show respect for international rules, should be careful to avoid hyperbole if it wants the public to support future research into this important aspect of global climate.

Using field data and global satellite imaging, environmental scientists can estimate that more than 80% of Earth's surface has been transformed by long-extinct volcanoes. Scientists are able to monitor changes in the volume, salinity and rate of evaporation from bodies of water, and track disruptions to the hydrological and carbon cycles associated with large-scale deforestation.

A comparison of the Gariwerd seasonal calendar with other Aboriginal and Torres Strait Islander peoples' seasonal calendars and with Western planting schedules over time illustrates different approaches to crop selection and land management in response to environmental change. In this area of study students compare Earth's changing features, examine different ways to measure and make predictions about changes in Earth's four systems, and explore different options for managing environmental changes and challenges.

The selection of learning contexts should allow students to develop practical techniques and undertake fieldwork to examine change or disruption to ecosystems and local landscapes over time. Students develop their skills in the use of scientific equipment and apparatus. They perform comparative tests of ecological function such as measuring the infiltration rates through rocks and soils with different permeabilities, and design practical solutions to challenges such as erosion and curbing water run-off. Students may obtain secondary data for analysis from landscape mapping tools.

Outcome 2

On completion of this unit the student should be able to analyse how changes occurring at various time and spatial scales influence Earth's characteristics and interrelated systems, and assess the impact of diverse stakeholder values, knowledge and priorities in the solutions-focused management of a selected regional environmental challenge.

AREA OF STUDY 2

How do Earth's systems change over time?

Key knowledge

Area	Section
Earth's dynamic systems	
• transformative processes occurring during Earth's deep history that shaped the formation of Earth's four interrelated systems	3.1
• changes and disruptions to landscapes, ecosystems and biomes that influence their distribution and ecological characteristics	4.1, 4.2
Data and modelling	
• ways of using data and models to study Earth's systems and changes in Earth over time	5.1
Managing environmental challenges	
• the role of innovation and science in responding to challenges as a result of environmental change and disruption	5.2
• the contribution of scientific data, new technologies, regulatory frameworks and diverse stakeholder values, knowledge and priorities in managing environmental challenges of regional relevance	5.3

CHAPTER

3

Earth's deep history

CASE STUDY 3.1
Joint management to pave the way for the future

Piera Sfameni , Bachelor of Science student, Deakin University, with acknowledged assistance and thanks to Suzanne Nunn (National Indigenous Knowledge Education Research Innovation (NIKERI) Institute, Deakin University) and Parks Victoria

Cultural burning is a traditional fire regime and the primary method of land management prior to colonisation in order to prevent Country from burning. There is a connection that binds Indigenous people to the land, one that has manifested from thousands of years of cultivating Australian landscape.

The method of cultural burning is the use of small, cool and controlled flames of low height, thinking about the nature of the habitat being burnt including soil type, moisture and vegetation. It creates a mulch layer on the surface of vegetation to trap soil moisture and prevent the spread of fire. The size and duration of the burn does not follow a specific formula but rather draws on traditional knowledge of the country.

This burning is directed towards removing foreign and invasive material from the land, including fire-prone plant material, and promoting regrowth. Cultural burning encourages a more fire-resilient landscape and rejuvenates the habitat to allow native flora and fauna to flourish.

In contrast, the Western practice of hazard-reduction burns conducted by state authorities is a generalised method of reducing fuel load per hectare that may feed fires. It is often seen that this mode of burning is not appropriate for areas and can scorch the earth, with the generation of heat that alters the soil chemistry and degrades soil moisture. This method treats all types of habitats equally and doesn't take the same care as cultural burning to differentiate the types of vegetation, ultimately mismanaging the land.

There is a movement, particularly after the ravaging wildfires of 2020, for cultural burning to be implemented in mainstream practices. The uptake of Aboriginal cultural lore can tremendously aid in mitigating the onslaught of environmental disasters and maintain a healthier landscape. These are the very practices that may be introduced through joint management of national parks and

reserves to ensure more sustainable and efficacious management of the land and a skill to be learnt from our traditional owners.

The Victorian *Traditional Owner Settlement Act 2010* sought to give back control of the land that was owed to our First Australians and forge a new pathway of joint management that encourages a three-way collaboration between traditional owners, Parks Victoria and relevant third-party agencies. This collaboration pays respect to Aboriginal sophisticated and expansive knowledge of the land that has culminated over 60,000 years.

An experiential review conducted by Parks Victoria, who manage parks and reserves on behalf of the state, evaluates the efficacy and challenges in implementing joint management of the land and the overall benefits for the health of our landscape. Joint management is a product of state policy that grants rights and responsibilities to traditional owners and grants them a voice in the decisions made towards managing Country.

Suzanne Nunn is a lecturer at the National Indigenous Knowledge Education Research Innovation (NIKERI) Institute at Deakin University. Suzanne conducted a review of the uptake of joint management in 2015 on behalf of Parks Victoria, looking at partnerships with the traditional owner groups Yorta Yorta, Gunaikurnai, and Dja Dja Wurrung. The results held great promise for an effective and functional environment management and potential to initiate change within the landscape into the future.

Figure 3.1. Lands being burnt for management purposes. Credit: CSIRO CC BY 3.0

It was determined that the success of joint management hinged on a mutual understanding and respect between both groups in order to establish a harmonious relationship. This approach was one that acknowledged both world views to incorporate into new management practices.

The journey to creating healthy Country is one that could take many generations. As stated by Marian Reid, writer at the Australian Conservation Foundation, "Country's been mismanaged for 200 years and it's not going to be an overnight fix."

In essence, there is much that can be learnt from Indigenous practices.

Questions

1. **Determine** the science required to understand this case study.
2. **Describe** the types of technology that would assist with understanding or solving issues in this case study.
3. **List** the many stakeholders involved in this case study.
4. Using the definitions presented in 'Stakeholder values' (p 82), **describe** the values and priorities of the stakeholders involved. **Justify** your choice/s.
5. **Identify** the regulatory frameworks used to protect the environment that is described this case study.

3.1. Origins of the solar system and formation of Earth

Transformative processes occurring during Earth's deep history that shaped the formation of Earth's four interrelated systems

The origins of the **solar system** and how **Earth** was formed are being continually studied by many scientists to better understand which of the many **theories** and **models** is the most accurate.

The most widely accepted theory is that the solar system settled into its current layout about 4.5 billion years ago. At that time, the solar system was a cloud of dust and gas, with a small percentage of heavier **atoms** formed earlier in the history of the universe. This cloud was known as a **solar nebula**. **Gravity** collapsed the material in on itself, with the atoms now colliding more frequently and violently generating more and more heat. These collisions increased the temperature to a point that the **protons** in the atoms began to fuse with each other (**nuclear fusion**). This fusion transformed matter into large amounts of energy, resulting in the formation of the **Sun**.

The material not absorbed during the process of nuclear fusion was held in a swirling orbit by the Sun's gravity. This gravity then pulled in other material, including dust particles, forming larger and heavier clumps. These heavier elements collided and bound together with the denser material forming the core at the centre of the new planet Earth. The pressure and heat from the **radioactive decay** of elements resulted in molten material around the core. It was probably around this time that Earth's **magnetic field** formed (Figure 3.2). Eventually the surface cooled, creating the crust, leaving the molten layers underneath that form the outer core and mantle.

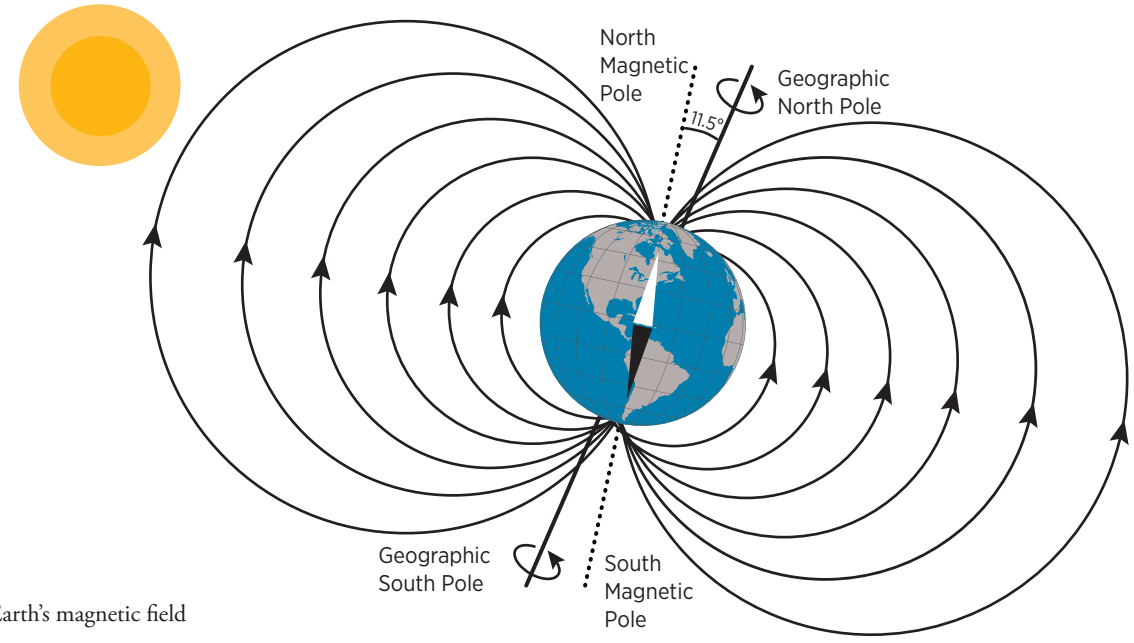


Figure 3.2. Earth's magnetic field

Student activity 3.1
Just for fun: Hubble telescope

The NASA Hubble space telescope explores the universe continuously. Since its launch in 1990 on the space shuttle *Discovery*, the Hubble telescope has discovered many extraordinary things about the universe, including the idea that the universe is not only expanding but accelerating its speed of expansion. Hubble has given us the first recordings of the atmospheric composition of distant planets and let us see our closest neighbouring galaxy, Andromeda, which has led scientists to predict the two galaxies will one day come together in a gigantic collision.

Use this link to explore the many discoveries of the Hubble space telescope and find out what Hubble saw on your birthday: https://www.nasa.gov/content/goddard/what-did-hubble-see-on-your-birthday.

The Sun

The Sun is the primary source of energy for all life on Earth. The Sun is just close enough to Earth to sustain life without harming it. In fact, Earth receives only about one-billionth of the Sun's energy output.

The Sun is a fireball of **hydrogen** (72%) and **helium** (28%) gases. The extremely high temperatures and pressures of its inner core strip **electrons** from atoms to leave bare **nuclei** of hydrogen, which fuse to form helium gas. This nuclear fusion reaction (Figure 3.3) releases enormous amounts of **solar energy** as heat, light and other radiation.

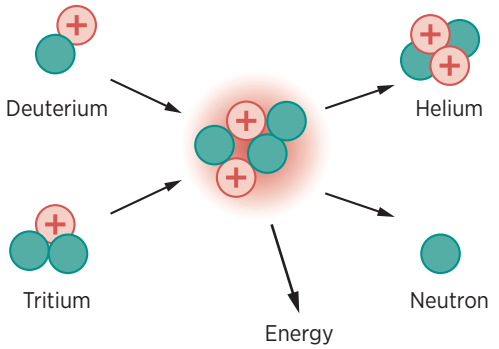


Figure 3.3. Nuclear fusion reactions release solar energy

Solar cycles

People have known for 150 years that the Sun's activity level goes in **cycles**. Over a period of about 11 years, the Sun cycles through times of lots of activity (called the **solar maximum**) and times of low activity (the **solar minimum**) as can be seen in Figure 3.4. The level of activity is visible to us in the form of **sunspots** – dark spots on the Sun's surface, usually relatively close to the Sun's equator. Although they look small in relation to the Sun, they average roughly the size of Earth, and some are as big as 20 Earths. Sunspots, and associated flares, are a sign of changes in the Sun's magnetic field. Because the Sun's interior contains flows of hot gas, the shape and intensity of its magnetic fields change quite rapidly. Sunspots are regions of intense magnetic field which are cooler than the surrounding surface and hence look darker. The magnetic field rises out of the surface of the Sun, and streams of charged particles (**plasma**) can erupt into a solar flare.

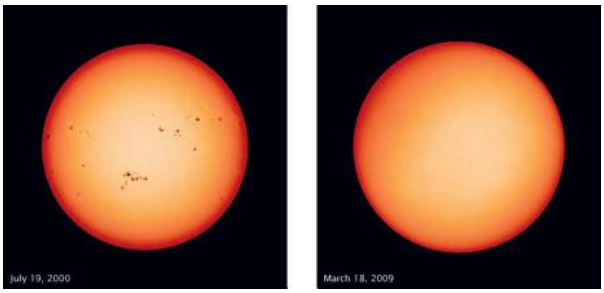


Figure 3.4. Sunspots at a solar maximum (left) and a solar minimum (right). Images courtesy SOHO, the EIT Consortium, and the MDI Team, NASA

Scientists have debated whether the solar cycle affects our weather, climate and sea surface temperatures. The difference in the Sun's output between solar maximums and solar minimums is less than 1%. Records show a historical correlation between sea surface temperatures and the activity level of the Sun, but temperature increases in recent years are greater than could be accounted for by solar activity. The International Panel on Climate Change has concluded that the Sun's activity does not account for global warming.

Although not responsible for global warming, the solar cycle does influence water and air circulation patterns around the globe and may influence cloud cover. The difference between outputs at the maximum and minimum is up to tenfold in the extreme ultraviolet portion of the solar spectrum, and this is thought to influence the chemistry of the **stratosphere** (the atmospheric layer above 15 km altitude). At solar maximum, ozone concentrations are higher in the stratosphere, which can affect that layer's temperatures and winds.

Solar flares can also cause **geomagnetic storms**, which can affect our communication satellites, overload our power grids and drown out radio transmissions. Large clouds of plasma hitting Earth's magnetic fields also cause the **southern** and **northern auroras**.

Electromagnetic radiation

Most of the energy radiated from the Sun is **electromagnetic radiation**. Electromagnetic radiation travels in 'packets' (photons) at the speed of light, almost 300,000 kilometres per second (km/s). The photon is the smallest unit (quantum) of light and other forms of electromagnetic energy. **Photons** are generally regarded as particles with zero mass and no electric charge. Radiation can be of different wavelengths and frequencies.

The **wavelength** is simply the length of one wave of radiation. **Frequency** is the number of waves passing by per second and is measured in hertz (Hz). The shorter the wavelength, the higher the frequency of the electromagnetic radiation and the higher the energy of the photons.

The entire set of electromagnetic waves is called the **electromagnetic spectrum** (see Table 3.2 and Figure 3.5).

Data analysis 3.1 Representing data: Constructing graphs

Use the dataset table provided by the Bureau of Meteorology Space Weather Service to graph the observed monthly sunspot numbers from 2002 to 2020 (Table 3.1.). Use the following website to update your data to include the year we are in presently: https://www.sws.bom.gov.au/Solar/1/6.

Table 3.1. Observed monthly sunspot numbers

Observed monthly sun spots												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2002	184.6	170.2	147.1	186.9	287.5	128.8	161.1	175.6	187.9	151.2	147.2	135.3
2003	133.5	75.7	100.7	97.9	86.8	118.7	128.3	115.4	78.5	97.8	82.9	72.2
2004	60.6	74.6	74.8	59.2	72.8	66.5	83.8	69.7	48.8	74.2	70.1	28.9
2005	48.1	43.5	39.6	38.7	61.9	56.8	62.4	60.5	37.2	13.2	27.5	59.3
2006	20.9	5.7	17.3	50.3	37.2	24.5	22.2	20.8	23.7	14.9	35.7	22.3
2007	29.3	18.4	7.2	5.4	19.5	21.3	15.1	9.8	4.0	1.5	2.8	17.3
2008	4.1	2.9	15.5	3.6	4.6	5.2	0.6	0.3	1.2	4.2	6.6	1.0
2009	1.3	1.2	0.6	1.2	2.9	6.3	5.5	0.0	7.1	7.7	6.9	16.3
2010	19.5	28.5	24.0	10.4	13.9	18.8	25.2	29.6	36.4	33.6	34.4	24.5
2011	27.3	48.3	78.6	76.1	58.2	56.1	64.5	65.8	120.1	15.7	139.1	109.3
2012	94.4	47.8	86.6	85.9	96.5	92.0	100.1	94.8	93.7	76.5	87.6	56.8
2013	96.1	60.9	78.3	107.3	120.2	76.7	82.6	91.8	54.5	114.4	113.9	124.2
2014	117.0	146.1	128.7	112.5	112.5	102.9	100.2	106.9	130.0	90.0	103.6	112.9
2015	93.0	66.7	54.5	75.3	88.8	66.5	65.8	64.4	78.6	63.6	62.2	58.0
2016	57.0	56.4	54.1	37.9	51.5	20.5	32.4	50.2	44.6	33.4	21.4	18.5
2017	26.1	26.4	17.7	32.3	18.9	19.2	17.8	32.6	43.7	13.2	5.7	8.2
2018	6.8	10.7	2.5	8.9	13.1	15.6	1.6	8.7	3.3	4.9	4.9	3.1
2019	7.7	0.8	9.4	9.1	9.9	1.2	0.9	0.5	1.1	0.4	0.5	1.5
2020	6.2	0.2	1.5	5.2	0.2	5.8	6.1	7.5	0.6	14.5	34.5	23.1

Source: Bureau of Meteorology Space Weather Services https://www.sws.bom.gov.au/Solar/1/6

Visible light is only a small portion of this spectrum. Other than wavelength and frequency, there is no physical difference between a radio wave, an X-ray and a colour such as orange. Although we cannot see infrared rays, our bodies perceive them as heat. Some snakes have highly sensitive infrared receptors to help detect their prey.

The wavelength of radiation emitted from a body varies with the surface temperature of the body: hotter bodies radiate shorter wavelengths. The surface temperature of the Sun is quite high (about 5,800 °C), so solar radiation occurs in the shorter wavelength end of the electromagnetic spectrum (see Figure 3.5). Solar radiation reaching Earth's atmosphere is mainly in the wavelength range of 300 to 2,500 nanometres (a nanometre (nm) is one-billionth (10^{-9}) of a metre).

Each colour of the visible spectrum has its own range of frequencies and wavelengths. Red light has the lowest frequency and the longest wavelength of **visible light** and violet light has the shortest. The next shortest set of waves is **ultraviolet (UV) light**. Some flowers attract bees with patterns that can only be detected with UV light. Ultraviolet light causes sunburn; it has higher frequencies and energies than visible light. UV rays and the other short wavelengths are **ionising** rays; that is, they have enough energy to knock electrons off atoms to form charged particles called **ions**. Ionising rays can be dangerous to living things.

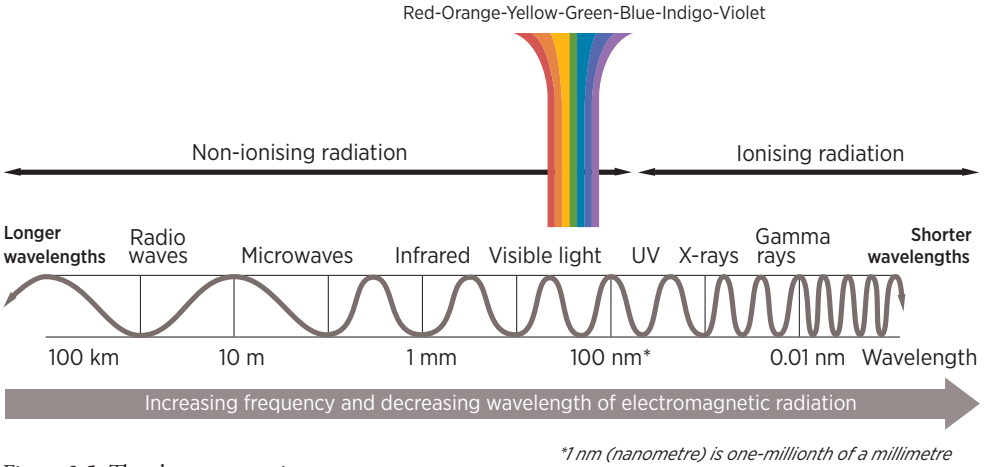
Electromagnetic radiation reaching Earth

About 38% of the radiation that reaches Earth is visible to the human eye as light. There is also a considerable amount of radiation at longer wavelengths, in the infrared part of the spectrum (53%), and a little radiation in the shorter wavelength ultraviolet part of the spectrum (9%). These electromagnetic waves bring both light and energy to Earth.

Table 3.2. The electromagnetic spectrum

Type of wave	Wavelength	Frequency	Notes
Radiowaves	0.1 mm to >100,000 km	1–10^{12} Hertz (Hz)	
Microwaves	millimetres to metres	10^{7}–10^{11} Hz	
Infrared waves	0.77–1,000 micrometres (μm)*	10^{11}–10^{14} Hz	
Light	0.39–0.77 μm	4–8 × 10^{14} Hz	Visible portion of the spectrum
Ultraviolet light	0.01–0.39 μm	8–300 × 10^{14} Hz	Visible to insects
X-rays	0.01 μm	3 × 10^{16} – 1 × 10^{21} Hz	Used in medicine
Gamma rays	Down to 0.00000001 μm	Up to 3 × 10^{22} Hz	Very high energy levels

**a micrometre (μm) is 10^{-6} of a metre*



**1 nm (nanometre) is one-millionth of a millimetre*

Figure 3.5. The electromagnetic spectrum

The photons that make up electromagnetic waves travel through space in straight lines. When they reach an object, which might be a molecule high up in the atmosphere, the surface of Earth or something in between, they will behave in different ways depending on the nature of that object (see Figure 3.6).

They could be:

- **transmitted** without bending if the object is transparent
- transmitted but bent (**refracted**)
- **absorbed** at the surface if the object is opaque
- **reflected** if the object has a surface they cannot penetrate
- or a combination of these.

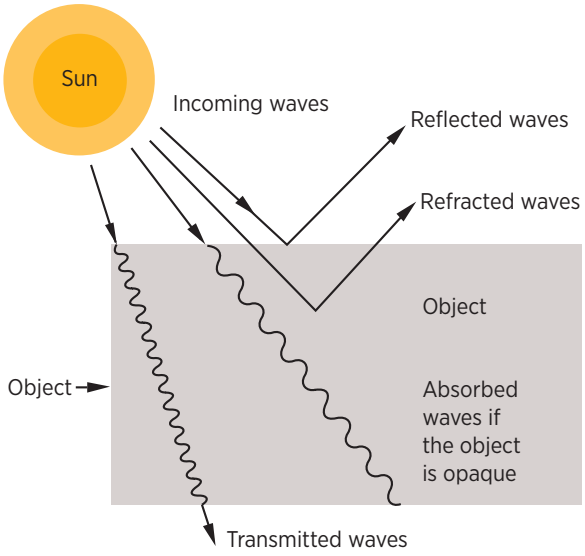


Figure 3.6. Alternative paths of electromagnetic radiation

Radiation coming from the Sun is refracted when it reaches Earth's atmosphere. Some radiation is also reflected back into space or absorbed in the atmosphere. Any radiation reaching the surface of Earth is also either absorbed or reflected.

Only a small portion of the Sun's energy is absorbed by Earth and life on Earth. About 34% of solar energy is reflected straight back into space. Another 19% is absorbed by the atmosphere, particularly **water vapour**, **carbon dioxide** and other gases. So just under half (47%) of the solar energy received by Earth reaches the planet's surface, though the amount reaching the surface varies greatly with location and time of year. **Ozone** in the stratosphere absorbs most of the ultraviolet radiation, so very little of this penetrates through the atmosphere. The radiation reaching Earth's surface is mainly in the visible and infrared part of the spectrum.

Some of the energy reaching the surface of Earth from the Sun is returned to the atmosphere in the form of heat produced by animals and plants. Eventually, almost all energy is **reradiated** into space as heat. The flow of energy to and from Earth can be seen in Figure 3.7.

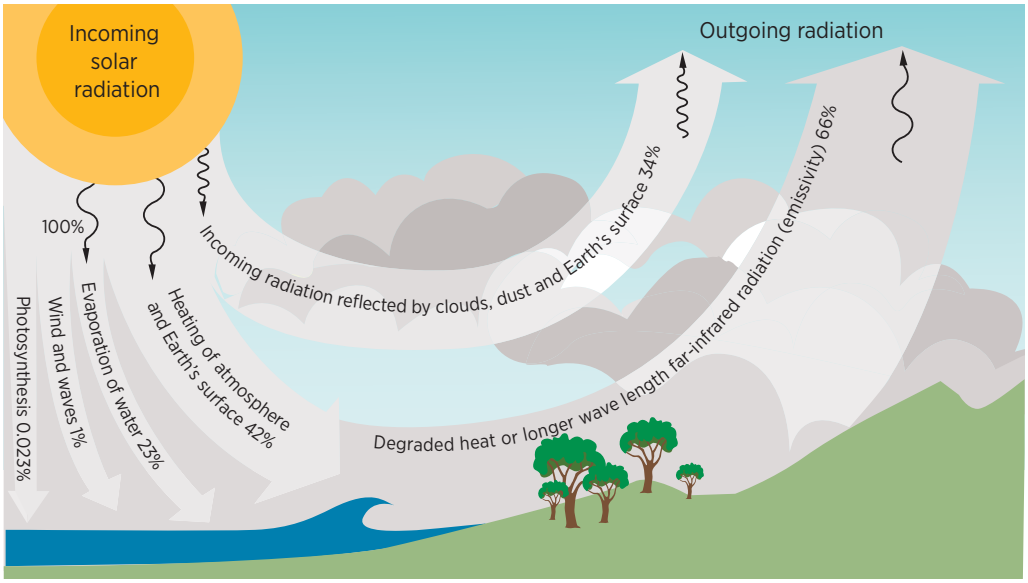


Figure 3.7. Flow of energy to and from Earth

Practical 3.1
Refraction and the spectrum of light

Aim

To understand how white light behaves when passed through different mediums.

Equipment

- 100 millilitre (mL) or 200 mL beaker
- straw or glass rod or spatula
- water
- Hodson light box kit
- power supply
- white paper
- ruler

Procedure

Part 1

1. Add water to the beaker to approximately ¾ full.
2. Insert a straw at an angle.
3. Look through the side of the glass at the straw.

Part 2

1. Set up the light box with a narrow single slit.
2. Place a piece of paper on the table in front of the Hodson box.
3. Place the rectangular prism at a right angle to the light beam. Accurately draw or trace the path of the light through the rectangular prism.
4. Rotate the rectangular prism so that it is now at an angle to the beam of light. Accurately draw or trace the path of the light through the rectangular prism. Look for *all* paths of the light.
5. Place a triangular prism in front of the single beam. Slowly rotate the prism until the single beam of white light is split into colours. Accurately draw or trace the path of the light through the rectangular prism. Look for *all* paths of the light.

Results

Part 1

Draw a diagram showing the appearance of the straw in the beaker viewed from the side.

Part 2

Draw annotated diagrams showing the path of the light through each of the prisms. Label each type of ray as reflected, transmitted, reflected or absorbed. Record the colours seen through the triangular prism and the order they are in.

Discussion

1. **Explain** why the straw appeared as it did in Part 1.
2. **Explain** why the white light was split into the colours in Part 2. Why do the colours appear in that particular order?

Formation of the atmosphere

During the formation of Earth, gravity also captured some of the swirling gases, forming the early atmosphere. Intense volcanic activity and the release of gases (known as **outgassing**) during Earth's formation produced a **primordial** atmosphere that had oxygen but only in small amounts.

As Earth cooled, the temperature decreased to a point where the water vapour in the atmosphere condensed, creating clouds and hence forming oceans. The oceans then absorbed a lot of the carbon dioxide from the atmosphere and a small amount of oxygen was produced through **photolysis** of carbon dioxide and water by ultraviolet radiation (Figure 3.8).

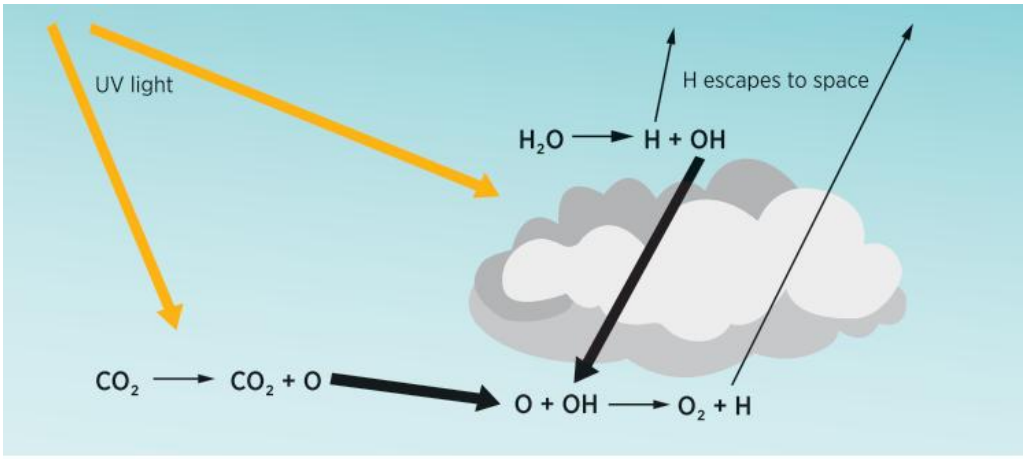


Figure 3.8. Photolysis of water vapour and carbon dioxide produce hydroxyl (OH) and atomic oxygen (O), respectively. In turn, those molecules produce oxygen gas (O_2), accounting for its appearance in low concentration in the primordial atmosphere

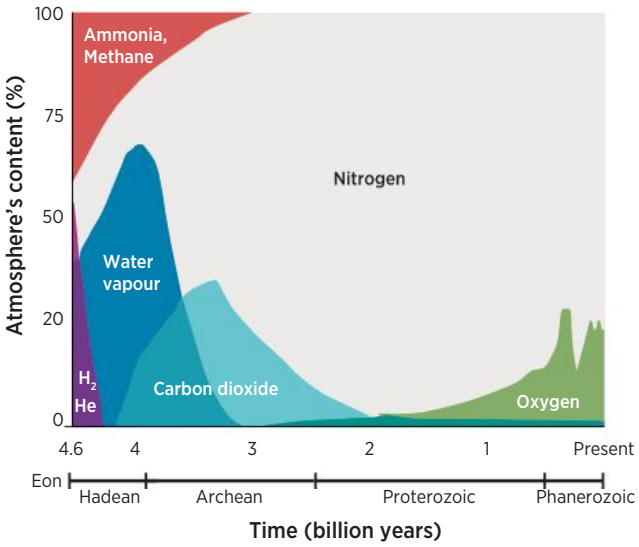


Figure 3.9. Composition of Earth's atmosphere over geologic time

Oceanic **cyanobacteria**, the first photosynthetic organisms to use visible light and produce oxygen, evolved around 2.5 million years ago (mya). They carried out photosynthesis on such a large scale that they consumed most of the carbon dioxide in the atmosphere and released enough oxygen to make permanent changes (Figure 3.9). Over time, **aerobic** organisms evolved and started consuming the oxygen.

Formation of the lithosphere

As explained earlier (see p 23), the **lithosphere** is the outermost solid layer of the planet and comprises the crust and upper mantle. The lithosphere has two forms of crust: **continental crust** (which is about 40 km thick) and **oceanic crust** (about 10 km thick). Together with the upper mantle, each plate is about 100 km thick.

During Earth's formation, the hot molten surface of the planet was exposed to the extremely low temperatures of space, which solidified the early crust – probably as one single unbroken layer. Millions of years after it formed, the crust broke into smaller, mobile sections called **plates** that fit together like a giant jigsaw puzzle. These plates move extremely slowly, about 1 to 12 centimetres (cm) each year. The continents and oceans resting on these plates are carried around with them. This movement is known as **continental drift**.

Continental drift

First proposed by geophysicist and meteorologist Alfred Wegener, continental drift theory was used to explain how Earth's continents shifted position. In 1912, Wegener postulated that the continents once formed a giant supercontinent called Pangaea. This giant landmass broke apart and into two large landmasses: a northern continent called Laurasia and a southern continent called Gondwana. These two large continents eventually broke up and moved to form the continents as we know them today (Figure 3.10).

Plate tectonics

Wegener's continental drift theory had one major limitation: it could not explain *how* continents moved about the surface of the planet. In the 1960s, scientists had discovered enough about Earth to develop the theory of **plate tectonics** to explain the processes causing continents to move, mountains and ocean trenches to form, the sea floor to spread, and earthquakes and volcanoes.

Movements of the lithosphere are caused by powerful **convection currents** created as hot and less dense material within the molten part of the mantle rises and colder rocks sink. These currents push around the molten material, which nudges the overlying lithosphere plates. Some of the heat escapes to the surface of the lithosphere through cracks and vents, appearing as volcanoes, hot springs or steaming pools of boiling mud.

Because the plates are moving at different rates and in different directions, they are pushed together or pulled apart at the boundaries. The forces involved become obvious at boundaries between neighbouring plates, where plates crash up against each other or pull apart.

Collisions between **converging** continental plates can push up mountain ranges or cause volcanoes and earthquakes (Figure 3.11). For example, the Himalayas have formed over the past 50 million years from the convergence of the Indian plate into the Eurasian plate, a process that continues today.

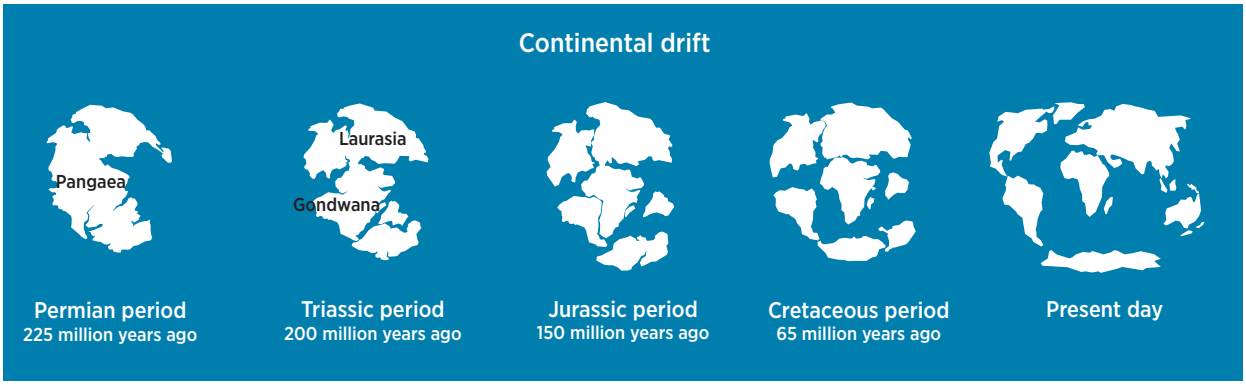


Figure 3.10. Positions of Earth's tectonic plate at five stages over the past 225 million years

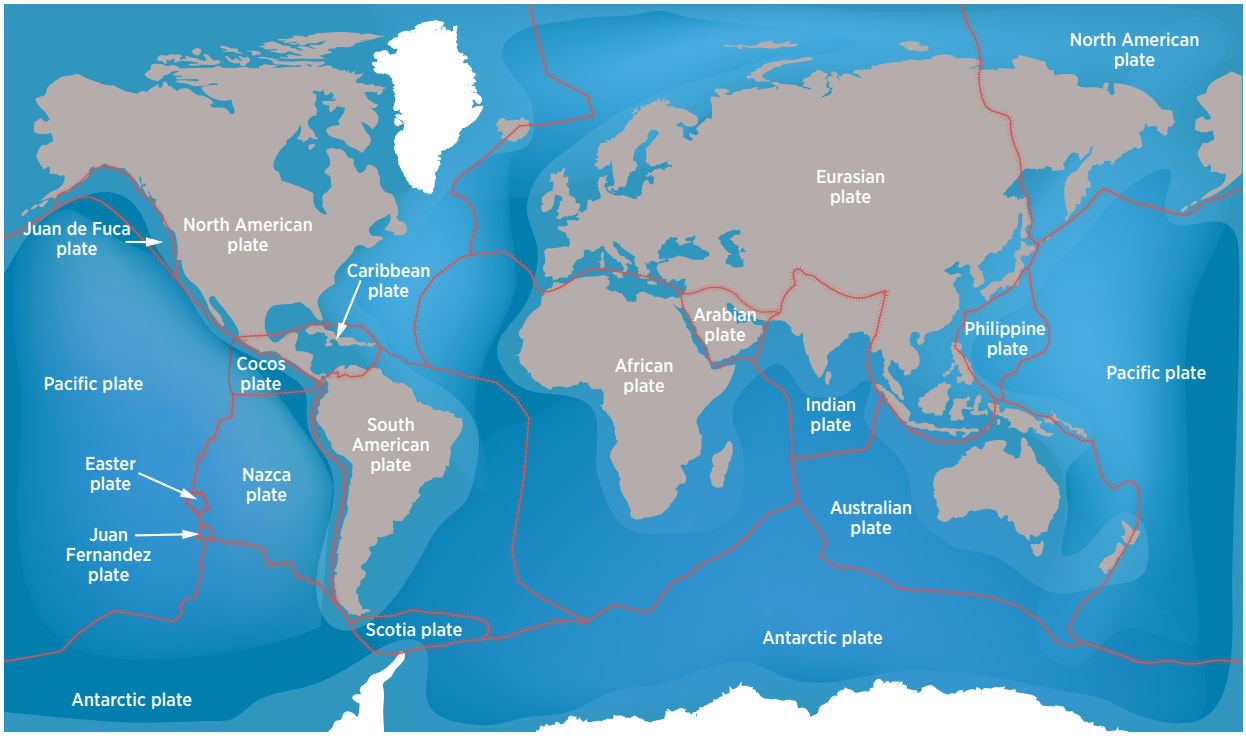


Figure 3.11. Earth's major tectonic plates

When two oceanic plates converge, the heavier plate gets pushed under the other (a process called **subduction**), forming an ocean trench and returning its material to the mantle. The water carried down with the oceanic crust is released, causing more magma to melt and erupt in large volcanoes. The result can be an arc of volcanic islands at the plate boundary, such as the islands of Japan and the Philippines, and also increased earthquake activity.

Subduction zones also occur where oceanic and continental plates meet. The heavier oceanic plates are pushed below the continental crust, which can crumple upwards. This is the process that has occurred on the eastern side of the Pacific Ocean where it has created the Andes mountain range in South America. In fact, much of the Pacific Ocean boundary falls within the 'Ring of Fire', so named because of the frequent volcanic and earthquake activity caused by plate movements.

Plates sliding past one another can set off earthquakes: friction between the rigid plates sets up tremendous strains that are released when the plates jerk suddenly forward, sending shock waves through the rock. The 1,300 km long San Andreas fault in California, which has caused notable earthquakes in San Francisco and also threatens Los Angeles, occurs where two plates are sliding past each other.

New seafloor forms on the boundary of plates that are moving apart from one another (**diverging**). In the line between the spreading plates, the mantle wells up to form a mid-ocean ridge of underwater mountains around a rift valley. Magma from the mantle wells up in the valley and spreads out to both sides, creating new crust. This seafloor spreading is slow, ranging from 20 to 120 mm/year.

Student activity 3.2
Science skills: Defending explanations

Fossil evidence of the small fern *Glossopteris* has been found throughout Australia, Antarctica, Africa and South America. Devise an explanation for the widespread presence of the plant and justify it with evidence.

Discuss your evidence as a class. You might like to assign some class members with the task of doubting your evidence and producing counter evidence.

Figure 3.12. Fossil example of *Glossopteris*. Credit: akhenatenator CC0 1.0

The rock cycle

The rocks in the lithosphere are classified into three major groups, based on their origin.

Igneous rocks form when magma from deep in Earth's crust and the upper layers of the mantle cools and solidifies. The most common igneous rocks are granite and basalt. Some igneous rocks form from volcanic lava flows, others form from magma that did not reach the surface, but cooled slowly, forming larger mineral crystals. Ultimately, all rocks (and soils) are derived from igneous rocks.

Sedimentary rocks form from deposits of eroded particles of rock and soil and the remains of dead organisms that fall to the bottom of seas and lakes. Over time, the increased pressure on the layers of sediments compresses them into rocks. Sedimentary rocks include limestone, mudstone and sandstone.

Metamorphic rocks are igneous or sedimentary rocks that have been altered by heat, pressure and chemical change within Earth's crust. They include slate, marble, quartzite and schists.

The material in magma, rocks and soil cycle through these different rock types as shown in Figure 3.13.

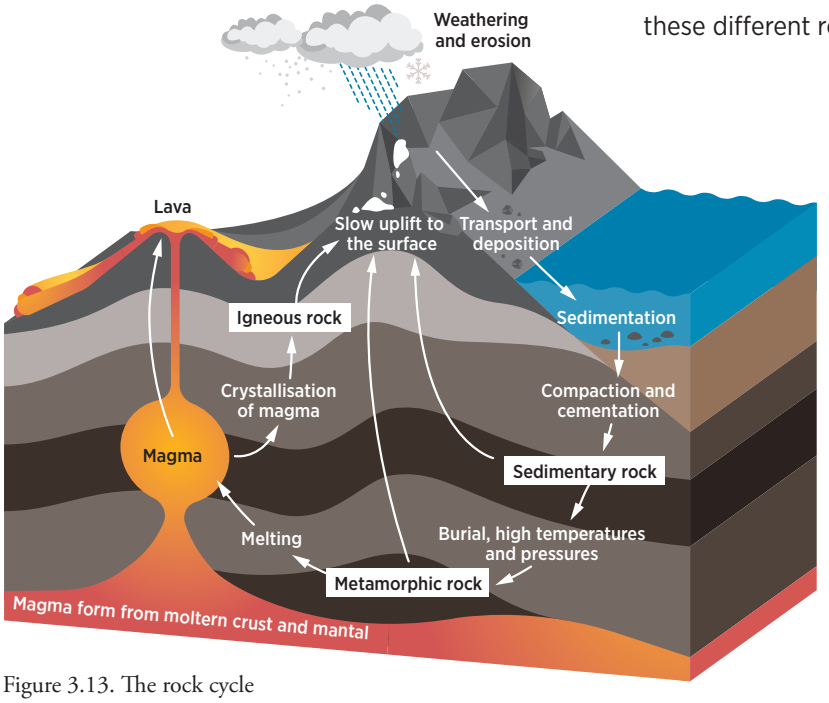


Figure 3.13. The rock cycle

CASE STUDY 3.2
Dating Earth with rocks

Earth is constantly changing: its crust is continually being created, modified and destroyed. As a result, rocks that record its earliest history have not been found and probably no longer exist. Nevertheless, there is substantial evidence that Earth is 4.5 to 4.6 billion years old. The principal evidence for the age of Earth comes from **radioactive dating**, a method of dating rocks and minerals using radioactive isotopes.

Isotopes of an element have the same number of protons but a different number of neutrons in their nucleus. For example, carbon-12, carbon-13 and carbon-14 are all isotopes of the element carbon, with respective mass numbers of 12, 13 and 14. In **radioactive isotopes**, the nucleus is unstable and over time will spontaneously break down into a more stable arrangement. Uranium is an example of this as it makes itself more stable by shedding particles and energy in the form of radiation.

Radioactive elements were incorporated into Earth when the solar system formed. All rocks and minerals contain tiny amounts of these radioactive elements. The process of radioactive isotopes breaking down is known as radioactive decay.

Radioactive decay occurs at a constant rate, specific to each radioactive isotope. The **half-life** of an isotope is the time it takes for half of the atoms in a sample to decay from the unstable radioactive isotope to the stable element.

Many different radioactive isotopes and techniques are used for dating. All rely on the fact that certain elements (particularly uranium and potassium) contain a number of different isotopes whose half-life is exactly known. Knowing the half-life allows us to measure the age of a rock or mineral by measuring the relative concentrations of their isotopes.

The oldest rocks on Earth, found in western Greenland, have been dated by four independent radioactive dating methods at 3.7 to 3.8 billion years. Rocks 3.4 to 3.6 billion years old have been found in southern Africa, Western Australia and the Great Lakes region of North America. These oldest rocks are metamorphic rocks but some originated as lava flows and some as sedimentary rocks. The debris from which the sedimentary rocks formed must have come from even older crustal rocks. The oldest dated minerals (4.0 to 4.2 billion years) are tiny zircon crystals found in sedimentary rocks in Western Australia.

Indigenous perspectives: Space and time

Indigenous Australians describe time in cycles, which contrasts with the dominant linear timescales of Western descriptions of time. The Western scientific concept of time begins at a certain point (the Big Bang) and progresses in a line to the present. The concept of time throughout the world is culturally constructed, and white Australians who have descended from European settlers largely determine time as past, present and future.

Within Indigenous Australian culture, time is seen as passing through cycles, and environmental changes are observed over different time scales.

- Changes in recent time includes cycles of night and day and lunar months.
- Medium-term changes in the environment include the seasons, which are indicated by the movement of **constellations**, weather patterns and altered animal behaviour. Some patterns, like holding travelling ceremonies, are repeated every few years.
- Long-term change is described through the analogues of the **Skyworld** causing seasons on Earth.

A calendar of Indigenous seasons links star movements, plant flowering, animal migration and weather changes (Figure 3.14). Ecologists and land managers can use Indigenous calendars to better understand the cycles of specific regions. The calendars relate to practices of burning, food and harvesting activities that have been carried out over the past 10,000 years or more. This long-term perspective gives insight into the impacts of climate change by providing a reliable record of shifts in seasonal cues and variations.

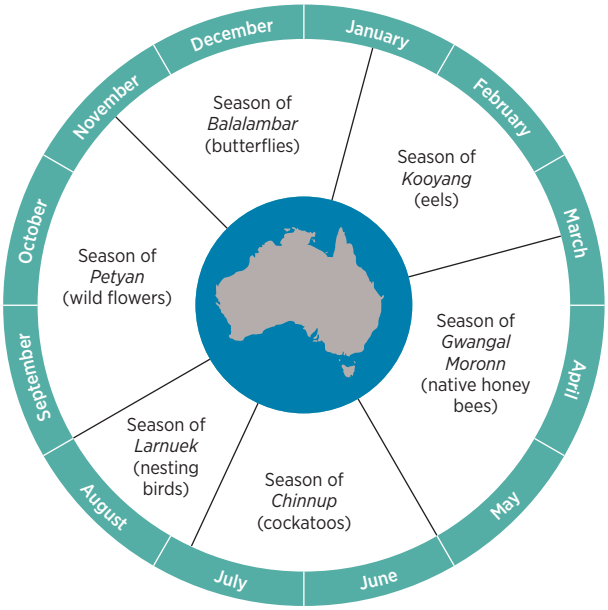


Figure 3.14. Season calendar developed for the Gunditjmara people of south-western Victoria. Note that the actual timing of the seasons would vary from year to year

Critical thinking and discussion 3.1

1. What is Earth's magnetic field and why is it important?
2. What is the most comprehensive evidence of continental drift? How does this help to explain the theory of continental drift?
3. What is the Ring of Fire? How does it provide evidence for the occurrence of plate boundaries surrounding the Pacific Ocean?
4. How does the surface of a material affect reflection of light?
5. Do denser materials refract light more or less than less dense materials? Why?
6. Where does most refraction happen in the atmosphere? Why?
7. Explain how refraction in water affects aquatic organisms.
8. Are pores desirable in soil? Justify your answer.
9. What types of biotic organisms are found in soil? Explain the importance of soil fertility.
10. What is soil compaction? How does it occur? Discuss the negative effects associated with it.

CHAPTER

4

Processes changing Earth

4.1. Environmental changes: short term

Changes and disruptions to landscapes, ecosystems and biomes that influence their distribution and ecological characteristics

Earth is a dynamic system, naturally undergoing continuous change on a range of time scales. Some environmental changes occur in relatively short cycles, while others take thousands of years. Large environmental changes can fundamentally change the ecosystems and biomes on the planet. Earth is over 4.5 billion years old. In this context, short-term changes occur in timeframes of days to years.

Changes within years

Daily changes

Activity that occurs regularly and predictably on a daily basis is following a **circadian rhythm**. Most birds are **diurnal**, becoming active during daylight hours, such as a rooster crowing when the sun rises. The name of the common lawn daisy (day's eye) comes from its habit of opening its petals by day and closing them at night. Many Australian native animals, such as possums, are **nocturnal**, coming out to look for food at night. Animals active at dusk and dawn, such as kangaroos, are called **crepuscular**.

Many organisms, including humans, follow these rhythms even when the surrounding environment is held constant and there is no indication of the time. This is why travelling by jet makes us feel out of phase with our new time zone. It takes a few days for our internal biological clock to adjust to a new time zone. External cues, such as sunlight, can help reset our clock.

Monthly changes

Lunar rhythms are associated with the movement of the Moon around Earth, which takes 28 to 29 days. Because the changing heights of tides correspond to the changing positions of the Moon in relation to Earth and the Sun, many intertidal marine organisms follow a lunar and tidal rhythm.

At low tide, wading birds such as sandpipers and spoonbills feed on the exposed mudflats. At high tide, carnivorous fish hunt among the mangroves and sea anemones unfurl their tentacles to trap tiny animals.

The common galaxias (or jollytail), a small migratory fish that lives in fresh water as an adult, times its autumn breeding to coincide with the extreme high tides at the new or full moon. These fish spawn in estuarine vegetation at the high tide mark, so the fertilised eggs remain out of water until the next extremely high tide a fortnight or so later sweeps them out to the sea for their juvenile stage.

Seasonal changes

Changing seasons bring changes in light, temperature and rainfall, leading to variation in the frequency and intensity of storms, floods, droughts and fires. Seasonal changes can affect the availability of food, and many organisms have adaptations that help them survive harsh seasonal conditions.

Plant and animal reproduction is influenced by seasons. Most wildflowers appear in spring, and many animals are born in spring as food becomes more abundant after a harsh winter. **Deciduous** trees drop their leaves in response to cool temperatures in autumn. These trees originate from cold climates, where leaf fall is part of the preparation for winter **dormancy**, conserving water at a time when water may freeze and become inaccessible to the plant. Many of these changes are triggered by a change in temperature and/or day length.

Some animals migrate from one place to another at certain seasons. The most amazing journeys are undertaken by certain migratory birds and fish. Short-tailed shearwaters depart each autumn from southern Australia on their 15,000 km migration to feed in the northern Pacific Ocean. They return the following spring, usually to the same burrow, to raise their young. Victoria's short-finned eels swim to the Coral Sea to spawn and then die. The larvae take up to 3 years to reach the river where their parents lived. Then, 10 to 25 years later, the mature adults set off on the long journey back to their birthplace.

Student activity 4.1
Science skills: Recording

Seasonal changes

Choose an ecosystem, such as the desert, alpine meadow, coastal mudflat, dry sclerophyll forest or temperate rainforest. For that ecosystem, research:

- changes in the climatic patterns from season to season
- the effects of these changes on the ecosystem
- seasonal changes in the behaviour or characteristics of an organism that lives in this ecosystem, and the environmental triggers for these changes.

Changes over years

Weather conditions cycle through the days and seasons, but conditions can also differ from year to year, or over periods of years.

El Niño–Southern Oscillation

The **El Niño–Southern Oscillation** (ENSO), a short-term climatic cycle over 3 to 8 years, is partly the cause of Australia's characteristically unreliable rainfall. The El Niño–Southern Oscillation is the name given to the see-sawing changes in sea surface temperatures and average atmospheric pressure in and above the Pacific Ocean that affect weather patterns across the Pacific and Australia.

An **El Niño** year starts with a drop of 1 to 2 °C in the surface temperature of the western Pacific Ocean near Australia, and a rise in the surface temperature of the eastern Pacific near South America. This causes the winds blowing westwards from South America to slacken. Normally, these westerly winds carry water from the ocean to Indonesia and Australia. During an El Niño event, these winds fail to reach us, leading to drought in eastern Australia, while the west coast of the Americas may receive higher than average rainfall.

Eventually, the situation reverses and we move into a **La Niña** phase, when the eastern Pacific Ocean is cooler than average and air pressure over the central Pacific is higher than average.

Relatively low pressure systems over Australia bring more winter and spring rainfall to eastern, central and northern Australia and a wetter early wet season in northern Australia. The ENSO phenomenon is further explained in Exploring science 2 'Modelling Earth's weather' (p 92).

Drought

In eastern and northern Australia many, but not all, droughts are due to the ENSO phenomenon. ENSO-induced droughts last about a year and may sometimes extend across the whole continent. They occur at irregular intervals about every 3 to 8 years. Other random droughts can also affect much of Australia and may last several years.

Droughts have a major impact on the rural economy and lead to environmental problems, such as severe fires, dust storms and general land degradation. Very dry summers after wet winters can result in particularly fierce bushfires, many being set off by lightning strikes.

Floods

Figure 4.1. Major floods can affect large areas of urbanised land

It is common for parts of Australia to experience droughts that are ended by floods. Flash floods result from intense storms and are localised and short-lived. Longer lasting floods occur after heavy rain over the catchments of extensive river systems. These are much more widespread. The effects of flooding include loss of human life, wildlife and stock; damage to homes, businesses and infrastructure, such as roads and fences; lost production; land degradation and the spread of disease.

In Australia, flood damage costs more than $400 million each year, more than any other natural disaster other than bushfire.

Floods can have environmental benefits, and many ecosystems are adapted to receiving regular floods. Floods flush salts from the soil and recharge underground water systems. Floods also deposit sediments on the flood plains, leading to the development of rich soils. Flooded rivers also allow fish to disperse to billabongs on the floodplain, and flooded wetlands support large colonies of breeding waterbirds. The floods caused by wet season storms and cyclones in northern Australia bring life to dry desert areas.

Glacial melting

Around 10% of Earth's surface is covered by glacial ice, including the large icesheets of Antarctica and Greenland, ice caps and glaciers. Australia is the only continent without glaciers. Glaciers even occur in the tropics, for example, in the Andes mountain range in northern South America, in Papua New Guinea and on Mount Kilimanjaro in east Africa. Glaciers are often an important source of water for people and ecosystems below the glaciers.

Glacial ice forms when snow stays in place long enough to get compressed into ice by new snow falling on top of it. Glaciers flow like very slow rivers, and those in the mountains can carve out huge U-shaped valleys as they erode the land surface. In a stable climate, the inputs (new snow accumulating at the top of the glacier) will, on average, replace the outputs (ice lost at the bottom where it melts or where ice blocks calve away). At any one time, a glacier may be advancing or retreating, depending on the current balance of those inputs and outputs. This balance depends on precipitation, humidity, wind, slope, surface reflectivity and, particularly, temperature. Because of this, glaciers are a useful indicator of changing climates.

Today, with increasing global temperatures, we are seeing an almost universal retreat of glaciers and icesheets, around the world, as well as the thinning of sea ice in the Arctic. Glacier monitoring data shows this retreat is speeding up, with new record annual losses being recorded many times since 2000. Figure 4.2 shows a retreating glacier.

Figure 4.2. This glacier has retreated significantly over the past few decades. Credit: Boris Kasimov CC BY 2.0

White snow and ice reflect a lot of the Sun's energy that reaches their surface. This is because they have a high albedo, which is a measure of the reflectivity of Earth's surface. As glacial ice retreats, and darker rock is exposed, more energy is absorbed by Earth because dark surfaces have a lower albedo (and reflect less solar radiation). Thus, there is a positive feedback loop: global warming causes glaciers to melt so more dark rock is exposed and more heat is absorbed leading more global warming.

The melting fresh water from glaciers contributes to a rise in the global sea levels and also affects ocean currents and global climate. The lighter fresh water pushes down the heavier salt water, altering the **thermohaline circulation**, large-scale ocean currents driven by gradients of heat and salt (see 'Thermohaline circulation', p 88). In the short term, changes are felt in the region of melting glaciers, such as off the coast of Greenland or the Antarctic, but in the medium to long term, effects are felt in the atmosphere and the wider ocean.

Land cover changes

Some of the most obvious medium-term changes to our environment are those caused by human use of the land. Land use describes the human activities taking place on the land. These include forestry, conservation, cropping, grazing, residential and commercial development, industry, mining and recreation. One important aspect determining land use is land tenure, particularly whether the land is public land (owned by government) or private land.

These various land uses, to a greater or lesser extent, alter the physical aspects of the land and the land cover. Land cover describes the vegetation types, soil, water bodies and artificial structures on the land. Not all changes in land cover are human-induced. Bushfires, floods, landslides and volcanic eruptions can all change the vegetation, soil and other physical attributes of an area. However, the impact of human activities is extensive and, with modern technologies, our power to alter landscapes is unprecedented in history. The massive land cover changes caused by humans building towns and cities and growing food have caused many environmental problems, including loss of biodiversity, salinity, erosion, deforestation, depletion of resources, increased flooding, desertification, climate change and pollution of soil, water and air. Mapping land uses and land cover, and monitoring ecosystem condition, provides vital information to help us manage the land sustainably – fulfilling our needs for food, products and living space while conserving natural ecosystems and environmental processes.

Desertification

Around 41% of Earth's land surface comprises arid, semi-arid and dry sub-humid areas known collectively as **drylands**. More than 2 billion people live in the drylands, of which 90% live in developing countries, especially in Africa and Asia. Drylands can support productive grasslands, woodlands and forests, but a combination of human activities and climate change is causing, or threatening, degradation of large areas of dryland, turning them into deserts. This is the process of **desertification**, which is an issue of global concern and the subject of the United Nations Convention to Combat Desertification (UNCCD).

Desertification is caused by heavy farming pressure that the land can't cope with, for example, over-grazing, over-cultivation, excessive fertiliser use, excess water extraction, poor irrigation and deforestation. These practices increase soil erosion, salinity and acidification, reduce soil fertility and water storages, and increase soil and water pollution. Droughts and floods can exacerbate land degradation, as do more subtle climatic changes such as changing rainfall patterns and evaporation rates.

This overuse of land is often driven by poverty and food insecurity (see Chapter 12, p 200), and pressure to support families and communities. Thus, poverty and hunger both cause, and result from, desertification, which is therefore also influenced by technology, global markets, political instability and wars, and other social and economic factors. The relationship between changing climate and desertification is similarly complex. Climate change is increasing desertification, and desertification increases greenhouse gas emissions as carbon sinks are lost and vegetation is burnt or rots.

Student activity 4.2
Science skills: Drawing justified conclusions

A close look at natural environmental changes

1. Investigate a recent natural disaster that has caused changes to Earth's systems.
2. Identify the changes that have occurred as a result of the disaster. Discuss whether these changes are truly natural and/or to what extent human presence has contributed or influenced the impact on Earth's systems.

You could investigate: the April 2015 earthquake in Nepal, Queensland floods in 2010–11, Typhoon Haiyan in the Philippines in November 2013, the 2004 Boxing Day tsunami, the Black Saturday bushfires in Victoria in February 2009 or the Black Summer bushfires of 2019–20.

Ecological succession

Ecological succession describes a shift in ecosystems and biomes over time that lead to changes in distribution of plant and animal species and the ecological characteristics of an area.

- **Primary succession** describes the formation of ecosystems in areas of brand-new land, for example, after volcanic activity or a glacier receding.
- **Secondary succession** describes changes in mature biomes or ecosystems after a major disturbance such as clearing for agriculture or bushfire.

Primary succession

When land is newly formed or available as a habitat, the first organisms to arrive are autotrophic **colonisers** like lichen and mosses followed by small plants. Their spores (or plants' seeds) arrive on the wind and settle in rock crevices. Colonisers typically have adaptations that allow them to survive these difficult conditions: they grow quickly, complete their life cycle in 1 year, produce many spores or seeds, survive temporary drought and flood, tolerate direct sunlight and can grow in shallow soils with low nutrients.

Colonisers trap dust and produce acids that break down the rock and turn it into soil, so their presence makes the environment more hospitable for other species. As colonisers grow and die, erosion creates tiny fragments of rock that combine with the organic material to form a simple soil. Over time, wind-dispersed seeds of more complex autotrophs arrive and settle into the soil.

Colonisers cannot usually survive competition from other species, so they soon die out. As a rule, the first plants to arrive in a brand-new ecosystem will be low grasses or herbaceous plants capable of withstanding harsh conditions. The growth of plant roots stabilises the soil, and the cycle of growth and death creates more nutrient-rich, deeper soil. Over time, larger shrubs and woody plants will be able to grow in this environment, which brings animals into the area seeking food and shelter.

Changes in weather patterns or changes in vegetation structure over time influences the coexistence of different species and the general assembly of the community. Over hundreds of years, an ecosystem is created on what was once bare rock. Plant species continue competing for resources (such as water, nutrients and sunlight), and altering the environment, until the climax community is reached. At this stage, plant species composition is stable and self sustaining until disrupted by an ecological change event (such as a bushfire, flood, landslide) or a long-term process (such as climate change).

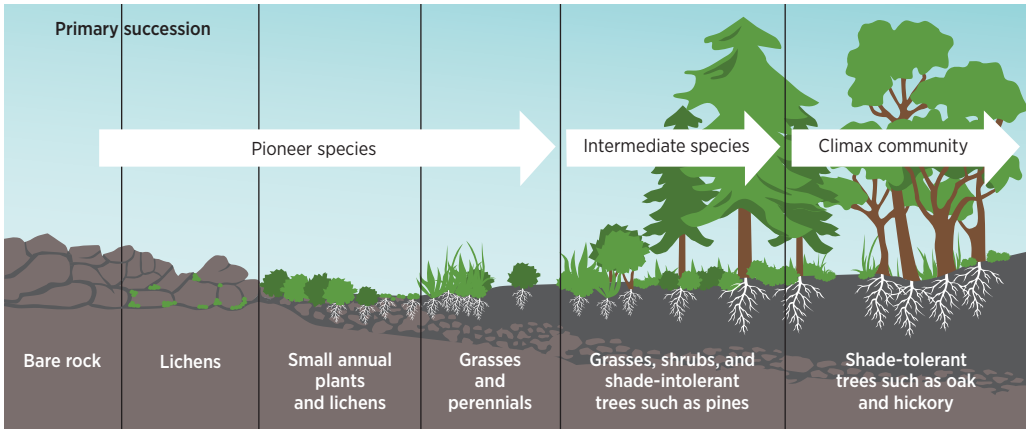


Figure 4.3. Gradual succession of the landscape from primary succession and pioneer species through to the climax community

CASE STUDY 4.1
Primary succession in the Galapagos

The Galapagos Islands archipelago sits in the Atlantic Ocean around 1,000 km to the west of Ecuador in South America. It is one of the most famous examples of how changes in landscapes can influence an ecosystem.

Thirteen main islands sit over the top of a tectonic 'hotspot', where super-heated rock rises up to the surface of Earth and meets the cooling ocean. The islands, built via a series of volcanic eruptions along with changes in sea levels, were once bare rock.

Winds from the north-east and south-east first carried spores of moss, lichen and algae to the bare, newly formed islands. Over time, as the soil was created and became more stable and nutrient rich, seeds from plants brought in by ocean currents or the winds, settled and germinated.

We do not know how many different sorts of land animals have made the 1,000 km journey over the ocean to the Galapagos Islands. However, the semi-desert biome created on the islands means that land animals who do arrive must be able to survive dry, hot windy conditions. Many species who did establish populations have over time evolved into new species, so many of the species found there today are **endemic** to the Galapagos. All influence the ecosystem in their own way.

Secondary succession

Secondary succession describes changes in mature biomes or ecosystems after a major disturbance such as clearing for agriculture or bushfire. With the loss of animal and plant species in the area, light, space and nutrients become available for seeds (that were perhaps once dormant) to germinate. Reduced competition brings in new animal species. Secondary succession is similar to primary succession in that the process builds up more complex ecosystems over time.

Figure 4.4. Example of secondary succession after fire.
Credit: Pascal Vuylsteker CC BY-SA 2.0

CASE STUDY 4.2
Secondary succession

Disturbances in an ecosystem play an important role in enabling biotic communities to reorganise and re-establish. Each year, cyclones in Australia's tropics damage homes and disturb local forested areas. This disturbance can flatten large trees, which lets sunlight penetrate to the forest floor, allowing new trees to germinate and grow.

The loss of large trees reduces population numbers of arboreal animals (those that live in trees) and favours smaller animals that move around the forest floor. This in turn brings in different seeds and plants that can grow in the newly exposed forest floor. As the new communities begin to establish, the forest floor is again protected from full sunlight, and the understorey plants begin to grow. A new understorey provides habitat for animals who favour those conditions, which in turn fosters continuing regeneration of, and ecological succession within, the forest ecosystem.

Practical 4.1 Creating a secondary succession photo diary

Aim

To document changes to a fire-affected ecosystem and link these changes to the concepts of secondary succession.

Materials

Camera (if you have access to a field site affected by the 2019–20 bushfires)

or

Google Earth on an iPad or desktop

Procedure (with access to a field site)

1. If your home or school is in an area affected by the 2019–20 bushfires, or if you have easy access to such an area, select a location to document.
2. At your location, choose a position from which to make your observations. NOTE: You might like to record the position coordinates to ensure you return to the same location each time you visit.
3. Take a photograph in three different directions from your position. Record in your logbook the date, weather and any other observations of the site.
4. Return to this site at regular intervals throughout the semester, perhaps weekly or fortnightly. Ensure that your photographs are taken from exactly the same position each time.
5. Collate your logbook and photographs into a photo diary or journal of the area.

Procedure (using Google Earth)

1. If you do not have easy access to a bushfire-affected area, you can choose a recently burnt location anywhere in Australia and use Google Earth.
2. Record the coordinates of your chosen location.
3. Take screenshots of these coordinates over the same period.
4. Use Bureau of Meteorology data to note the weather at your location each day that you gather your photographs.
5. Collate your logbook and screenshots into a photo diary or journal of the area.

Analysis and conclusion

Summarise your journal and and discuss the changes in the ecosystem over the time of your study, referring to the principles of secondary succession.

Safety considerations in the field

- Wear personal safety gear when in the field including hat, sunscreen and hiking boots.
- Beware of snakes and insects when gathering data.
- Gather your field data in pairs.

Student activity 4.3
Science skills: Establishing an evidence-based argument

The Hawaiian islands and primary succession

The Hawaiian islands were formed by a hotspot under Earth's crust. Volcanic eruptions led to lava rock protruding above the ocean's surface, thus forming islands. As Hawaii's tectonic plate shifts north, new islands continue to form over the volcanic hotspot. Since the northernmost islands are older than those to the south, they have had more time to undergo ecological succession.

1. Investigate the establishment of vegetation and wildlife on the Hawaiian islands. Has each of the islands reached its climax community or are the islands in different stages of primary succession?
2. The Big Island of Hawaii has a volcano that is currently erupting, submerging established forests beneath the volcanic material and extending the southern coastline of the island. Using your knowledge about ecological succession, discuss whether this marks the beginning of primary succession or secondary succession.

Critical thinking and discussion 4.1

1. **Outline** two events that can trigger a primary succession event.
2. **Describe** the role played by the first autotrophic organisms to colonise an area during a primary succession event.
3. Use the following website to research the formation of the Hawaiian Islands: https://www.nationalgeographic.org/media/alien-deep-geology/.

   Write an informative article (similar to the primary succession case study above) to **describe** primary succession in the Hawaiian islands.
4. In 2011, Mission Beach in far north-east Queensland was hit by cyclone *Yasi*. **Predict** how this led to secondary succession in the local wet tropical rainforest ecosystems and what changes may have occurred.
5. Use the following website to research ancient Australian rainforests:

   http://whc.unesco.org/en/list/368.

   Suggest why these regions of Australia show little evidence of succession.

Figure 4.5. The Hawaiian island of Kauai is the second oldest of the main Hawaiian islands

Indigenous perspective: Cultural burning

Aboriginal Australians have a deep understanding of the effects of vegetation disruption and the principles of ecological succession.

Aboriginal cultural burning has long been acknowledged as an effective land management tool in many areas of Australia. Before an area is burnt, an evaluation of the contributing biotic and abiotic factors from all of Earth's systems is made. Cultural burning uses small, cool fires to gently disturb the ecosystem. The burning encourages the growth of grasses and other food plants favoured by kangaroos and other meat animals. The result is easier hunting, and no large out-of-control fires that damage the larger trees and clear land.

Many white settlers reported that they could ride their horses at full gallop through the trees as there was little undergrowth. The same forests today, without cultural burning, are thick with undergrowth. Settlers also noticed that the

Figure 4.6. Kangaroo apple (*Solanum aviculare*).
Credit: John Tann CC BY 2.0

kangaroo apple *(Solanum aviculare)* was abundant after fire when the seeds store was activated. They could see that fire was used by Aboriginal Australians to manage food sources over the short and medium term.

Their deep knowledge of the land lets Indigenous Australians manage a food-growing system from season to season that harnesses the natural processes for long-term sustainability. This contrasts with modern agricultural practices that drastically modify the landscape to grow our food.

4.2. Environmental changes: long term

Changes and disruptions to landscapes, ecosystems and biomes that influence their distribution and ecological characteristics

Changes over decades

The greenhouse effect

In 'Electromagnetic radiation' (p 48), you saw that solar radiation reaches Earth mainly in the wavelength range of 300 to 2,500 nm. A high proportion of that energy is absorbed by Earth and then reradiated into the troposphere as infrared (heat) radiation at much longer wavelengths, about 4,000 to 20,000 nm (or 4 to 20 µm; a micrometre (µm) is 10^{-6} of a metre). Some of this reradiated energy escapes into space, but the rest is absorbed by gases in the troposphere where it contributes to warming the troposphere and Earth's surface. This process is called the greenhouse effect.

The greenhouse gases in the atmosphere keep the temperature of Earth's surface fairly constant, at an average of 15 °C. Without greenhouse gases in the atmosphere, all the thermal radiation would be emitted to space – Earth's temperature would be about 30 °C colder, and life as we know it would not have developed.

The main greenhouse gases are water vapour, carbon dioxide, methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons and halons. Water vapour is the most abundant greenhouse gas. Carbon dioxide is the next most abundant and the one which contributes most to the enhanced greenhouse effect. Greenhouse gas molecules absorb those frequencies of radiation that match their characteristic resonant frequencies. In doing so, they gain kinetic energy, which is why the temperature rises.

Studies of climate over a geological time scale show that Earth's climate has changed dramatically in the past 4.5 billion years. Figure 4.7 shows temperature changes over periods in Earth's history: Earth was very hot early in its history and then over millions of years became very cold, with smaller fluctuations. These changes have occurred because of volcanic activity, tectonic movement, the evolution of Earth's biota and asteroid impacts. Data on past climates comes from **ice core samples**, fossilised coral and salt deposits from areas that once contained lakes or oceans.

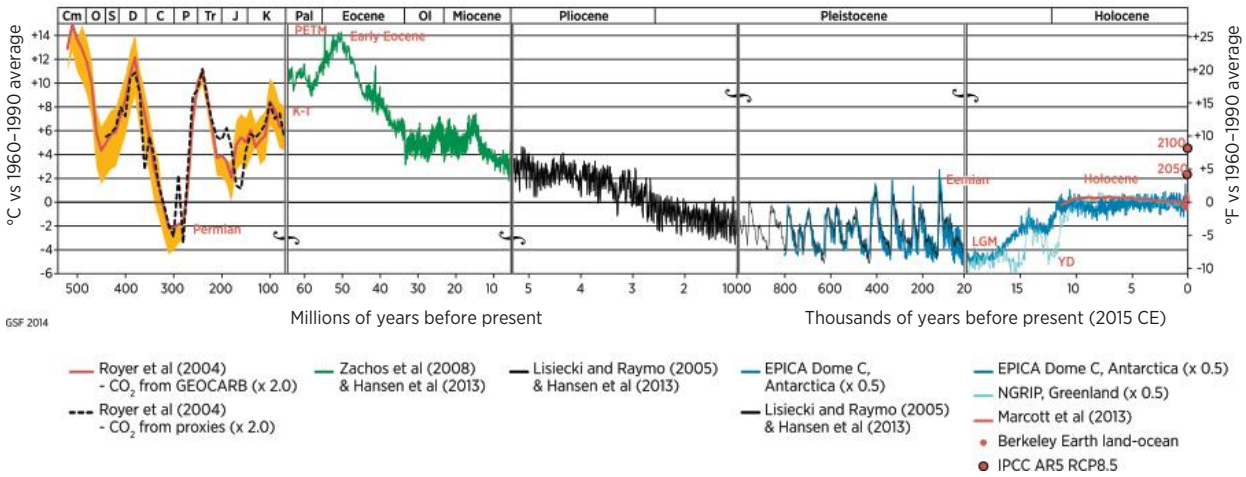


Figure 4.7. Temperature of Earth over geological time.
Credit: Glen Fergus CC BY-SA 4.0

Now human activities are increasing the concentrations of greenhouse gases, enhancing the greenhouse effect and warming the planet. This enhanced greenhouse effect is causing **climate change** – not just increased temperatures but associated changes in rainfall, humidity, cloud cover, winds and storms, and other aspects of our weather patterns. The temperature has been stable over the last 10,000 years, but we are currently moving out of the Holocene and temperatures are rising at a rate never before seen. This confirms that the rise is human-induced climate change and not part of the natural temperature cycles.

Effects of climate change

Current **climate models** predict that the global average temperature will continue to increase over the coming years. **Climate** patterns fundamentally influence ecosystems and biomes, so a changing climate will affect the distribution of ecosystems and biomes.

Tropical regions

Current predictions show tropical rainforests drying out and turning into savannah woodlands, grasslands and potentially even deserts. The major probable cause is disruption to the water cycle (see 'Water cycle' p 34) caused by rising global temperatures. Reduced rainfall and humidity, along with a rise in temperature, will ultimately reduce growth of rainforest plant species and favour species more tolerant of drought.

Alpine regions

Temperature increase will inevitably shrink alpine regions, as snow depth and area decreases. This will reduce the distribution of plant (and then animal) species that characterise these biomes. It has already been observed that both plant and animal species are moving to higher altitudes in areas such as the Bogong High Plains in Victoria. In the Patagonian ice fields, snow and glacial ice are being lost at alarming rates, leaving behind lakes and dark rock, thus changing the structure of the food web and thereby the ecosystem.

Figure 4.8. The endangered mountain pygmy-possum needs snow depths of at least 1m in winter to keep it warm during hibernation. As the snow moves to higher altitudes, the possum is forced to follow it. Credit: Zoos Victoria

Coral reefs

Coral reef ecosystems will be affected by both changes in sea temperature and ocean acidification. Warmer ocean temperatures at the tropics will lead to bleaching, and eventual death, of many hard and soft coral species. Shallow subtropical waters further from the equator may become more favourable locations for the building and maintenance of the limestone coral structures that define the coral reef biome. However, ocean acidification is already making it harder for corals to build strong skeletons.

Temperate regions

Drylands support ecosystems such as tussock grasslands, dry woodlands and temperate forest. Some studies predict that the disruption to the water cycle, caused by warming temperatures, will affect dryland ecosystems more than any others. Less overall rainfall and an increase in flood and bushfire events may result in loss of topsoil from erosion, loss of many plant species and an overall shift in the boundaries of these areas (see 'Desertification', p 61).

Data analysis 4.1 Modelling future changes in Australia's ecosystems

Use the Climate Futures Tool to examine predicted changes in climate variables such as average rainfall, humidity, maximum and minimum temperatures in Australia.

1. Go to the website: https://www.climatechangeinaustralia.gov.au/en/projections-tools/climate-futures-tool/detailed-projections/. You will first need to register a free account.

   Once registered, you can sign into the Climate Future Tool at: https://www.climatechangeinaustralia.gov.au/en/projections-tools/climate-futures-tool/introduction-climate-futures/.

2. In Scenario, select 'B1 - low emissions'.
3. In Year, select '2030'.
4. In Select classifying variables and seasons, choose 'Mean Surface Temperature', 'Annual' and 'Rainfall'.
5. Click on each biome region shown on the map of Australia and take notes on how the temperature and rainfall will be affected.
6. Repeat steps 2 to 5, choosing 'A1B – medium emissions' and then 'A2 – high emissions'.
7. As part of your results, make predictions on how each outcome may affect the distribution of that particular biome.
8. Record your information in a table as shown below.

		Emissions scenario			Predictions of possible changes to ecosystem distribution
Ecosystem type	Variable	Low	Medium	High	
Wet tropics	Rainfall (%)				
	Surface temperature (°C)				
Southern slopes (alpine)	Rainfall (%)				
	Surface temperature (°C)				
Southern and south-westerns flatlands	Rainfall (%)				
	Surface temperature (°C)				
etc.	Rainfall (%)				
	Surface temperature (°C)				

Critical thinking and discussion 4.2

1. Use the following article to **describe** the purpose and process of collecting ice core samples for climate modelling: https://www.scientificamerican.com/article/how-are-past-temperatures/.
2. Refer back to Figure 4.7, which shows Earth's climate history. **Predict** the likely main drivers of the climate of each time period.
3. **Discuss** how changes to tropical rainforest distribution in Australia may affect animal species with tiny geographic ranges, such as the southern cassowary.

Changes over millions of years

Mass extinctions

Around 65 mya, most of the dinosaurs died out (although some **evolved** into present-day birds). But it wasn't only the dinosaurs that died out – around 75% of all plant and animal species on Earth became extinct. An event like this is called a **mass extinction** to contrast with the much lower rate of species extinction that occurs all the time. Of approximately four billion species that have evolved in the 3.5 billion years that Earth has supported life, around 99% are extinct. Over Earth's history there have been five mass extinctions, caused by a variety of factors, plus a whole range of smaller extinction events. Each of these mass extinctions changed the course of evolutionary history, such as the disappearance of the dinosaurs allowing the rise of mammals. Because mass extinctions are such notable events, they generally mark the boundary between different geological periods.

Ordovician–Silurian mass extinction

Life existed mostly in the sea in the **Ordovician** period (488 to 443 mya). Organisms at that time included trilobites, cephalopods, reef-building invertebrates and jawless fish, which were the first vertebrates. Apart from algae, all plants were unicellular. The mass extinction that ended the Ordovician and marked the beginning of the **Silurian** period was triggered by the large landmass of **Gondwana** (as it existed before joining North America, Europe and Siberia to form Pangaea) gradually moving to a position over the South Pole. This led to the globe cooling, large ice sheets forming and sea levels lowering. Carbon dioxide may also have played a role in these climatic changes, with the rocks of the relatively new Appalachian mountains in North America weathering in a process that locked up carbon from the atmosphere: the silicate rocks reacted with atmospheric carbon dioxide and water, trapping carbon in the resulting sediment and cooling the planet as atmospheric carbon dioxide decreased.

Late Devonian extinction

In the **Devonian** period (416 to 359 mya), the land supported the first ferns and insects, and some fishes evolved limbs and became the first land vertebrates. There was a great diversity of fishes, and the period is nicknamed 'the age of fishes'. The climate was generally warm and sea levels were high. The later Devonian extinction occurred over about 20 million years, particularly affecting life in shallow, tropical seas which became devoid of oxygen. It's not clear what caused this extinction. Several factors may have played a role, including a meteor or comet impact, global warming, excessive sedimentation or nutrient run-off.

Permian–Triassic extinction

In the **Permian** period (299 to 251 mya), all the continents were formed into one landmass, called **Pangaea**, leaving the rest of the globe covered by a large ocean. Amphibians and reptiles had evolved, as had the ancestors of mammals and dinosaurs. The forests had seed ferns, tree-ferns, conifers, cycads and gingkos. The Permian–Triassic extinction, also known as 'the great dying' is the greatest mass extinction on record. Around 95% of all species became extinct, especially marine organisms such as all the trilobites, and many insects, vertebrates and plants. Again, the cause or causes of this massive extinction are not clearly understood.

Triassic–Jurassic extinction

The survivors of the Permian–Triassic extinction recovered gradually, coping with the effects such as low oxygen levels during the **Triassic** period (251 to 199 mya). There were no polar ice caps and the climate was generally hot and dry. The first dinosaurs and the first mammals were appearing, and pterosaur reptiles were the first animals after insects to evolve powered flight. In this extinction, animals were more affected than plants, freeing up ecological niches that the dinosaurs took advantage of in the **Jurassic** period (199 to 145 mya). Volcanic activity associated with seafloor spreading in the breakup of Pangaea may have contributed to the mass extinction, but other causes have also been suggested.

Cretaceous–Tertiary extinction

The Cretaceous–Tertiary extinction (65 mya) is the event that killed off the dinosaurs (apart from those which became the ancestors of birds), as well as ammonites and pterosaurs, and many marine invertebrates and flowering plants. The cause is most likely to be the impact of a huge asteroid, whose crater has been discovered on Mexico's Yucatan Peninsula. However, a changing climate resulting from volcanic activity, and a falling sea level, may have already been making life hard for some species.

The sixth mass extinction?

Scientists are now starting to call the rapid loss of species we see today the sixth mass extinction. It is caused by human activity, especially our alteration of habitat and our impact on climate change. Extinction is occurring 100 to 1,000 times (perhaps 10,000 times) faster than natural, background levels. At today's rates of extinction, we could reach species losses equivalent to a mass extinction within 250 to 12,000 years. This is a much faster rate than occurred in any of the big five extinction events. One whole class of vertebrate, the amphibians, are under threat, with one-third of the world's 6,300 species of amphibian already threatened with extinction.

CHAPTER

5

Data and science in understanding and managing the environment

5.1. Studying Earth's systems

Ways of using data and models to study Earth's systems and changes in Earth over time

Scientists increasingly use **models** to explore changes in Earth's systems over time. Models can be very accurate because of the power of modern high-performance computers for 'big data' collection and analysis.

Scientists use models to gain a better understanding of a particular aspect of the world. Models can help you visualise something well known or discover something new. They can be physical models, like the model of Earth known as a globe, or they can be computer models. Computer models are valuable because they can assimilate multiple data sources to simulate many interacting aspects of environmental systems and allow scientists to predict the impacts of climate change.

Data is the information used by scientists to understand something. For example, scientists might use wind speed data to measure the severity of a cyclone. In environmental studies, many different sources of data are typically combined to produce a complete picture.

For example, wind speed data will be more useful to predict the severity of a cyclone if it is coupled with atmospheric pressure data and tide data. Combining these three types of data will help scientists predict the likelihood of a critical storm surge.

Measuring past climates

We have only had instruments to measure temperature, rainfall and other climate data for 140 or so years. To reconstruct historical climates from a few hundred years ago to far back in Earth's history, we need to look for other sources of data.

One approach is to analyse concentrations in gas bubbles from very deep ice core samples – these are samples of the atmosphere at the time the bubble formed – but they are hard to obtain. Consquequently, **palaeoclimatologists** (scientists studying past climates) look for evidence from more easily accessible sources – indirect records of past climate known as **proxy data** (Table 5.1).

For example, fossil pollen grains can be evidence of particular plants having grown in a certain place at a certain time. The types of plant can indicate what the climate was like at that time. Table 5.1 lists some of the data sources used by palaeoclimatologists to determine historical climates.

Exploring science 2 'Modelling Earth's weather' (p 92) looks at how data and models work together to predict global weather events and patterns.

Table 5.1. Examples of proxy data used in palaeoclimatology

Proxy data	Link to climate
Annual growth bands in stalagmites and stalactites in caves	Width of bands indicates periods of floods and drought
Minerals in stalagmites and stalactites in caves	Radiometrical analysis indicates climate conditions when the structure formed
Temperatures measured in boreholes drilled into Earth's crust	Temperature profile (temperatures at different depths) indicates past surface temperatures
Oxygen isotopes and trace metals in coral skeletons	Skeleton composition indicates the temperature of the water in which the coral grew, and thus historical ocean temperatures
Scar trees and charcoal deposits in forested areas	Scars and deposits indicate timing and intensity of past fires
Fauna and flora fossils	Fossils indicate what species were present in a geographical area at a particular time, and thus past climates
Pollen from flowering plants	Pollen grains and spores that were washed into lakes and deposited as sediment indicate the type of vegetation around the lake at different times in history
Historical references and documented evidence from church records, harbour ice freezes, harvest dates and ships logs	Historical records indicate climate and weather conditions in recorded history

Indigenous perspectives: Data and models

Data can be in the form of numbers (such as wind speed and air pressure or heights and lengths), but it can also be direct observations. As humans we collect hundreds of different pieces of data a day and our brains model that data to make sense of it. This type of observational data gathering to make sense of the natural world has been happening for tens of thousands of years in many **First Nations cultures** around the world.

Indigenous Australians have a long history of collecting observational data and using it to establish models of past geological changes. Aboriginal and Torres Strait Islander peoples believe that at the end of the Creation period their ancestors took the form of birds and other economically important animals as well as plants. Data generated from the observations of landforms and animal interactions was collated into models best described as stories. These ancient story models are very similar to contemporary computer models in that they take connected pieces of observational data and integrate them in order to clearly visualise the interacting components.

Figure 5.1. Google Map satellite image of Gerum Gerum. Credit: Imagery ©2021 CNES / Airbus, Maxar Technologies, TerraMetrics

Figure 5.2. Holes in the limestone representing where Waak threw his spear. Credit: denisbin CC BY-ND 2.0

A story made from observation of the landscape can be found just beyond the Victorian border in the Coorong region of South Australia, where the Indigenous people are in the Ngarrindjeri language group. This part of Australia is characterised by white sandy beaches, long lakes and salt pans. One of these salt pans, called Gerum Gerum (and known also as Pipe Clay Lake, Figure 5.1), is considered a sacred place of burial for the people of the Coorong. Observational data collected at Gerum Gerum has been used to model the story of the creation of four islands within the lake and a fifth that is connected to the land by a thin piece of land.

According to museum researcher Norman Tindale, the story is of the Owl (possible a barn owl) and Mopoke (boobook owl) ancestors who challenged Waak, the Crow, at Gerum Gerum. They would let Crow live nearby at Salt Creek if he could throw five consecutive boomerangs in complete circles. Crow threw four of them successfully but the fifth was caught by the wind and fell short. Owl and Mopoke then tried to spear Waak but he got away to the south-east where his tracks remain as a series of salt pans. Waak eventually stopped on the edge of the Coorong and could see he was no longer being chased. As he looked around from his high vantage point, he thrust his spear into the ground in places that could later be seen as holes in the limestone cliffs (Figure 5.2).

This story is an example of a theoretical model being created through the observations of animal interactions along with geographical features. In that way it is similar to the theory of continental drift.

5.2. Innovation and science

The role of innovation and science in responding to challenges as a result of environmental change and disruption

With the many environmental changes and disruptions occurring on a global scale, scientists are exploring **innovative** ways to respond to these challenges. Two areas of environmental challenge are increased atmospheric carbon dioxide and reduced availability of fresh water. To address these issues Australia has committed vast amounts of scientific effort and money in research projects that investigate technical solutions.

Carbon capture and storage

Increased atmospheric carbon dioxide is one of the most pressing issues in modern environmental science. Given the scale of the problem, a range of solutions need to be adopted, from avoiding producing carbon dioxide (for example, by switching to renewable energy), to capturing and storing carbon dioxide that is produced while we still use fossil fuels, to extracting carbon dioxide that is already in the atmosphere.

The Cooperative Research Centre for Greenhouse Gas Technologies (CO_2CRC) is primarily concerned with developing the science and technologies for carbon dioxide capture and geological storage – known as carbon capture and storage (CCS) or carbon **sequestration**.

Capturing carbon

Carbon capture is the process of capturing carbon dioxide that would otherwise be emitted from industrial processes.

More than half of the carbon dioxide pollution in Australia comes from coal-fired power plants. Technology exists that can capture the carbon dioxide usually released during the burning of coal before it is released into the atmosphere. This process takes place in the **pre-combustion** phase and can be applied to any fossil fuel, not just coal. The fossil fuel is **reacted** with steam and oxygen, which produces a synthetic gas called syngas (composed mainly of carbon monoxide, carbon dioxide and hydrogen). A further reaction turns the remaining carbon monoxide into carbon dioxide, and the carbon dioxide is removed leaving hydrogen that can then be burnt to turn power-producing turbines. These plants exist today, but the technology is only used in new power plants – Australia's old coal-fired power plants don't use this process.

Carbon can also be captured post-production by separating out carbon dioxide from exhaust gases in a facility's smoke stacks before the gases are released to the atmosphere. CSIRO is also researching a process for extracting carbon dioxide directly from the atmosphere.

Capturing carbon dioxide from exhaust gases or the atmosphere requires the gases to be forced under pressure through a **membrane** with special gas-absorbing solvents that will selectively absorb carbon dioxide.

Carbon dioxide captured by one of these methods is then forced by pressure into a liquid state where it can be transported either via pipes or truck to a storage facility.

Storing carbon

Carbon can be stored in two ways:

- Captured carbon can be stored underground, known as **geological sequestration.**
- Carbon taken up by plants in photosynthesis can be stored in large reserves of plant matter, a process known as **biological sequestration**.

Geological sequestration

Once captured, carbon dioxide needs to be stored in a secure location from which it can not escape to the atmosphere. Ironically, this is sometimes done deep underground in pockets of rock left vacant by the **extraction** of fossil fuel gas! Before such a site is used for geological sequestration, it must be studied to determine that stored carbon dioxide will not escape.

Figure 5.3. Location of the CO_2CRC's Otway International Test Centre research facility

A suitable site will:

- be within rocks that are not **permeable**
- be geologically stable (not prone to earthquakes)
- not be **infiltrated** by groundwater or prone to flooding.

Several sites in Australia have been identified as suitable for geological sequestration. One is already operational in the Otway region of south-west Victoria where the CO_2CRC research test facility is located (Figure 5.3). A much larger site has also been identified in the Petrel Sub-basin off the coast of the Northern Territory. The Petrel Sub-basin consists of two Mesozoic ocean reservoirs (Figure 5.4). The Jurassic saline reservoir is considered to be the better site as it is sealed with approximately 300 m of overlying rock.

Biological sequestration

Another approach to sequestration is to take advantage of the fact that all plants use carbon dioxide for photosynthesis, so are potentially very large **carbon sinks**. Storing carbon in plants is known as biological sequestration. However, terrestrial plants are susceptible to fire, and if a forest burns it releases its carbon dioxide into the atmosphere.

To overcome this limitation of plants as a long-term carbon sink, scientists are investigating the idea of underwater biosequestration – in seaweed farms.

Kelp and other macroalgae are highly efficient at storing large amounts of carbon dioxide. Seaweed is currently grown for use in food, medicine and beauty products on a small scale, but scientists are investigating the viability of establishing seaweed farms on a much larger scale as a carbon sink. The farmed seaweed would take up atmospheric carbon dioxide as it grows. Then it would be harvested and sunk down deep in the ocean where the carbon dioxide would be trapped for a very long time (Figure 5.5).

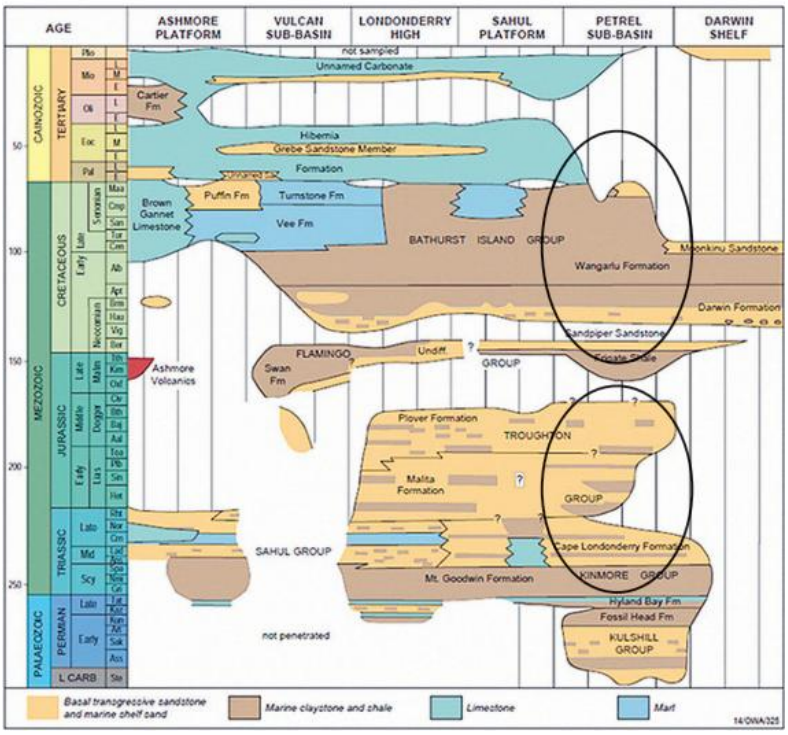


Figure 5.4. Benthic composition of the Petrel Sub-Basin showing the two Mesozoic reservoirs CC BY 4.0

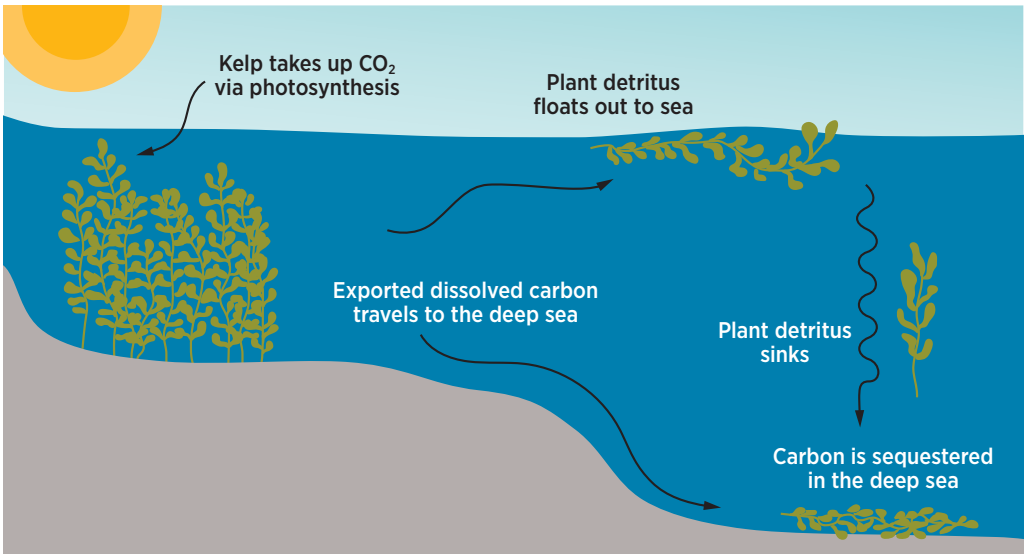


Figure 5.5. Marine seaweed forests show potential in the use of biological sequestration

Making fresh water

With changes to weather patterns and a growing human population, supplies of fresh drinking water are becoming limited in some towns and cities. Innovative technologies that can make available reliable, climate-independent and economically viable fresh water supplies for industry, irrigation and drinking include desalinating seawater and reclaiming wastewater.

Desalinating water

Many countries use **desalination** as a way of securing fresh drinking water that doesn't rely on patterns of rainfall. Table 5.2 lists Australias desalination plants.

Table 5.2. Australian desalination plants

Desalination plant	Initial investment ($million)	Completion date	Capacity (gigalitres per year)
Perth Seawater Desalination Plant (Kwinana) – Western Australia	387	2006	45
Southern Seawater Desalination Plant (Binningup) – Western Australia	1,400	2012	100
Gold Coast Desalination Plant (Tugun) – Queensland	1,200	2009	49
Adelaide Desalination Plant (Port Stanvac) – South Australia	1,830	2012	100
Victorian Desalination Plant (Wonthaggi) – Victoria	3,500	2012	150
Sydney Desalination Plant (Kurnell) – New South Wales	1,890	2010	90

Source: Australian Water Association, Desalination fact sheet www.awa.asn.au/AWA_MBRR/Publications/Fact_Sheets/Desalination_Fact_Sheet.aspx

Methods for desalination can be categorised into two major processes: thermal and membrane. Thermal processes use heat to evaporate water, collecting the fresh water as condensation and leaving behind the dissolved salts. The membrane process usually involves **reverse osmosis**, where water is pushed through a **semipermeable** membrane containing tiny pores which are only big enough to allow the smaller water molecules through, leaving behind the larger salt particles.

A number of social, environmental and economic issues are associated with constructing and operating desalination plants, including high energy usage, capital costs, operating costs associated with treating different concentrations of salt water, and environmental impacts of construction and operation.

Reclaiming water

Water reclamation is a process that converts wastewater into water that can be re-used for other purposes, including agricultural irrigation, replenishing surface water and groundwater, **potable** water (fit for drinking), and other residential and industrial requirements. Reclaimed water (also referred to recycled water) is a reliable water source that is climate-resilient and economically sound.

Recycled water can come from a number of sources. **Greywater** from households comes from showers, baths, hand basins and the laundry. **Stormwater** harvesting consists of collecting water from stormwater drainage systems, including the run-off from roads and buildings. Reclaiming water from **wastewater** involves treating the water outflow from sewerage networks and treatment plants, or from industrial wastewater.

Water treatment plants must follow strict guidelines when treating wastewater to produce safe, usable water. In Australia, these guidelines can be found in the 2006 *National guidelines for water recycling: managing health and environmental risks*. Uses for wastewater are varied and depend on the level of treatment of the reclaimed water. Reclaimed water can be used for watering recreational parks, agricultural and horticultural irrigation, groundwater recharge, firefighting, environmental water and drinking water.

In Australia, the most significant barriers to using reclaimed water as a potable source are the cost associated with the process and community attitudes and social acceptance.

Many places around the world use recycled water on a much larger scale than is common practice in Australia.

Practical 5.1
Demonstration: 'Gulp' drinking water

Aim

To illustrate the actual amount of Earth's water that is available for drinking.

Materials

- small fish tank – 4 litres (L) in capacity
- eyedropper
- 3 small clear containers – 1 cup size
- tablespoon
- measuring cup
- world map and/or globe
- tap water

Teacher preparation notes: Pre-label a small fish tank as 'Total water on Earth' and pre-label the three small cup-size clear containers as 'Total fresh water', 'Total liquid water', and 'Usable water'.

Demonstration

1. Begin with the following demonstration for the entire class. However, allow students an opportunity to participate in the demonstration in some way.

a) Fill the fish tank with 4 L of water. The fish tank represents all the water on Earth.

Discuss the possible locations of all Earth's water: salt water oceans and seas; frozen polar ice caps and glaciers; fresh water lakes and rivers; marshes and estuaries; groundwater and atmospheric water vapour.

Use the world map and/or globe to see landmass, ocean and polar ice cap distributions.

b) Remove ¼ cup of water from the fish tank. Pour the water into the small container labelled 'Total fresh water'. This first small container represents Earth's supply of fresh water.

The water left in the fish tank is all salt water from oceans and seas. We cannot drink it.

Fresh water is found on land. Discuss the possible locations of land water, such as lakes, ponds, rivers, streams and groundwater.

Use the world map and/or globe to see the distribution of land versus ocean.

c) Take 4 tablespoons of the fresh water and pour them into the small container labelled 'Total liquid water'. This second small container represents the liquid water that is available to us. The water left in the 'Total fresh water' cup is frozen in glaciers and ice caps or is in Earth's atmosphere. We do not have access to this water either.

Did you know? 80% of Earth's water is surface water. The other 20% is either groundwater or atmospheric water vapour. Over 90% of the world's supply of fresh water is located in Antarctica.

d) Using the eye dropper, remove one drop of water from the 'Total liquid water' cup.

Place the drop into the third small container labelled 'Usable water'. This container represents the water we can use. It is only a small percentage of the 'Total fresh water' because a lot of fresh water is either polluted or too hard to get.

Discuss the value of water conservation and anti-pollution efforts when so little water is truly available for our use.

continued next page

Practical 5.1 (continued)

2. Discuss these water facts:

a) On average, each of us uses about 250 L of water every day: 62.5 fish tanks of water every day!

b) One water-saving toilet full flush uses 4 L of water and a half flush uses 3.5 L. A water-saving shower head uses 9 L per second (how much water does a 10-minute shower use?) A half-full bathtub takes 190 L of water. Leaving the tap on when brushing teeth uses 7.5 L of water. Dishwashers use an average 15 L of water. The clothes washer uses approximately 100 L of water.

3. Water conservation will make a significant impact on future water demand and environmental conditions.

   Use the water-saving tips found at https://www.sustainability.vic.gov.au to develop a water conservation plan with your family. Discuss the plan with your family and note any barrier to implementing the plan. Try to determine ways to overcome these barriers by discussing with your class. Report on the success of your implementation plan.

Critical thinking and discussion 5.1

1. **Compare** and contrast the social, economic and environmental impacts, both positive and negative, of using desalination and reclaimed water.
2. **Outline** the social, economic and environmental impacts of biological sequestration.
3. **Investigate** the method of water reclamation via sewage treatment.
4. Are there any similarities between desalination of water and water reclamation? **Explain**.
5. **Explain** why there are so many difficulties with using reclaimed wastewater for potable water supplies.
6. **Outline** the social, economic and environmental impacts of using reclaimed water.

Student activity 5.1
Science skills: Synthesising data

Using the information provided below, compose a compelling argument based on evidence for building the Wonthaggi Desalination Plant.

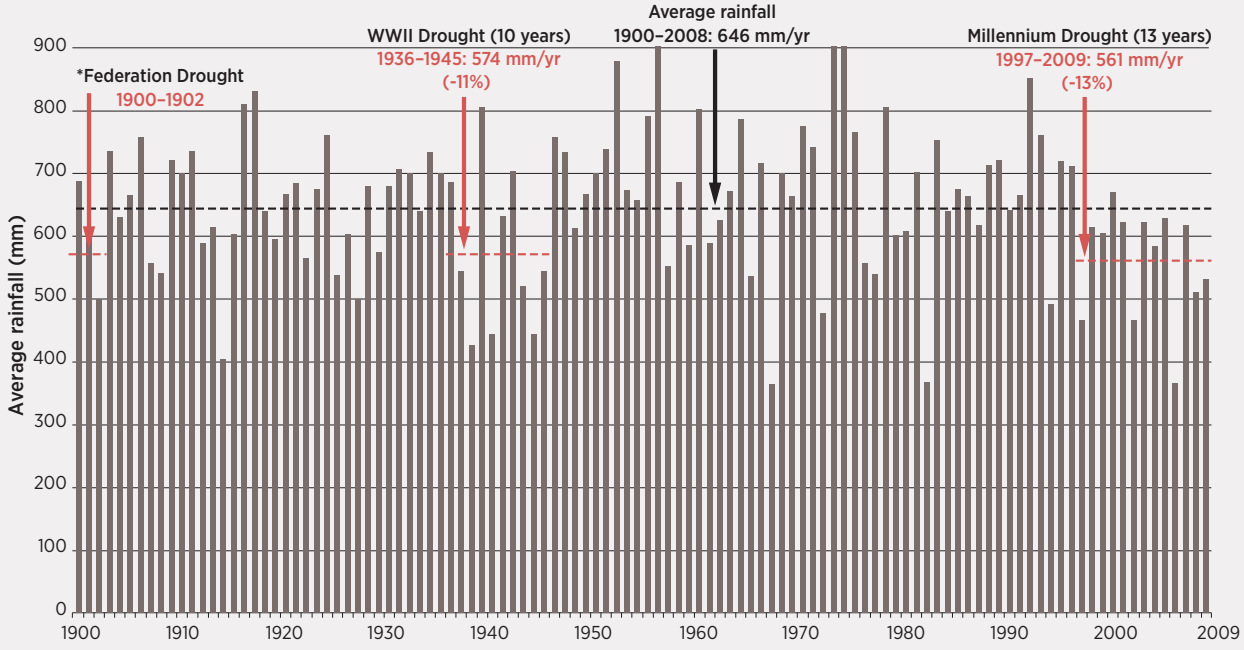
You can add to the dataset by considering geographical location, average rainfall, average climatic conditions, similarities/differences and population.

Table 5.3. Reduction in inflows to water storages July 1997 – August 2009 compared to the long-term average

Region/river system	Average inflows GL/year	% reduction
Central Region (1996–2006)		
Bunyip	148	-41
Yarra	1,054	-29
Maribyrnong	113	-41
Werribee	102	-51
Moorabool	97	-60
Barwon	360	-34
Western Region		
Corangamite	249	-84
Otway Coast	842	-30
Hopkins	344	-40
Portland Coast	350	-56
Glenelg	681	-65
Avoca	1	-90
Wimmera	303	-77

Region/river system	Average inflows GL/year	% reduction
Northern Region		
Murray	7,618	-43
Kiewa	689	-23
Ovens	1,758	-33
Broken	308	-53
Goulburn	3,363	-49
Campaspe	352	-72
Loddon	373	-74
Gippsland Region		
East Gippsland	714	-33
Snowy	2,162	-49
Tambo	298	-44
Mitchell	885	-38
Thomson	366	-43
Latrobe	847	-43
South Gippsland	912	-41
Macalister	496	-40

Source: The State of Victoria Department of Environment, Land, Water and Planning 2016.



*Federation Drought is formally between 1895 and 1902, however rainfall data is not available prior to 1900.

Figure 5.6. Annual rainfall across Victoria: drought periods compared to long-term average

5.3. Managing environmental challenges

The contribution of scientific data, new technologies, regulatory frameworks and diverse stakeholder values, knowledge and priorities in managing environmental challenges of regional relevance

As the human population grows, and with it our impact on the environment, the scale of environmental challenges that we must manage also grows. A healthy environment provides valuable **ecosystem services**, such as provision of fresh air and water, climate regulation and genetic resources. As we change (and damage) the environment, many problems, including land management issues such as erosion, salinity and drought, provide management challenges to governments, landowners and environmental groups.

A key principle of **intergenerational equity** is that future generations have access to the same environmental resources that we do. Solutions to these environmental challenges are found in the application of both scientific and technological advances, and government regulation and policy. Which solutions are developed and applied are influenced by the various **stakeholders** who have input to decision-making.

Modern technologies

Global satellite images are a useful tool for observing change over large regions of Earth. By examining and tracking changes in images taken over a period of time, scientists obtain large-scale visual data of how these changes are affecting the environment. Issues that can be tracked and mapped using satellite images include logging, large-scale erosion, bushfire damage and sea level changes.

Geographic information system (GIS) technology uses computer software to map geographical information in layers over a map. These maps allow us to analyse changes in land to show patterns in those changes. Issues such as coverage of weed species, urbanisation and coral bleaching can be analysed using this technology.

Stakeholder values

Stakeholders are individuals or organisations who have an interest in decisions being made that affect a natural or man-made system, such as a development proposal or new legislation. Stakeholders bring a set of values that need to be evaluated and responded to as part of the planning and management.

An example of a stakeholder is a farmer who owns land adjacent to a proposed mine. The mine will affect the farm with noise pollution during construction and operation (among other things). The farmer is concerned that the values central to the proper operation of the farm will be ignored. The processes involved in giving permission for building and operating the mine must consider how the noise from the mine will affect the welfare of the animals on the surrounding farms. This should be communicated to the stakeholders, and their objections (if any) should be considered before the plan can progress.

Usually we think of stakeholders as being the humans involved, but some argue that the environment, and individual organisms within the environment, are also stakeholders. For example, in 2017 the Whanganui River in New Zealand was officially recognised as a legal person, bringing an end to the longest running New Zealand court case – it went for 160 years!

The way people value the environment depends on their world view, ranging from the traditional perspectives of the First Nations peoples to anthropocentrism, ecocentrism, biocentrism and technocentrism.

Aboriginal and Torres Strait Islander peoples' **traditional values** lie in the close relationship they have with the natural world, which underlies their identity and way of life.

Their traditional beliefs and practices ensure that the land provides what they need while at the same time they maintain and manage the land with care. These values of "without the land, we are nothing" (as said by Djapirri Muninggirrity from Nhulunbuy in the Northern Territory) show the close connection Indigenous people have to Country, and are an integral part of the traditional management of the environment.

Anthropocentrism values the environment as a resource to serve and provide for the human population. Meeting the needs of the population in terms of food security, air quality or availability of fresh water is important for the greater good of the human population. Local councils, farmers and natural resource corporations (such as Melbourne Water) all have a vested interest in maintaining the natural environment to provide for the population, while placing an economic value on the environment.

Privileging the economic benefit of anthropocentric values establishes a preference for these values. For example, the animal agriculture industry requires a constant flow of fresh water for the production of food for livestock as well as the drinking water demands of its farmed animals. However, the impact that intensive farming has on climate change affects drought events, contributing to water scarcity in Australia. Therefore the anthropocentric values have a knock-on effect, inadvertly having a negative effect on the agriculture industry.

Ecocentrism recognises the ecosphere and all of its parts (biotic and abiotic) as being of central importance. It attempts to redress the impacts associated with the anthropocentric view that humans are more important than other parts of the world.

Biocentrism holds the value of Earth and its living organisms in high regard, irrespective of their usefulness to humans. Unlike ecocentrism, it places an equally high value on abiotic components of the environment

Technocentrism values technology and its ability to control and protect the environment. Environmental problems are seen as challenges to be solved using rational, scientific and technological means.

CASE STUDY 5.1
Aboriginal voices are missing from the Murray–Darling Basin crisis

Bradley J. Moggridge, Indigenous Water Research, University of Canberra, and Ross M Thompson, Chair of Water Science and Director, University of Canberra

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https://theconversation.com/aboriginal-voices-are-missing-from-the-murray-darling-basin-crisis-110769

The Murray–Darling crisis has led to drinking water shortages, drying rivers, and fish kills in the Darling, Macintyre and Murrumbidgee rivers. This has been the catalyst for recommendations for a Royal Commission and creation of *two* independent scientific expert panels.

The federal Labor party has sought advice from an independent panel through the Australian Academy of Science, while the Coalition government has asked former Bureau of Meteorology chief Rob Vertessy to convene a second panel. Crucially, the first panel contains no Indigenous representatives, and there is little indication that the second panel will either.

Indigenous meaning

Water for Aboriginal people is an important part of survival in the driest inhabited landscape on Earth. Protecting water is both a cultural obligation and a necessary practice in the sustainability of everyday life.

The Aboriginal peoples' world view sees water as inseparably connected to the land and sky, bound by traditional lore and customs in a system of sustainable management that ensures healthy water for future generations.

Without ongoing connection between these aspects, there is no culture or survival. For a people in a dry landscape, traditional knowledge of finding, re-finding and protecting water sites was integral to survival.

Today this knowledge may well serve a broader vision of sustainability for all Australia.

While different Aboriginal Nations describe this in local ways and language, the underlying message is fundamentally the same: look after the water and the water will look after you.

Native title

In the current crisis in the Darling River and Menindee Lakes, the focus should be on the Barkandji people of western New South Wales. In 2015, the native title rights for 128,000 km^2 of Barkandji land were recognised after an 18-year legal case. This legal recognition represented a significant outcome for the Barkandji people because water – and specifically the Darling River or Barka – is central to their existence.

Under the New South Wales *Water Management Act 2000*, Native Title rights are defined as Basic Landholder Rights. However, the Barwon–Darling Water Sharing Plan provides a zero allocation for Native Title. The Barkandji confront ongoing struggles to have their common law rights recognised and accommodated by Australian water governance regimes.

The failure to involve them directly in talks convened by the Murray–Darling Basin Authority and Basin States, and their exclusion from the independent panels, are further examples of these struggles.

Over the past two decades, Aboriginal people have been lobbying for an environmental, social, economic and cultural share in the water market, but with little success.

The modern history of Aboriginal peoples' water is a litany of "unfinished business", in the words of a 2017 Productivity Commission report.

In 2010 the First Peoples' Water Engagement Council was established to advise the National Water Commission, but was abolished prior to the National Water Commission's legislative sunset in 2014.

The New South Wales Aboriginal Water Initiative, tasked with re-engaging NSW Aboriginal people in water management and planning, ran from 2012 until the Department of Industry water disbanded the unit in early 2017. In a 2018 progress report the Murray–Darling Basin Authority described New South Wales as "well behind" on water sharing plans.

Even after a damning ABC *4Corners* report shed light on alleged water theft and mismanagement, the voices of the Aboriginal people of the Murray–Darling Basin were absent.

In May 2018 the federal Labor party agreed to a federal government policy package of amendment to the Basin Plan, including a cut of 70 billion litres to the water recovery target in the northern basin, and further bipartisan agreement for better water outcomes for Indigenous people of the basin.

While the measures also included A$40 million for Aboriginal communities to invest in water entitlements, a A$20 million economic development fund to benefit Aboriginal groups most affected by the Basin Plan, and A$1.5 million to support Aboriginal waterway assessments, how worthwhile are they in a river with no water?

The recent crisis emphasises the perpetual sidelining of Aboriginal voices in water management in New South Wales and beyond. Indigenous voices need to be heard at all levels, with mechanisms that empower that involvement. Indigenous communities continue to fight for rights to water and for the protection of its spirit.

Questions

1. **Identify** the stakeholders in this issue.
2. Assign each stakeholder a value from the list above and **justify** your decision.
3. **Identify** the regulations that are relevant to this issue.

Regulatory frameworks

Governments set up **legislation**, regulations and standards that control what is permitted – this is the **regulatory framework**. How people can use or affect the environment is controlled by such regulations, which are established at all levels of government: Commonwealth, state or territory, and local. In special cases, like the Murray–Darling Basin which overlies parts of Queensland, New South Wales and Victoria and all of the Australian Capital Territory, intergovernmental bodies take a leading role.

Commonwealth Government

The Commonwealth Government of Australia plays a major role in setting regulatory frameworks for protecting and managing the environment. The Department of Agriculture, Water and the Environment is responsible for administering many of the relevant laws. Its role is to be an effective, responsive and trusted regulator of the environment and agriculture sector. The Department of Agriculture, Water and the Environment implements regulatory frameworks that are responsive to:

- community values and expectations
- technology advances and industry practice
- economic growth and market pressures
- international and national agreements.

The regulatory frameworks designed by the Commonwealth Government ensure key pressures, such as climate change, land use change, habitat fragmentation and degradation, invasive species, and energy demands, are addressed.

Key Commonwealth environmental legislation includes:

- *Environmental Protection and Biodiversity Conservation Act 1999*
- *Climate Change Authority Act 2011*
- *Water Act 2007*
- *Renewable Energy (Electricity) Act 2000.*

State Government

In Victoria, the Department of Environment, Land, Water and Planning (DELWP) is a big department responsible for the protection of the environment (among other responsibilities). DELWP encompasses agencies such as Parks Victoria (who manage public reserves), the Environment Protection Authority (EPA, who protect the environment from pollution and waste), Sustainability Victoria (who promote environmental sustainability) and many catchment management authorities and water corporations who manage our resources.

DEWLP and its many agencies operates within existing environmental regulatory frameworks, and they have enforcement powers to make sure that individuals and businesses comply with regulations. In Victoria, a total of 117 legislative acts together form a strong regulatory frameworks for protecting the environment. They cover a range of areas, such as:

- **energy, environment and climate change** – 71 acts including the *Aboriginal Land Act 1991*, *Flora and Fauna Guarantee Act 1988*, *National Parks Act 1975*, *Wildlife Act 1975*, *Environment Protection Act 2017* and the *Climate Change Act 2017*
- **local government** – 11 acts including the *Local Government Act 1989*, *Libraries Act 1988* and the *City of Melbourne Act 2001*
- **planning** – 25 acts including the *Environmental Effects Act 1987*, *Geographic Place Names Act 1998* and the *Planning and Environment Act 1987*
- **Water** – 10 Acts including the *Catchment and Land Protection Act 1994*, *Conservation, Forests and Land Act 1987* and the *Murray-Darling Basin Act 1993*.

Critical thinking and discussion 5.2

1. **Outline** how websites such as NASA's Earth Observatory (https://earthobservatory.nasa.gov/) make modern technology that can be used to track environmental changes (such as deforestation and sea level rises) available to the average person.
2. **Discuss** how the management of environmental issues, such as the clearing of land for residential development, is affected by the needs of a wide variety of stakeholders and how ideas may need to adapt to a local context or change for a specific development project.
3. **Explain** the importance of placing value in traditional Indigenous beliefs in caring for the natural environment.
4. **Compare** the terms 'anthropocentric' and 'ecocentric'.
5. **Outline** the environmental changes caused by animal agriculture.
6. The DELWP Forests and Reserves web page (https://www.forestsandreserves.vic.gov.au/) has information on the management of parks reserves and forests in Victoria.
   Three links – to 'Anglesea Futures', 'Hanging Rock' and 'Forest Reports' – take you to initiatives that involve input from stakeholders to specific issues. Choose one issue, and discuss which stakeholders have contributed to decision-making or management of that particular issue.
7. Research Adani's Carmichael coal mine.
   Outline the positive and negative opinions that various stakeholders have on the project.
   Summarise your information in the a table like the one below (you might want to add more stakeholders to the left hand column).

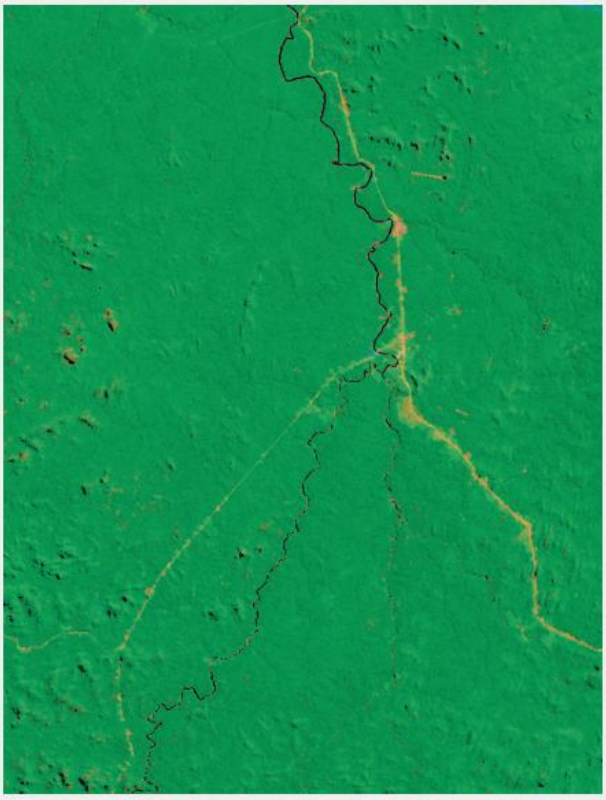
Stakeholder	Positive opinion on the mine	Negative opinion on the mine
Adani shareholders	example: Will make money for shareholders	
Local residents	example: May create jobs	
Queensland Government		
Traditional Indigenous land custodians		example: Will destroy cultural spaces
Stop Adani volunteer group		

Data analysis 5.1
Using satellite images to map deforestation

Examine the two images in Figure 5.7, which show the same section of the Amazon rainforest in western Brazil in 1975 and 2012. Urban areas are represented by pink shading, light green shading represents agricultural land and dark green shading shows natural rainforest.

1. **Describe** the natural and human-built features that can be seen in image (a).
2. **Describe** the differences between the two images.
3. **Estimate** the percentage of land area that has changed over the 37-year period.
4. **Suggest** explanations for these changes.
5. **Outline** how the use of this data can assist with land management and sustainable development in the Amazon in the future.

(a) 1975



(b) 2012

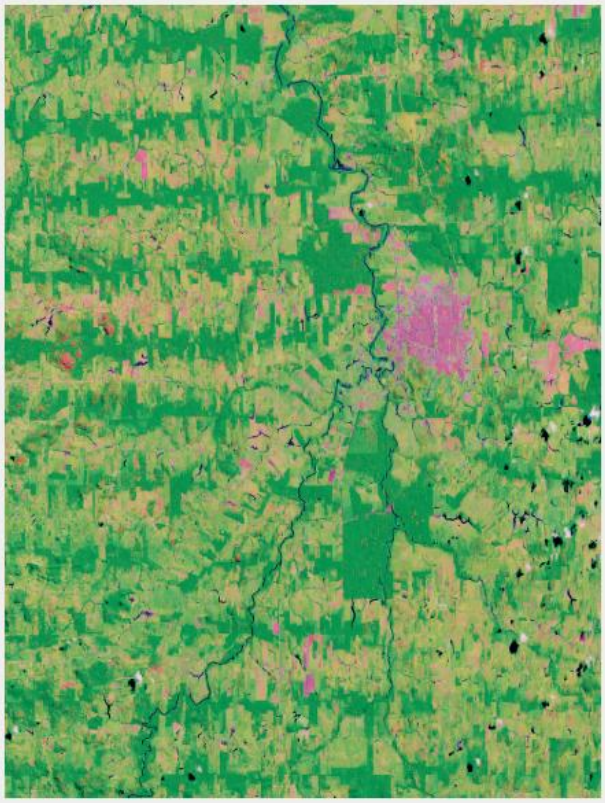


Figure 5.7. Satellites images of a location in the Brazilian rainforest. Images courtesy Landsat team, NASA/USGS

5.4. Earth's weather systems

Global weather systems are driven by the interactions of ocean temperatures, currents and atmospheric conditions. Weather systems have been studied for centuries, and modern climate models draw on multiple data inputs to make reliable predictions. Australia's weather conditions vary from one year to the next, and the many factors influencing our climate are recorded and analysed by the Australian Bureau of Meteorology.

Key weather system factors

Key factors influencing Australian global weather systems include thermohaline circulation, the El Niño–Southern Oscillation, the Walker Circulation, trade winds and the Indian Ocean Dipole.

Thermohaline circulation

In the surface layer of the ocean (the upper 100 m), the water is salty and relatively warm. These waters circulate around the globe in currents driven mostly by wind. At greater depths is a lower layer of much colder and less salty water. Mixing between these two layers only occurs in a few places on the globe, and the resulting slow flow of water through the Atlantic, Indian, Pacific and Southern oceans can take 1,600 years. Because this slow movement is caused by differences in saltiness (haline) and temperature (thermal) of these water bodies, the current is known as **thermohaline circulation**.

Saltiness and temperature both affect the density of water: cold water is denser than warm water, and salty water is denser than less salty water. Thermohaline circulation (Figure 5.8) starts at Earth's poles, where lack of sunlight and cold winds cause the ocean water to get very cold and dense. Sea ice forms from water molecules and leaves behind the salt (brine exclusion), so the ocean waters get saltier and even denser. In the Southern and North Atlantic oceans, this dense water sinks below the surface to the ocean floor, filling up sea floor basins and setting up slow, deep currents that flow away from the poles. Warmer surface waters are pulled towards those sinking zones, and the surface water layer is replenished with upwellings of bottom water in the Pacific and Indian oceans.

Thermohaline circulation conducts heat from one part of the globe to another and, by controlling the rate at which ocean waters are exposed to the surface, can influence carbon dioxide levels in the oceans and atmosphere. If warming global temperatures cause large ice melts that flood oceans with fresh water, the dense water may not form and sink to the extent it does now. This would weaken thermohaline circulation and affect temperatures around the globe.

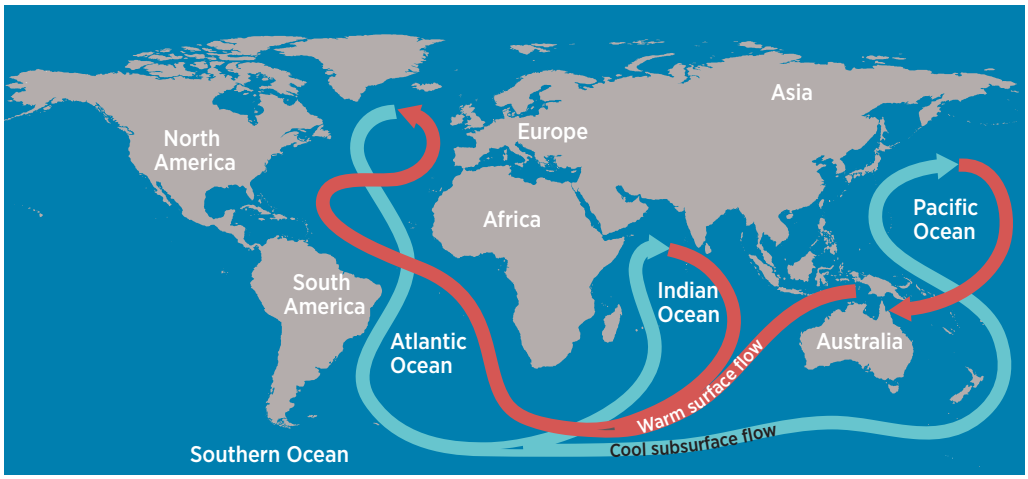


Figure 5.8. Thermohaline circulation around the globe

El Niño–Southern Oscillation

The tropical Pacific Ocean covers almost half of Earth's surface and is responsible for triggering El Niño events. El Niño climate events influence storm activity, rainfall and terrestrial temperature across the globe. Weather variations are influenced by ocean currents as well as other variables such as ocean surface temperature and atmospheric pressure. When scientists look at these variables together and consider how they interact and where they are overlapping, they can begin to predict one of the largest and most influential climate systems: that of El Niño–Southern Oscillation (ENSO) (Figure 5.9).

ENSO is the oscillation or flipping between El Niño and La Niña conditions. El Niño describes the climatic conditions that occur when there is warming of the central and eastern parts of the tropical Pacific. This warming leads to a change in weather patterns across the Pacific. Scientists have tracked this warming pattern and determined that it occurs every 3 to 8 years.

ENSO has three phases: El Niño, La Niña and neutral.

- In the **neutral** phase, steady trade winds blow from east to west and ENSO is largely inactive and is influenced by the Walker Circulation (Figure 5.10).
- During **La Niña**, easterly winds increase and push warmer water towards Australia that creates a large warm pool of water. This increases condensation and Australia enters a wetter period with lower daytime temperatures.
- During **El Niño** the opposite happens with an increase in westerly wind pushing the warm water towards South America where it pools. This decrease in condensation over Australia causes lower rainfall and higher daytime temperatures.

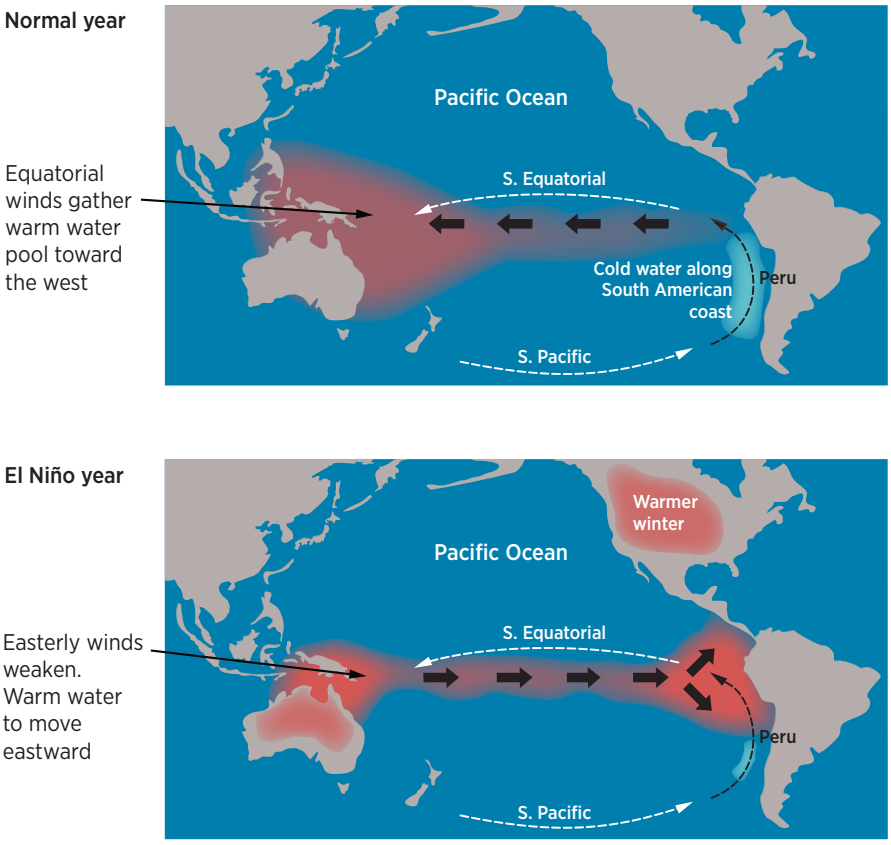


Figure 5.9. El Niño–Southern Oscillation

Walker Circulation

Warmer waters alone do not drive ENSO weather patterns; ENSO is also associated with other driving climate factors such as the Walker Circulation.

The **Walker Circulation** (Figure 5.10) describes the east–west circulation of the atmosphere above the tropical Pacific Ocean. This pattern is driven by air rising over the warmer ocean regions, usually in the west and then descending over cooler ocean areas (usually to the east). Walker Circulation patterns fluctuate with that of the Southern Oscillation.

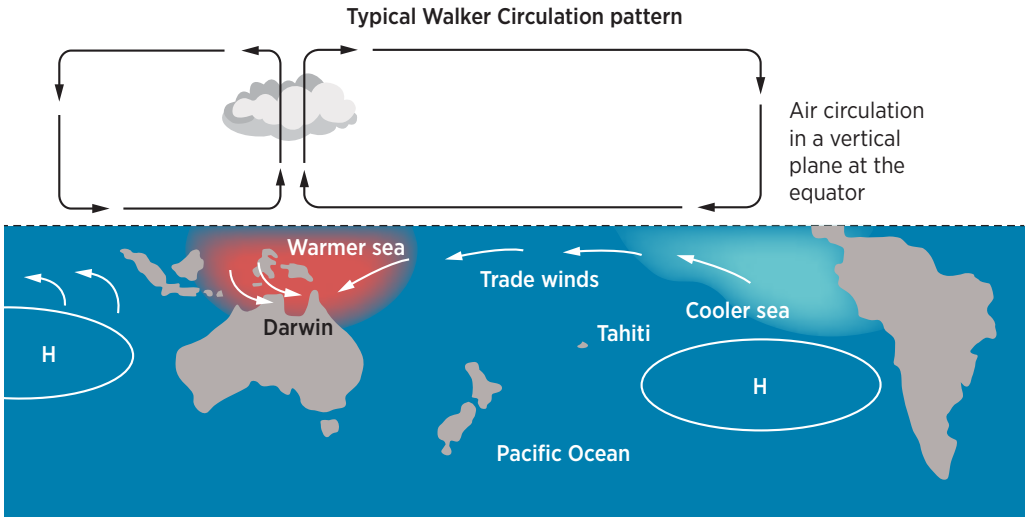


Figure 5.10. Walker Circulation patterns (a) typical, (b) during El Niño

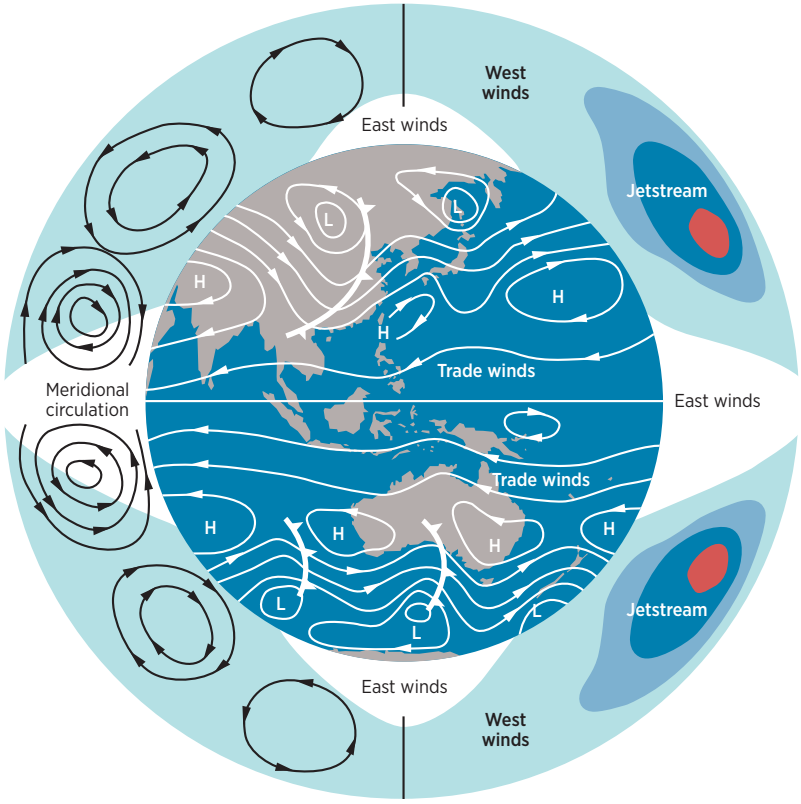


Figure 5.11. General circulation of the atmosphere

Trade winds

Trade winds have been used by sailors for centuries as a reliable assistance for ships sailing from Europe to Africa and from the Americas to Asia. Trade winds in the Southern Hemisphere sit to the north of Australia's high pressure systems (Figure 5.11). These winds are very reliable due to the Coriolis effect: Earth's rotation deflects the atmosphere in a curved wind pattern. By influencing the winds, the Coriolis effect also drives surface ocean currents.

Indian Ocean Dipole

The Indian Ocean also affects Australian rainfall and temperature patterns. Tropical sea surface temperature and the variation in temperatures from year to year in the western and eastern Indian Ocean cause the **Indian Ocean Dipole** (IOD). The IOD causes changes to weather patterns that Australia experiences, particularly rainfall.

Like ENSO there are three phases for the IOD: positive, neutral and negative. Positive and negative IOD phases usually begin in Australia in autumn or winter; they return to neutral when the northern Australian monsoon arrives.

During a neutral phase, water from the Pacific flows through Indonesia and keeps seas to Australia's north-west warm. The warm surface water ensures that the air in the atmosphere rises and travels to the far western part of the Indian Ocean, causing warm westerly winds to blow towards Australia. Tropical temperatures are normal and the IOD has little influence over Australian weather.

During a negative phase, those westerly winds become stronger, pushing warmer water towards the north-west coast of Australia. This pool of warm warmer water pushes cooler water below the thermocline down, making it difficult for cooler water to reach the surface. As the warm water moves east across the Indian Ocean the clouds follow, causing rainfall to southern Australia.
In a positive phase the reverse happens, causing drier climatic conditions across Australia.

EXPLORING SCIENCE 2
Modelling Earth's weather

Only when scientists bring together a number of models can they start to make predictions as to the behaviour of dominant climate drivers. They need to take all the climate factors outlined above and interpret the data in an integrated way (Figure 5.12). This data collection begins in space where satellites collate images and measurements of surface wind, sea level and sea surface temperatures.

Sea level measurement data is useful because warm water has more volume than colder water; also, when water is pushed by trade winds to one side of the ocean, the sea level there will rise. Sea levels have been recorded as much as 60 cm higher in the Philippines than on the southern coast of Panama. NASA satellites can measure the sea level of the entire Pacific Ocean within 5 cm.

Satellites can also assist with monitoring and and collecting data on upwelling currents (Figure 5.13). Upwelling currents bring nutrients up from deep, cooler waters to the surface. These newly available nutrients cause phytoplankton growth and chlorophyll blooms. Satellites can be programmed to detect pigments in phytoplankton, giving scientists valuable data that can be integrated into climate models.

In addition, an extensive array of instruments moored across the Pacific Ocean collect data on weather and ocean conditions that feed into ENSO models (Figure 5.14)

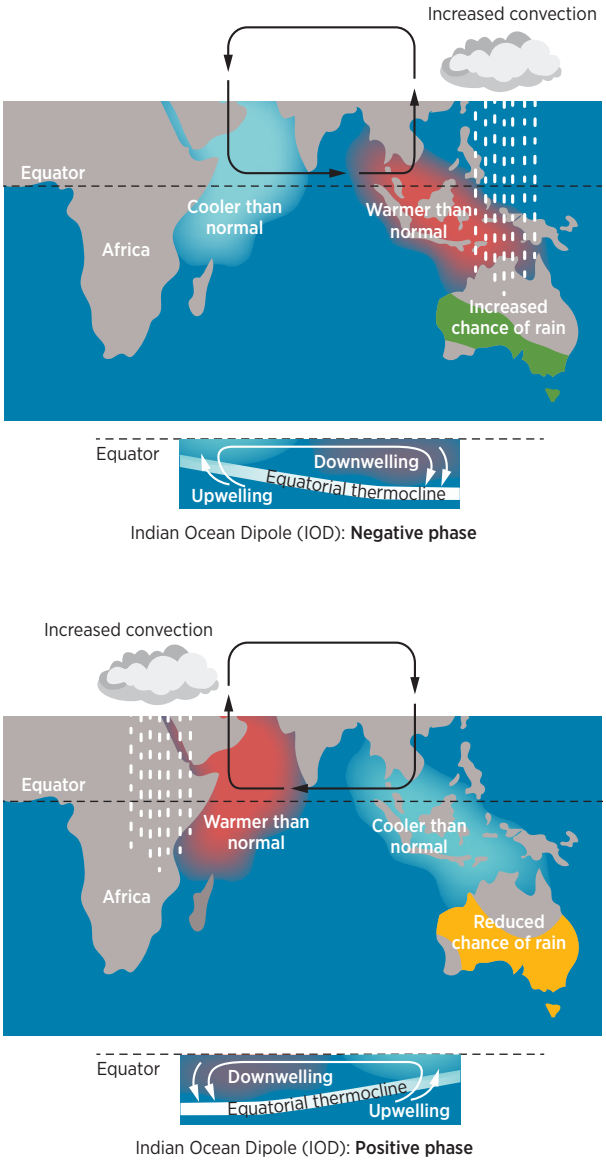


Figure 5.12. A combination of the thermohaline circulation, ENSO and IOD models

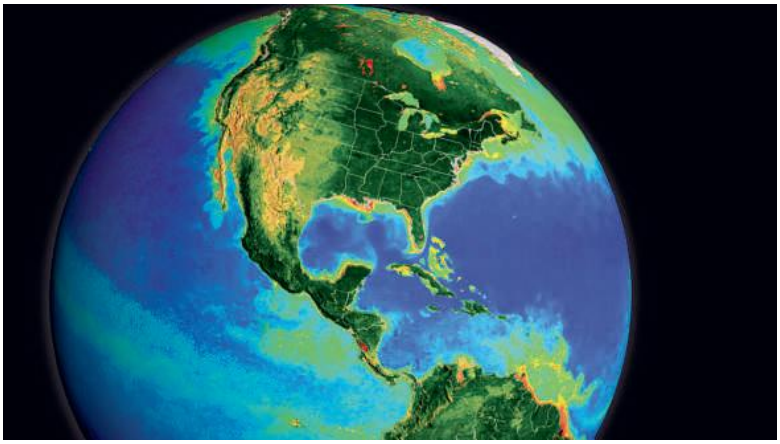


Figure 5.13. NASA satellite image showing phytoplankton pigment that indicates upwelling. Credit: NASA's Goddard Space Flight Center

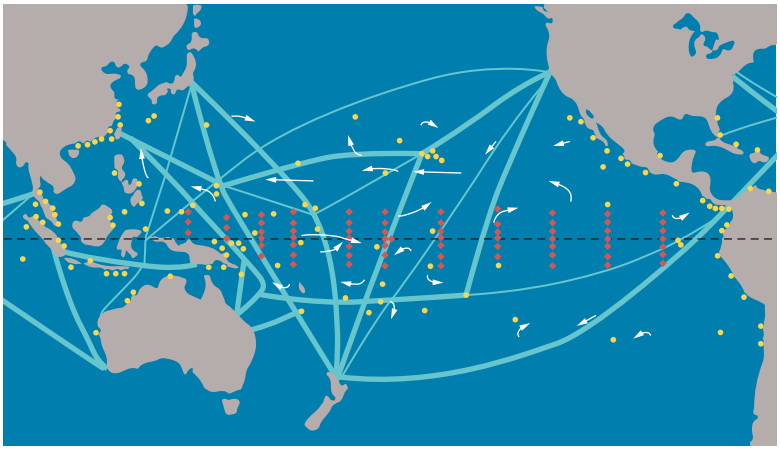


Figure 5.14. ENSO observing system. Credit: NOAA

Questions

Climate events have a huge impact on the Australian landscape, and weather patterns change over time.

1. From your memory **list** all the major weather events you can recall.
2. Can you **present** evidence from your own experience of a significant climate event?
3. **Suggest** what your ability to recall a significant climate event tells you about the importance of data collection and modelling.

Ecosystems are subject to change in response to biotic or abiotic disturbances, or variations in the magnitude or frequency of disturbances, which can have flow-on effects for the atmosphere, biosphere, hydrosphere and lithosphere. In this area of study students adapt or design and then conduct a scientific investigation into the monitoring of ecosystems or their components and/or change in ecosystems. The investigation must include the generation of primary data.

The student-adapted or student-designed scientific investigation should take an Earth systems thinking approach and should relate to knowledge and skills developed in Area of Study 1 and/or Area of Study 2.

Outcome 3

On completion of this unit the student should be able to draw an evidence-based conclusion from primary data generated from a student-designed or student-adapted scientific investigation related to ecosystem components, ecosystem monitoring and/or change affecting Earth's systems.

AREA OF STUDY 3

How do scientific investigations develop understanding of how Earth's systems support life?

Key knowledge

Area	Section
Investigation design	
• environmental science concepts specific to the scientific investigation and their significance, including definitions of key terms	6.1
• scientific methodology relevant to the investigation, selected from: classification and identification; controlled experiment; correlational study; fieldwork; modelling; product, process or system development; or simulation	6.2
• techniques of primary qualitative and quantitative data generation relevant to the investigation	6.2
• accuracy, precision, reproducibility, repeatability and validity of measurements in relation to the investigation	6.4
• health, safety and ethical guidelines relevant to the selected scientific investigation	6.3
Scientific evidence	
• the distinction between an aim, a hypothesis, a model, a theory and a law	6.1
• observations and investigations that are consistent with, or challenge, current scientific models or theories	6.1
• the characteristics of primary data	7.1
• ways of organising, analysing and evaluating generated primary data to identify patterns and relationships, and to identify sources of error	7.1
• the use of a logbook to authenticate generated primary data	6.1, 6.2, 6.4
• the limitations of investigation methodologies and methods, and of data generation and/or analysis	7.2
Scientific communication	
• the conventions of scientific report writing including scientific terminology and representations, standard abbreviations and units of measurement	7.3
• ways of presenting key findings and implications of the selected scientific investigation	7.3

CHAPTER

6

Investigation design

CASE STUDY 6.1
Ancient volcanic eruptions disrupted Earth's thermostat, creating a 'Snowball' planet

Grant Cox, Research Fellow, University of Adelaide, and Alan Collins, Professor of Geology, University of Adelaide

This article was originally published in The Conversation, *13 September 2017.*

https://theconversation.com/ancient-volcanic-eruptions-disrupted-earths-thermostat-creating-a-snowball-planet-82215

One of the most extreme climate episodes the Earth has experienced was during the so-called Snowball Earth, 720 million years ago. During this period glaciers spanned from the poles to the tropics, resulting in a planet entirely covered by ice.

The Snowball Earth hypothesis has been the subject of scientific debate for around 20 years: scientists are both fascinated and perplexed about how the planet could descend into such a weird climatic state.

New research now points to spectacularly large volcanic eruptions as being key in this process.

We suggest this happened because large amounts of carbon dioxide were pulled out of the atmosphere after huge eruptions, and this led to a loss of heat from the Earth's surface.

Surprisingly, the mechanism for this appears to be rock erosion.

Different kinds of volcanoes

Relationships between volcanic eruptions and climate are well established. For example, sulfur injected into the atmosphere from the 1991 eruption of the Philippines' Mount Pinatubo lowered global temperatures by approximately half a degree for about 15 months. The sulfur reflected incoming solar radiation and lowered global temperatures.

Volcanoes like Mount Pinatubo are part of volcanic arcs that produce relatively small volumes of erupted materials. Across the world, arc volcanoes together produce less than 1 one cubic kilometre (km^3) of erupted material per year.

Compare this to a type of volcanic eruption referred to as a 'large igneous province' (we'll refer to them here as a LIP).

Figure 6.1. The crater of Mount Pinatubo, taken from the air in the Philippines.

Figure 6.3. The Columbia River has eroded through deposits left by a past LIP volcanic eruption.
Credit: Kirt Edblom CC BY-SA 2.0

These eruptions are spectacularly large, producing in excess of 100 km^3 per year of lavas, and crucially, have total eruption volumes in excess of 1 millon km^3 and cover an area greater than 1 million km^3. (For comparison, the area of South Australia is roughly 1 million km^2). These are continental-scale resurfacing events.

More than 300 of these LIP eruptions have been recognised throughout Earth's history, and they appear to peak in semi-regular cycles.

Long-term climatic effects

While some relatively small volcanic eruptions will have short-term climatic effects, the long-term effects of LIP volcanoes may be profound.

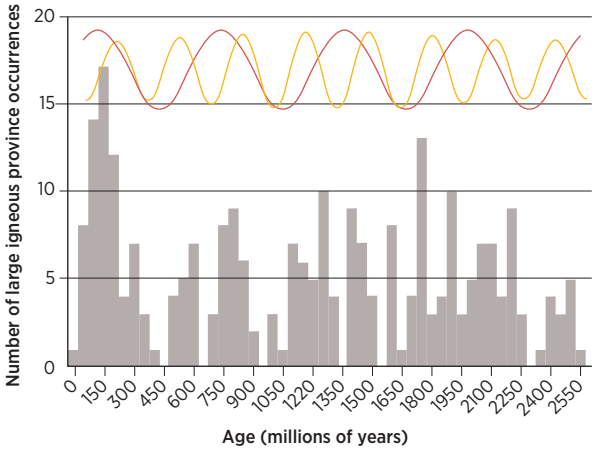


Figure 6.2. Identified large igneous provinces through Earth's history. While the record is semi-continuous, spectral analysis using a technique known as fast fourier transform suggests that large igneous province eruptions show evidence of complex cycling with periodicities of approximately 300 and 500 million years. Raw data can be found at http://www.largeigneousprovinces.org. Author supplied

The reason for this boils down to simple chemistry. Carbon dioxide in the atmosphere dissolves in rain, and falls to the ground where it reacts with silicate minerals in the rocks. Carbon dioxide forms bicarbonate, and ultimately becomes locked away in limestones and shale rock formations.

Over hundreds of thousands of years, the amount of carbon dioxide in the atmosphere is quite effectively regulated in this way. Scientists estimate that weathering of rocks consumes approximately 600 million tons of carbon dioxide per year.

Geological formations from LIP volcanic eruptions are particularly susceptible to this process, as they are largely composed of basalts, a type of fine-grained volcanic rock that weathers relatively quickly and soaks up carbon dioxide more effectively than other rocks, such as granite.

But LIP volcanic eruptions can also affect climate in another way: through triggering photosynthesis.

Linking volcanic eruptions to photosynthesis might seem strange, but it all comes down to nutrients. We have recent shown that the erosion of geological formations such as basalt from LIP volcanoes fertilises rivers and oceans by releasing phosphorus.

Phosphorus is an essential component of DNA and all life requires it. Over long time periods, phosphorus is the nutrient that regulates the rate of photosynthesis. And when photosynthesis takes place, it too pulls carbon dioxide from the atmosphere.

Descent into Snowball Earth

Our most recent paper focused on determining if the erosion of basalt from LIP volcanoes contributed to the reduction in atmospheric carbon dioxide associated with Snowball Earth. Initial modelling predicted a halving of atmospheric carbon dioxide would be required to drive the Earth into the Snowball state.

To do this, we measured different forms (known as isotopes) of the rare earth element neodymium (Nd) that track the erosion of basalt in sedimentary rocks. We particularly focused on the contribution of eroded basalt in shales, which are rock formations created from continental erosion.

Also, we measured isotopes of the element strontium (Sr) in limestones, which record the chemical composition of ancient seawater.

From this work we found that basaltic erosion just before the Snowball Earth, was more than 100% greater than what we see today.

This basalt was sourced from three prominent LIPs, which erupted in a cascading sequence beginning 830 million years ago in Australia, 780 million years ago in North America and 720 million years ago in northern Canada. All three of these LIPs erupted in what was then the equatorial region, which favours fast erosion due to warmer temperatures and higher rainfall.

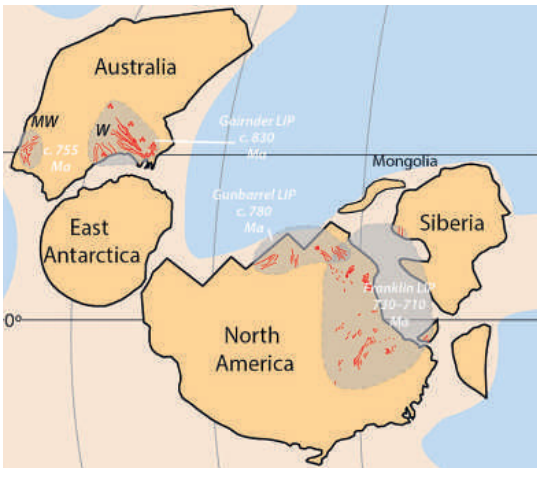


Figure 6.4. Eruption of the Gairdner, Gunbarrel and Franklin large igneous provinces in the wet tropics prior to the onset of severe global glaciation. The continents are shown in their approximate positions 720 million years ago. Author supplied

Finally, the impact of sulfur aerosols released by northern Canada's Franklin large igneous province just prior to glacial onset may have also induced further global cooling.

It is likely that this unique confluence of events allowed the planet to tip into a frozen abyss.

Complex interactions in the Earth system

Atmospheric carbon dioxide levels and global climate are regulated over long periods of time by the weathering of rocks. Over geologic time (hundreds of thousands of years) this process acts as a negative feedback on increasing atmospheric carbon dioxide. When higher temperatures drive higher rates of weathering, it acts as a kind of thermostat for the Earth.

However, this work demonstrates that the Earth's thermostat can fail spectacularly at times: the eruption of LIPs resulted in a Snowball Earth.

This period of time lasted from 720 to 635 million years ago and is known as the Cryogenian. It is a time of continental breakup and marks a major transition from a world dominated by bacteria to a world dominated by more complex life.

This highlights the complexity of the Earth system and the unexpected interactions between volcanism, climate and life.

Questions

1. **Determine** the science required to understand this case study.
2. **Describe** the types of technology that would assist with understanding or solving issues in this case study.
3. **List** the many stakeholders involved in this case study.
4. Using the definitions presented in 'Stakeholder values' (p 82), **describe** the values and priorities of the stakeholders involved. **Justify** your choice/s.
5. **Identify** the regulatory frameworks used to protect the environment that is described this case study.

6.1. Scientific investigation

Environmental science concepts specific to the scientific investigation and their significance, including definitions of key terms

The distinction between an aim, a hypothesis, a model, a theory and a law

Observations and investigations that are consistent with, or challenge, current scientific models or theories

Research project A.1 Introduction

As part of your school-based assessment, you are required to design and carry out an investigation of your choosing – Research project A. This chapter will assist you in completing this task by giving you a theoretical understanding of designing an investigation and then a practical component to help you carry out your investigation. This chapter is designed to give you opportunities to test some of your ideas or to complete your investigation.

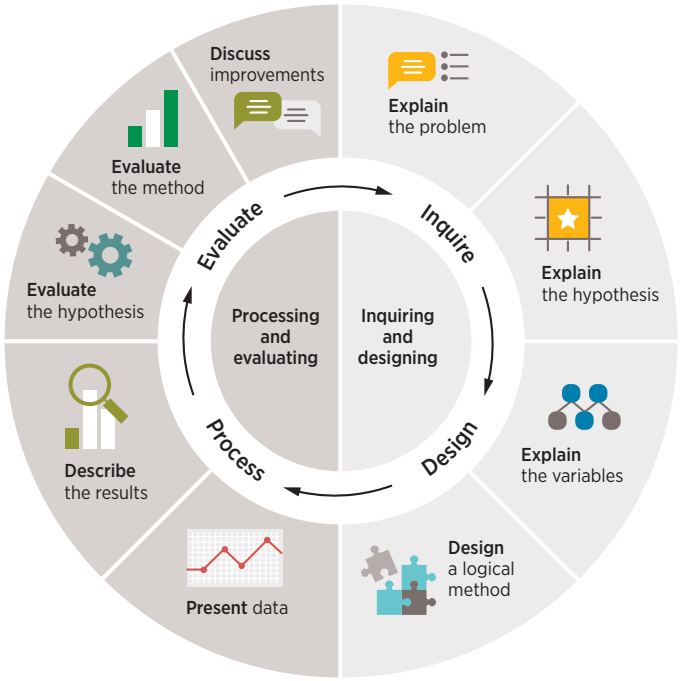


Figure 6.5. The scientific method shown as a cycle

The scientific method

A **scientific investigation** allows scientists to collect information and/or evidence to answer questions and solve problems. If the evidence cannot provide the solution to the questions, it may still be useful in leading to new questions or problems for investigation. Scientific investigations can take on a number of different forms. They can be an **experiment**, a **correlational** study, a **field** investigation or **secondary research**. They can also be **descriptive** or **comparative** in nature.

A scientific investigation that has an experimental basis uses a systematic process called the **scientific method** (Figure 6.5). This method collects measurable observations in order to answer a particular question of interest.

The scientific method approach typically includes the following steps:

1. Identify a research question or problem.
2. Form a hypothesis.
3. Determine the variables.
4. Design an experiment to test the hypothesis. This is called your methodology.
5. Gather data.
6. Present and analyse the data, describing what you found.
7. Discuss results.
8. Evaluate whether the evidence supports the hypothesis.
9. Draw conclusions.
10. Communicate the results and discuss improvements.

The scientific process is a highly creative process and is not always completed in a straight line as each phase can be revisited and refined depending on what the investigation uncovers. Adapting studies according to interim findings can produce great research.

The research question

The objective of all investigations is to answer the research question; therefore, the question must be specific and testable. The research question is often a short explanation of the problem. For example, a research question like 'What factors stop little penguins from coming ashore every night?' is a short explanation of the problem of little penguins not arriving every night for the Penguin Parade at Phillip Island.

The testable aspect of the question is found within the word 'factors'. The design of the investigation will determine which factors will be measured and what data will be collected. During the process of determining your research question, it is worth considering what type of data you want to collect so that it is reflected in your question. You can, of course, modify your question when you have considered other factors.

When you write up your research, you'll include your **aim**, which is a brief sentence describing the purpose of the investigation. It is the goal behind the testing of the hypothesis. The aim will address the investigation question.

The hypothesis

At the beginning of an investigation, scientists need to identify a testable scenario that can answer the research question. This testable scenario is called the hypothesis and at the end of the investigation will either be supported or refuted. Either outcome is an advance in scientific understanding: a study that refutes a hypothesis rules out the particular investigated scenario as the explanation, and this can open up possibilities for further investigation.

The **hypothesis** states the expected outcome of the experiment based on evidence and previous knowledge of the topic. It is a prediction of the expected results based on a cause-and-effect relationship. The hypothesis should be specific and relate directly to the aim. The data collected will either **support** or **refute** the stated hypothesis.

Null hypothesis

A **null hypothesis** is often used when scientific data will be analysed with statistics. The null hypothesis is that there is no relationship between the variables being studied. For example, if you are investigating whether the population density of a predator species is related to prey numbers on different islands, the null hypothesis is that predator density is not related to prey numbers.

If you survey the different islands and find a statistically significant difference between islands with high predator density and islands with low predator density, the null hypothesis is disproved. You can say that there *is* a relationship between predator density and prey numbers. Note, this does not prove that predator density *causes* the difference in prey numbers (or vice versa). There may be another factor, perhaps vegetation type, that influences both variables. You would need to carry out an experiment to make conclusions about cause and effect.

If the differences in prey numbers in areas with different predator densities are not statistically significant, then the null hypothesis is supported – that there is no relationship between density of predators and number of prey – and you would need to think of some other possible explanation for the pattern found on different islands.

Critical thinking and discussion 6.1

1. You have noticed your the local creek going through some changes, most noticeably some bird species and the frogs that used to be there seem to have disappeared. You have been studying water quality and know that there is more to an ecosystem than just what you can see on the surface. You know that aquatic macroinvertebrates ('macro' means large – in this case, visible to the naked eye) are an important part of the creek habitat so decide to investigate this further. Write an aim and hypothesis related to the question: Can macroinvertebrates indicate the health of a waterway?
2. Investigate the scientific evidence that supports Darwin's theory of evolution by natural selection. Use the Galapagos Islands as an example.
3. Go to https://phet.colorado.edu/en/simulation/legacy/greenhouse and use the simulation to model the impacts of the greenhouse effect.

Research project A.2 Literature review

Begin to read about the theories that will affect your investigation. Make notes about the information that has already been discovered about the subject you are investigating. This will be used in your discussion and conclusion.

Research methodology

The **methodology** is the general research strategy chosen for the investigation. The methodology guides your research practices and explains why certain **methods** or tools are being used in the research.

The research methodology consists of two parts:

- the type of investigation you will undertake – how you will investigate your question
- what will you investigate – the type of data you will collect and the data-collection tools you will use. These are the methods you use to collect data, for example, direct observation (such as surveying birds in a forest), sound recording (of a frog call), a questionnaire (to collect opinions).

This topic is investigated further in 'Scientific methodologies' on p 104. Learning about your chosen methodology helps you discover the best practices that are being applied to obtain the best results.

Presenting data: results

The data you collect will have to be ordered in some way. This is usually done by collecting measurements and displaying them in a table or collecting photographs from a specific site. These tables and photographs need to present a meaningful representation of the investigation ou have undertaken.

Data in tables could also be graphed, but you need to be careful that you display the data in the most appropriate graph. For example, data that shows height over time should not be presented as a pie chart, but a line graph would be appropriate. You should carefully consider how to display your data.

Discussion and evaluation

This is a section in the investigation where you discuss what your results mean and evaluate your hypothesis.

For example, in the investigation from the research question 'What factors stop little penguins from coming ashore every night?', data was collected over three different nights. One factor was tested each night. On the first night, noise was reduced to test if noise was affecting the penguins. On the second night, light was reduced to determine if light was affecting the penguins. On the third night, people were not allowed into the Penguin Parade to determine if people were the problem.

The investigation was designed to test which factors on the shore were affecting the little penguins so that the hypothesis that an onshore factor affected the penguins could be tested. On each of the three nights, penguins did not come ashore; therefore, the hypothesis was not supported. This means that the investigation would need to consider other factors in the discussion. The discussion and evaluation suggested a further investigation that would ask the same questions but collect data from ocean-based food sources.

Models, theories and laws

Scientists construct **models** to help explain complex concepts that are too difficult to directly display. A model represents a system based on observations or inputs that are known to be valid and accurate, sometimes under limited conditions or situations. Models can be physical (such as a model of a volcano) or conceptual (such as a mathematical equation or an **algorithm**). Often computer simulations are used to model scientific concepts, such as climate modelling.

A **theory** is an explanation of patterns in nature that is supported by scientific evidence. Theories become accepted when they have been observed to hold true multiple times by a number of scientists and when they are useful in explaining how the world works. Some theories are represented by models. Examples of theories are Darwin's theory of evolution by natural selection and Einstein's theory of special relativity.

A **law** is similar to a theory in that it is also an explanation of a natural phenomenon that is supported by scientific evidence and repeated experiments. In general, a scientific law describes a single phenomenon while a theory provides a conceptual explanation of how a more complex system works. Scientific laws are often expressed as mathematical equations that describe a relationship but don't explain it. Many laws are only true under limited circumstances. Some well known laws are Newton's law of gravity and the laws of thermodynamics.

Communication

Communication is one of the most important parts of the scientific investigation. This is where the wider scientific and general community come to know and understand the explanation provided by your investigation. You can communicate your finding through a scientific poster, a paper that can be published in a newspaper, magazine or scientific journal, or in an oral presentation.

Research project A.3
Write a research question

Any scientific investigation, regardless of the type, must start with a question to investigate or research.

On completion of this task you will have a question that you are ready to research.

1. Write down some things you are interested in researching. Maybe it is something you already know a little bit about or something you want to find out about. Make sure your ideas are original and realistic. Remember you have to actually investigate the question so make sure it is within your capabilities. Aim for around 10 ideas.
2. Now that you have some ideas use this table to keep brainstorming:

Possible topics	What I already know	Possible questions	What would I measure or observe?	What type of data could I collect?

3. From the list in the table, evaluate your ideas taking into consideration equipment availability, safety (is it safe for me and my subject?) and ethics (will an organism be put under stress or another form of duress?).
4. Choose an idea and develop a testable question. The question should:
   - be specific
   - be something you don't already know the answer to
   - give a hint as to how it will be tested
   - be able to be tested.
5. Check your question with your teacher.

6.2. Scientific methodologies

Scientific methodology relevant to the investigation, selected from: classification and identification; controlled experiment; correlational study; fieldwork; modelling; product, process or system development; or simulation

Techniques of primary qualitative and quantitative data generation relevant to the investigation

In this section you will learn about a number of methodologies that may have the potential to be used for your scientific investigation assessment in Environmental Science. You may choose to focus your method around one of these concepts.

Types of investigation

Classification and identification

Classification and identification investigations allow you to link theoretical concepts with practical tasks. For example, you can **classify** habitats into categories or **identify** species in an ecosystem. This type of investigation could be classifying a nearby parkland as a particular sort of ecosystem, like a grassland or an open woodland, based on flora found there.

Experiment

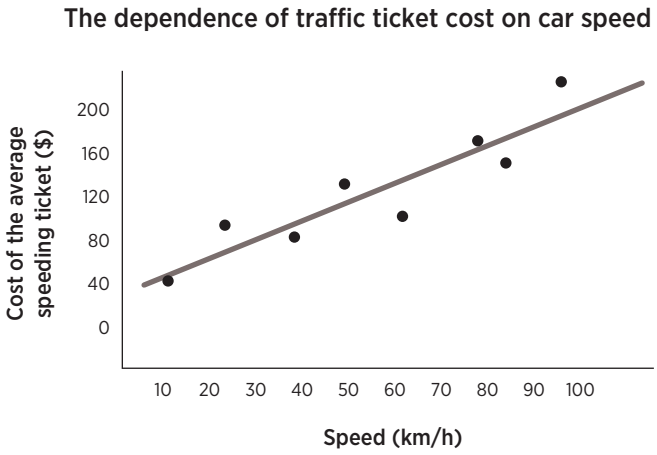
Scientific investigations are designed using the principle of a **fair test**. An experiment is one in which you directly **manipulate** one variable at a time to test a **hypothesis** – that is a fair test.

A way to generate reliable results is to include both a **control group** and an **experimental group** in your study. They are subject to exactly the same conditions except for one thing: the **independent variable**. That is the **variable** that you manipulate to test if it has an effect on your experimental subjects.

The variable that you measure during your experiment is the **dependent variable**. In a controlled experiment, you must control as many external factors as possible. The factors that you work to keep constant are called **controlled variables**. If you don't control important external variables, you won't produce valid results.

A controlled experiment in environmental science may ask the question: does adding fertiliser affect the pH of soil? In this experiment, you would add different amounts of fertiliser to different pots – 'amount of fertiliser added' is the independent variable. You would measure the pH of the soil – 'pH' is the dependent variable. Variables that you would want to control would include the type of fertiliser added, the type of soil in the pot and the water content of the soil. To ensure valid results in this experiment, you would have a control group with no fertiliser in the soil and at least five experimental groups with various amounts of fertiliser added.

Figure 6.6 is a graph of data collected in an experiment. You can see which axis shows the the independent variable (that you manipulate) and which shows the dependent variable (that will change). In a controlled experiment, you may find that the independent variable affects the dependent variable. The null hypothesis – that there is no relationship – would be disproved, and you could conclude that manipulating the independent variable caused the changes in the dependent variable (as long as you have controlled other variables).



Look at the graph on the left

- Which is the independent variable?
- Which is the dependent variable?

Figure 6.6. A graph shows the independent variable on the *x*-axis (horizontal line) and the dependent variable on the *y*-axis (vertical line)

Correlational study

A correlational study lets you investigate whether there is a **relationship** between two **naturally occurring variables**. In a correlational study, you do not manipulate any variables.

An example of a correlation study in environmental science is 'is there a relationship between fox numbers and nesting success of little penguins?'

Unlike an experimental study, you can't draw conclusions as to cause and effect from a correlational study. There may be all sorts of other variables affecting the data that may actually cause any results you find.

Secondary research

Secondary research investigations involve collecting and collating data that has already been gathered by other scientists. This collected data could be sourced from published scientific papers, online databases or other reputable sources. This type of investigation allows for the analysis of large datasets that have been collected over long periods of time or over large sampling areas.

Secondary research does not involve experiments. In environmental science, it is best suited to studies investigating large or historical datasets to find patterns in environmental factors.

Fieldwork

A **fieldwork** investigation is one in which you collect your results in the natural environment. It is an observational study with no manipulation of variables; all of your data collection is completed in nature.

Fieldwork studies allow you to investigate research questions in your local environment. Fieldwork skills differ from those needed for lab-based investigations. For example you may need to sample and identify plants or animals, record environmental conditions (perhaps with photographs) or measure water quality. Your study may involve collecting quantitative data (measures and counts) or qualitative data (types or categories) see 7.1 'Handling data', p 114). Fieldwork studies can be short or long term. They can be undertaken locally, within your school or at a river in your neighbourhood, or further afield like along the coast or in the mountains.

An example of a fieldwork study in environmental science is 'an investigation of species present in various zones along a rocky shore ecosystem'.

Modelling and simulation

Modelling investigations in environmental science are those that use a **physical model** to explain a concept or a **mathematical model** or computer **simulation** to predict or simulate a process over time.

Physical models can help to explain a concept by adding a visual representation of something that is either too big or too small to see clearly or represent an abstract idea, for example, 'a 3D model of the carbon cycle' or 'a diorama of a rainforest ecosystem'.

Mathematical models or computer simulations can be used for conducting virtual experiments or predicting changes to the environment, for example, 'using carbon emission data to predict future impacts of climate change in the local area'.

Product or system development

Your investigation could involve the **invention** or development of a product. You could focus on a sustainability concept that you are passionate about. If you choose to use this methodology for your investigation, remember to follow the **design process** (Figure 6.7).

1. Identify the problem. Ask yourself what it is that you are trying to achieve or solve with your product.
2. Brainstorm. Come up with a list of possible ideas to help with solving your problem.
3. Design. Draw sketches from one of your brainstorming ideas. Label your sketches to help you know what materials you will need for your design.
4. Build. This is the fun part!! Gather your materials and see if you can create a real-life version of your design. You may need to rethink ideas and change your design as you go.
5. After you have designed and redesigned to a point where you are happy with your design or prototype, communicate your design. This might be as a written piece in the school newsletter or a display in the local library.

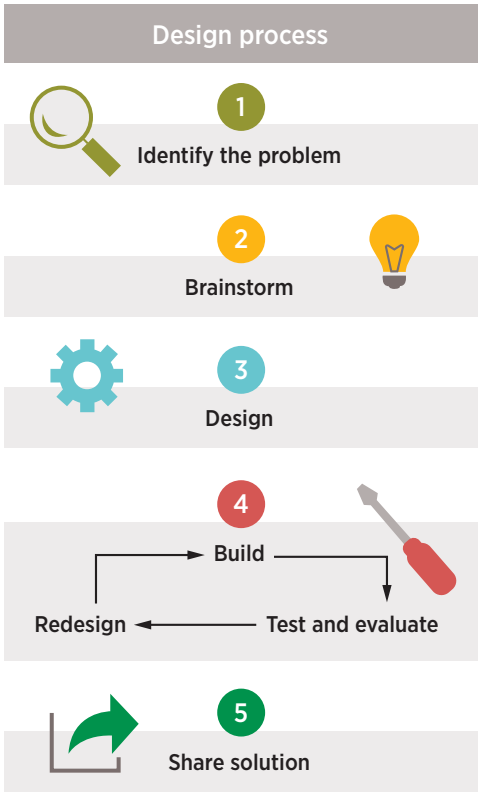


Figure 6.7. The design process for product development in environmental science

An example of an environmental science product development is the Seabin Project. Andrew Turton and Pete Ceglinski are two Australian surfers who have a passion for the ocean. They designed and created a product called the Seabin, an device that removes plastic pollution from the ocean. You can found out more information at https://seabinproject.com/.

Data-collection tools

Many environmental science investigations involve collecting data on biotic or abiotic components of the environment. Table 6.1 list some common data-collection methods. If your investigation involves collecting different types of data, you will need to research suitable data-collection techniques. Note that data you collect yourself is known as primary data, and data that you obtain from others is secondary data (this distinction is discussed further in 'Primary and secondary data', p 220).

Table 6.1. Data-collection techniques

Biotic or abiotic component	Primary or secondary data	Data-collection method
Wind speed	Primary	Handheld anemometer
	Secondary	Weather data from the Bureau of Meteorology
UV strength	Secondary	Weather data from the Bureau of Meteorology
Rock hardness	Primary	Test samples via hardness test
	Secondary	Use reference book to identify characteristics of sample
Salinity	Primary	Electroconductivity (EC) meter
Turbidity	Primary	Turbidity tube
Soil composition	Primary	Soil composition test
Insects	Primary	Pitfall traps, sweep net trapping, pooter
Aquatic invertebrates	Primary	Kick sampling, netting, seine nets
Vegetation	Primary	Transect, quadrats
Small animals	Primary	Spot lighting, radio collar, tracks and scats, trapping

Critical thinking and discussion 6.2

1. **Define** the terms 'independent variable', 'dependent variable' and 'controlled variable'.
2. A student designed an experiment in which they wanted to test which colour absorbs the most solar radiation. **Suggest** what the independent, dependent and controlled variables may be in such a controlled experiment.
3. **Explain** the need for a control group and an experimental group in a controlled experiment.
4. **Discuss** the importance of fieldwork investigations in environmental science.
5. **Outline** the importance of the design process when developing a product.

Data analysis 6.1
Visual model

Consider the visual model shown in Figure 6.8.

1. **Explain** what the model represents.
2. **Describe** the benefits and limitations of using this model as a representation of a geochemical cycle.

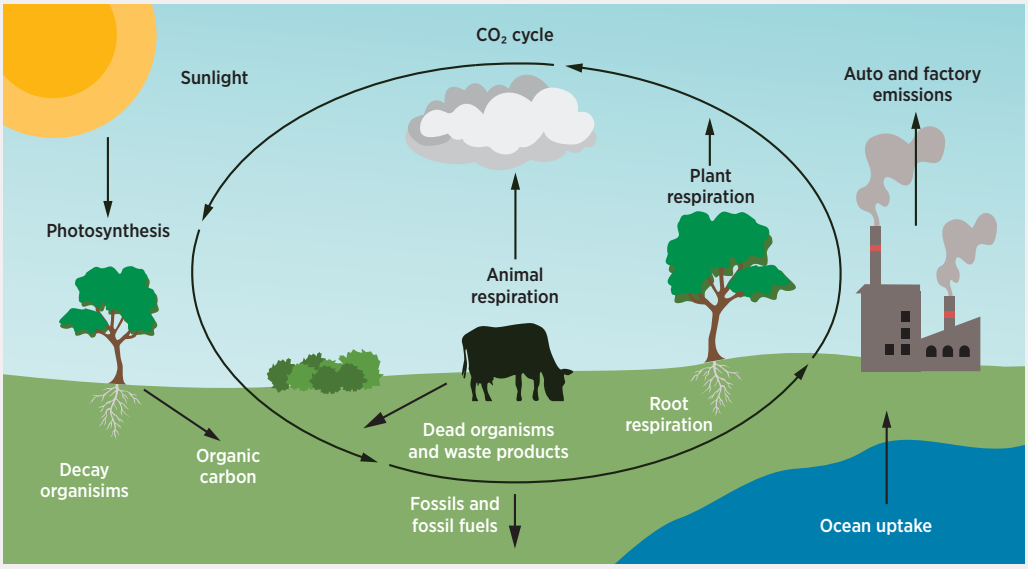


Figure 6.8. A visual model

Research project A.4
Design your methodology

Now it is time to design the methodology you will use to investigate the research question you designed in the previous section.

1. For each of type of investigation, devise an approach that could investige your research question.
   - Classification and identification
   - Controlled experiment
   - Correlational study
   - Secondary research
   - Fieldwork
   - Modelling and simulation
   - Product or system development.

   NOTE: You might find that some investigation types are not appropriate for your topic.
2. Choose which type of investigation can best answer your research question, and design a methodological technique for your investigation.

6.3. Health, safety and ethics

Health, safety and ethical guidelines relevant to the selected scientific investigation

Depending on your choice of investigation, there will be health and safety guidelines to consider as part of your investigation.

You will not be able to proceed with your investigation until you have outlined the **hazards** and **risks** associated with each potential danger. This is a legal requirement for all Environmental Science students.

In this case, a hazard is a source or situation that may cause harm, and the risk is the actual chance of the hazard causing harm.

Whether your investigation involves gathering data in the field or in a lab, all investigations will have some hazards and risks involved. Because of this, you will need to undertake a **risk assessment** to describe all hazards that may put you or others in danger during your investigation.

A risk assessment involves **identifying** the hazards, **assessing** the level of risk to you or others and implementing procedures or precautions to **control** the risks.

Identifying the risks

To thoroughly identify the risks associated with your investigation, you will need to think about your method:

- What activities will you be carrying out?
- Where will you be working? For example, in the lab, outdoors in the field, outdoors on school grounds.
- What could harm you or others during any steps of your method?

Assessing the level of risks

The assessment of how dangerous your risks are can be outlined with a combination of your own best knowledge, advice from your teacher and use of online resources such as the Material Safety Data Sheets (MSDSs) from Safe Work Australia (https://www.safeworkaustralia.gov.au/sds) and the RiskAssess online tool for schools (https://www.riskassess.com.au).

Be honest about the level of risks of each of your activities. You can use a graphic organiser such as a risk matrix, which is a table that compares the likelihood of your risks to the severity of the consequences (Figure 6.9).

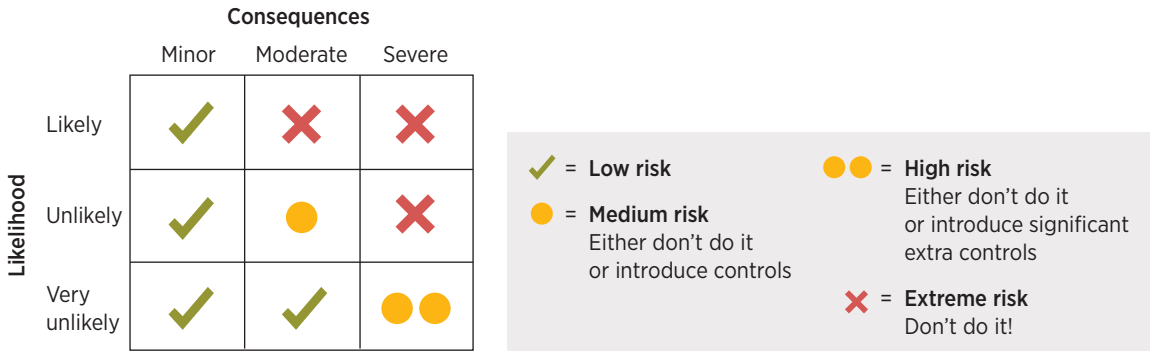


Figure 6.9. A risk matrix

Implementing precautions to reduce risks

Depending on your investigation, reducing risks may include steps such as:

- wearing **personal protective equipment**
- eliminating specific chemicals or finding alternatives
- working in a fume cupboard or working with a barrier between you and others
- having a first aid kit with you if you are working without a teacher
- choosing an alternative worksite to collect data.

Cause as little disturbance to the environment as possible by:

- not trampling native vegetation; use an existing path whenever possible
- returning logs and rocks you overturn to their original position
- returning any captured organisms to the same place they were collected
- keeping collection and removal of organisms (where permitted) to a minimum.

Note that Victorian schools may need ethics approval to collect organisms, depending on the species being collected.

Ethical and safety guidelines specific to outdoor investigations

Fieldwork investigations carry their own set of hazards, which include, but are not limited to, sun exposure, cold weather, working near rivers or lakes, insect and snake bites and knee or ankle injuries from uneven terrain.

Remember to consider these when creating your risk assessment.

Ethically, it is important that we consider the organisms living in the environments that we are working in. All measures must be taken to respect, and minimise any disturbance to, natural habitats and organisms while conducting your investigation.

Critical thinking and discussion 6.3

1. You and your partner have plans to take photographs on Saturday morning of the cliff faces at your local beach as part of your study of coastal erosion. An hour before you plan to meet, your partner texts you to say that they can't make it and that you should go by yourself to gather the data as your work is due next week. **Discuss** how you would respond in this situation.
2. **Describe** why ethical guidelines are as important to follow in environmental science fieldwork as safety guidelines.

Student activity 6.1
Risk assessment case study

Consider the following investigation to practise risk assessment techniques.

You are investigating the effect that depth of water has on the dissolved oxygen content of the water. You choose two different sites close to your school. Site 1 is a stagnant creek bed that only contains water during winter. This site is surrounded by mostly undisturbed bushland. Site 2 is a river that flows at medium pace through a local park. The park also contains a child's playground and picnic tables and is heavily covered in riparian vegetation.

Your method outlines your plan to use a water level meter to measure water depth at three randomly selected locations at each site. You also plan to use a dissolved oxygen (DO) probe at the same locations to measure dissolved oxygen levels.

Use the table below in conjunction with the risk matrix in Figure 6.9 to complete a risk assessment for the investigation in the following steps.

1. Identify the risky activities associated with this field investigation.
2. Identify the hazards that accompany each activity (for example, the risky activity might be hiking to the creek bed through the bushland, and the hazard associated might be the chance of twisting an ankle on uneven ground).
3. Use the risk matrix to complete a risk assessment for each hazard.
4. Outline the precautions you would implement to reduce these risks.

Activity	Hazard identified	Risk assessment (from matrix)	Precautions
Example: Hiking to Site 1	Twisting ankle on uneven ground	?	Wear hiking boots; do not undertake testing at dawn or dusk

Data analysis 6.2
Sodium hydroxide hazards

As part of your study on water health, you choose to test ammonia levels in your local waterway. You know that sodium hydroxide can be added to a solution to test for ammonia.

Before you begin, your teacher asks you to research the MSDS on sodium hydroxide and outline the hazards involved with using this chemical.

Use the Search Hazardous Chemicals tool on https://www.safeworkaustralia.gov.au/sds to discover the hazards involved with the use of sodium hydroxide. Outline your findings.

6.4. Data quality and investigation validity

Accuracy, precision, reproducibility, repeatability and validity of measurements in relation to the investigation

In any investigation is it critically important that you collect valid and reliable data. Only then will the conclusion drawn from that data be valid and accurate, and only then can we have confidence in the scientific process and findings. Maintaining rigour and integrity when collecting data is achieved by considering the principles of data accuracy, precision, reproducibility, repeatability and validity. When designing your investigation, pay close attention to how you will collect data with these principles in mind.

Accuracy and precision

The **accuracy** of a measurement is how close it is to the true value. You can improve accuracy by using a more sensitive data-collection technique or scale. For example, timing a swimming race electronically is more accurate than timing with a handheld stopwatch. And your results will be more accurate if you measure your classmates' heights in millimetres than if you measure in centimetres.

Accuracy becomes important when you are measuring very small increments (such as the growth of a plant over a day) or measurements that are very similar to each other (such as the distance between closely packed periwinkles).

Precision is how similar two or more measurements of the same thing are to each other. For example, if you take five measurements of the distance between the same two periwinkles and each time get the same number, then your measurements are precise.

You can be precise but not accurate. For example, if you take repeated measurements of weight of a trapped animal using a scale that is incorrectly calibrated, your measurements may be precise (similar to each other), but the weight will be incorrect.

Repeatability and reproducibility

One way scientists assess the quality and validity of research is by seeing if other studies of the same topic arrive at the same conclusion. This is particularly the case if an investigation has found surprising results. It is standard practice to clearly and thoroughly document your investigation methods so that other members of the scientific field can test the results for themselves. In re-doing an investigation, scientists look for both repeatability and reproducibility.

A **repeatable** investigation is one in which the same investigator measuring the same quantity, following exactly the same procedure under the same conditions arrives at the same results. Repeatability reassures the investigator that they are carrying out the investigation exactly the same way each time and the results are not being influenced by random or unkown variables.

A **reproducible** investigation is one in which another investigator measuring the same quantity in different conditions of measurement arrives at the same results. For example, you may have done a study that made conclusions about factors that affect reproduction of a spotted quoll population on the volcanic plains of western Victoria. It would be useful to replicate the study in another population to see if the findings are reproducible that is, closely align with the findings of the first study. If they are, that supports the idea that your results about factors affecting spotted quoll reproduction apply generally and not just in one circumstance.

Validity

Validity of a measurement refers to how closely it actually measures what it should be measuring. Validity of an experiment refers to whether it is actually testing what it aims to test; this relies on all of the above factors and a proper experimental methodology. Only investigations that collect data with accuracy and precision, and whose data is reproducible and repeatable, can be considered valid.

Critical thinking and discussion 6.4

1. An investigation has been designed to study the daily activities of a long-nosed potoroo colony. The hypothesis being tested is that long-nosed potoroos have a large range and therefore are susceptible to predation. The investigation will gather data by weighing the total amount of scats found in the vegetation where they are found for a moment. The data-collection phase will last 24 hours, after which a conclusion will be determined.

a) **Discuss** the validity of this investigation

b) **Outline** how you would improve the investigation, considering accuracy and precision, repeatability and reproducibility as well as validity.

2. Using valid data to show correlation in unrelated subject matters (such as in Figure 6.10) is a way for sceptics to introduce doubt into an investigation's conclusions.

a) **Discuss** why a correlation between two variables does not necessarily mean that one variable *causes* the other.

b) **Design** an investigation that uses secondary data to show that an increase in pirates does not cause climate change.

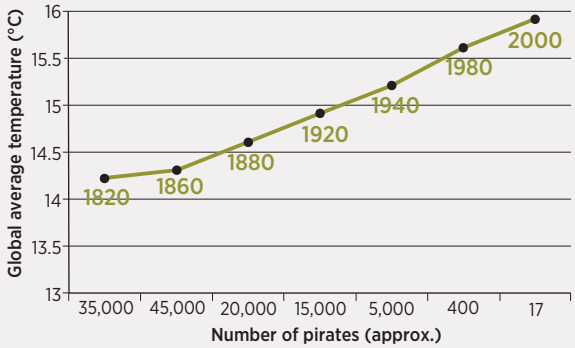


Figure 6.10. Global averaged temperatures vs number of pirates from 1820 to 2000

Research project A.5
Design your data-collection techniques

Use Table 6.2 to work out which data type (from column 1) is most suitable for your research project. Note this is the type of data you will collect and not the actual method of collecting the data.

Table 6.2. When to collect certain types of data

Data type	Useful when
Counting	Determining the amount of something – plants in a field, birds in a tree, fish in a creek
Measuring	Determining the distance an organism travels, rate of growth, length of roots, width of leaves
Mathematical equation	Determining the amount of biodiversity in an area, such as counting species richness
Monitoring	Determining changes to the range of a fish species, or changes in an area over time
Indirect observations	Direct measurements are difficult to obtain; for example, counting tracks or scats to determine the presence of a nocturnal animal in an area
Photographs	Determining changes that can only be perceived over long time periods, such as erosion or vegetation trampling

CHAPTER 7

Scientific evidence: investigation principles

7.1. Handling data

The characteristics of primary data

Ways of organising, analysing and evaluating generated primary data to identify patterns and relationships, and to identify sources of error

Primary data includes **observations** or **measurements** that you have collected yourself, either out in the field or in the lab. It is important that you keep an accurate, up-to-date **logbook** of your primary data in order to ensure the **reliability** of your field study.

Raw data is the primary data that you collect in your logbook. Generally, you will not present this data in the main section of your report, although you may choose to include it in an appendix at the end. Raw data is all the results you collect throughout the experiment.

Secondary data is data you obtain that someone else has collected (see 14.1 'Primary and secondary data', p 220). You will record, analyse and evaluate any secondary data that you use just as you do any primary data.

When you are ready to analyse your results, you will need to process this information. Ways of creating **processed data** can be seen in the next section of this chapter.

Raw data can be either qualitative or quantitative.

Qualitative data (also called categorical data) refers to results you collect that are described using words (or categories) only. For example, the names of different species found in a quadrat in a rocky shore ecosystem or the levels of sound given off by a wind turbine when using a scale of loud/medium/soft.

Quantitative data (also called numerical data) refers to results that you count or measure to get number values. For example, the concentration of sulfur dioxide in the atmosphere at a certain time (measured in parts per million) or the percentage cover of a local weed in a grassland ecosystem.
It is important to remember to specify the **units** you are using when collecting quantitative data.

Critical thinking and discussion 7.1

1. **Outline** the difference between raw and processed data.
2. **Construct** a Venn diagram to compare qualitative and quantitative data.
3. **Describe** why the reliability of data is important in environmental science field studies.

Data analysis 7.1
Types of data

Complete the following table by suggesting the data that may be collected in each example field study. Also note whether your suggested data is qualitative or quantitative.

Example field study	Data that could be collected	Qualitative or quantitative?
How does soil acidity affect plant growth?		
How does species distribution change with altitude in a temperate rainforest ecosystem?		
What factors affect erosion rates in farmland soils?		
How does water depth affect water temperature in a fresh water stream?		

Organising and displaying data

It is important during the design phase of the investigation to decide on what sort of data is to be collected and how it will be presented. Raw data and secondary data can be displayed in tables and graphs to make it easier for the reader to understand. Results from experiments can even be shown as photos or diagrams.

Not every single piece of data collected needs to be included. Look at the data and be **selective**; data not relevant to the purpose of the investigation does not need to be included. However, it is important not fall into the trap of **data manipulation** by excluding results that contradict the expected outcome of the investigation. If you obtain results that differ from what you expected, then you must include the results and discuss them. Only remove irrelevant data not related to the purpose of the investigation. For example, you may be investigating the flight distance of a budgerigar and in doing so have recorded the various colours of budgies that you saw flying. As you are investigating the flight distance, omitting the data on the colour of the bird is permitted, as it does not add to the story of flight distance.

You can display quantitative or qualitative data in tables. Tables are a way to organise the collected data, and a well-designed table can summarise data from multiple trials of an experiment or data collected from several collection sites in a fieldwork study.

Data shown in tables can often also be displayed in different graphical forms. Graphs can show patterns and trends that may not be obvious when the data is displayed in tables. Graphs can also help to identify outliers resulting from experimental errors or rare events in fieldwork. When analysing data from graphs it is important to include the **outliers** to identify their cause.

Choosing the appropriate graph to represent data is vital:

- Use a bar or **column graph** (Figure 7.1) if the investigation consists of comparing different trials or experimental groups, or if the independent variable is not numerical.
- A **time series plot** (Figure 7.2) is appropriate to show changes over time
- You can use a **line graph** (Figure 7.3) or a **scatterplot** with a **trendline** (Figure 7.4) to show relationships between dependent and independent variables.
- If the trend is not linear, a scatterplot with a **fitted** (or curved) trendline may best show the overall trend (Figure 7.5).

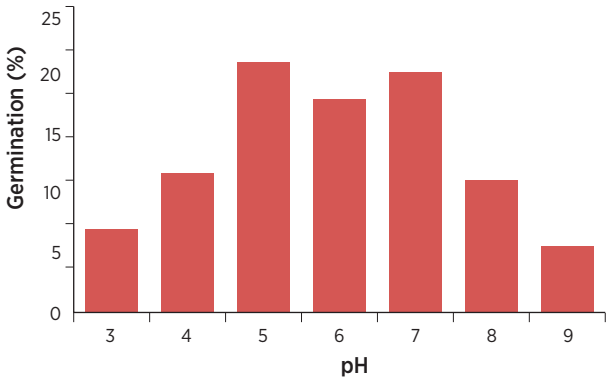


Figure 7.1. Column (bar) graph showing effect of pH on germination (%)

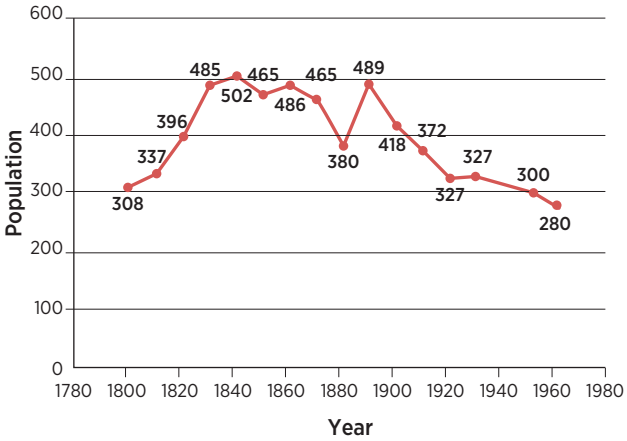


Figure 7.2. Time series plot showing population numbers over time

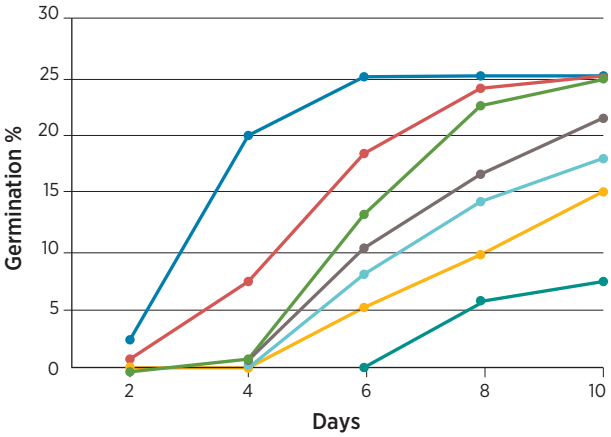


Figure 7.3. Line graph showing effect of light levels on seed germination over time

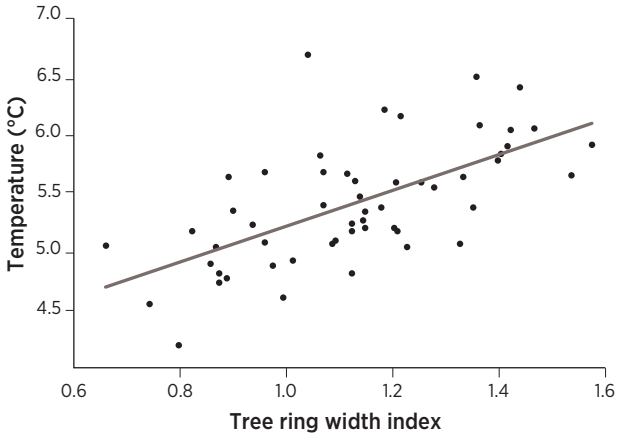


Figure 7.4. Scatterplot with straight trendline showing tree-ring width index against temperature CC BY 3.0

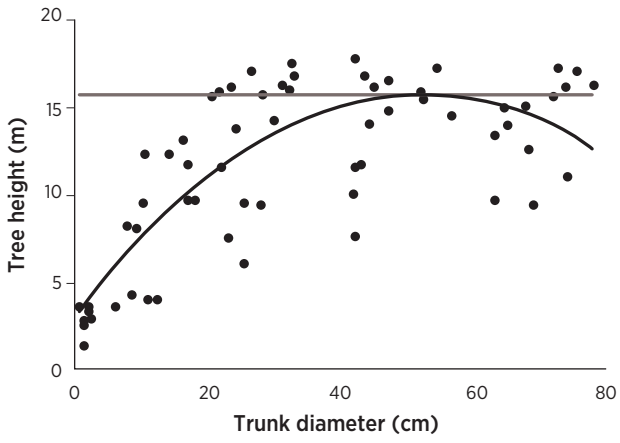


Figure 7.5. Scatterplot with curved trendline showing tree diameter against tree height

Figures include graphs, maps, photos and technical diagrams. A map may be included to show the location of the sample sample sites. Photos and/or diagrams can also be used to clarify and enhance tabulated and graphed results.

All tables and figures used to present data must be labelled with its type and numbered sequentially (that is, Table 1, Figure 1, Table 2 etc.) The label is then followed with a short title that briefly describes what is being shown. For example, 'Table 1. Number of macroinvertebrates at each site'.

Figure 7.5 shows an example of results displayed as both photos and as a graph.

Analysing data

Depending on the amount and type of data collected, you may need to perform calculations. The most frequent calculation involves averaging your results, for example, repeated measurements collected over multiple trials. You may also need to summarise the results using percentages or ratios, or use a particular mathematical or scientific formula. In each case, the first calculation is usually shown as a worked example, and then any other repeated calculations are included in an appendix.

Sources of error

Errors in scientific investigations are not mistakes; they are the difference between the measurements obtained from your sample and the true measurements you would get if you could perfectly measure the whole population.

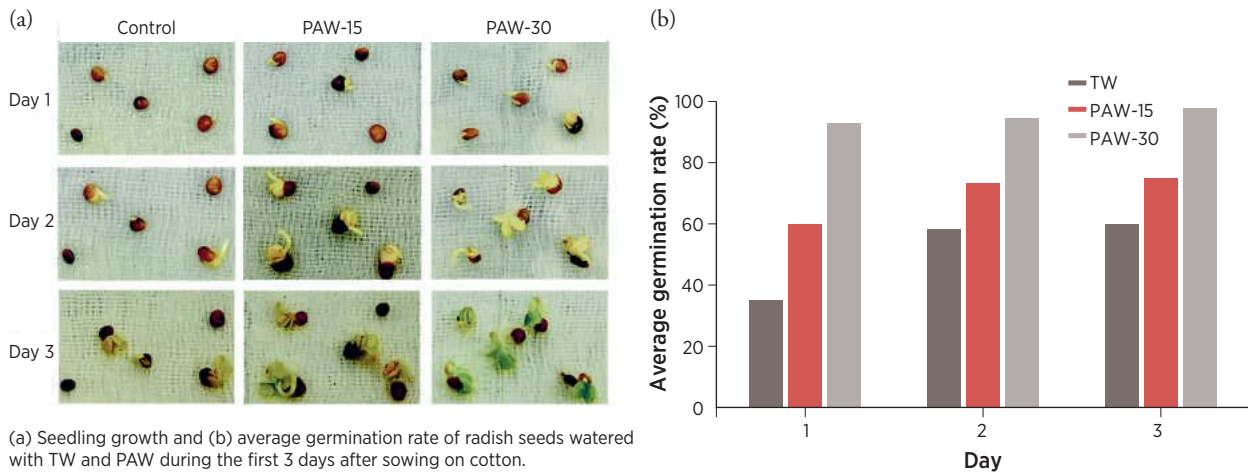
There are three types of error in scientific investigation, and different approaches are used to minimse each type of error.

Random errors are once-off, unpredictable errors that make measurements less precise. These are reduced by taking repeated measurements and calculating an average. Random errors are present in all measurements. They are unpredictable and can result in a range of readings. A common source of this error is an inability to accurately read instruments.

Systematic errors are errors in a repeated process or procedure that make the results less accurate. Systematic errors can produce a bias in the results. All the results will differ by the same amount, and replicating the experiment will not improve this type of error. Systematic errors can be caused by using uncalibrated equipment.

Personal errors (human error) result from mistakes, miscalculations or misreading instruments. These can be reduced by taking care and, if an error has been detected, repeating the experiment and avoiding that error.

A good investigation is designed to minimise errors. Sources of error will vary between experiments and investigations because of the different methods used.



(a) Seedling growth and (b) average germination rate of radish seeds watered with TW and PAW during the first 3 days after sowing on cotton.

Figure 7.6. Example of presenting results in a photo and graph. Credit: Sivachandiran & Khacef (2017) CC BY 3.0

Critical thinking and discussion 7.2

1. For each of the entries in the following table, **identify** the type of error and provide an explanation of how to overcome identify type of error.

	Type of error	Suggestion of how to fix error
A digital dissolved oxygen meter is being used to measure oxygen in a water sample and the readings are fluctuating		
The salinity levels in a water sample are measured with a digital conductivity meter and the results of one group are consistently higher than others for the same water sample		
The results of an experiment showed that all seeds germinated in a particular concentration of acid in one trial, but not any other trials of the same concentration		

2. For each of the following, **state** which type of graph would be best to present the data.

a) A field study collecting data on the number of Leadbeater's possums at three sampling sites over 5 years.

b) The growth of seedlings was measured to compare the effects of exposure to 24-hour light, 24-hour darkness and regular light patterns.

c) The germination of seeds when exposed to different concentrations of acid.

d) Global temperatures recorded from multiple sites over the last 100 years.

Data analysis 7.2
Tree growth

The heights of a number of eucalyptus trees of the same species in a local nature reserve were recorded over 30 years. A small sample of this data is shown in Table 7.1. The data shows the age (in years) and height (in metres).

1. **State** which is the independent variable and which is the dependent variable.
2. Using Excel or any other method, **construct** a scatterplot and determine the average rate of growth per year.
3. Does this species seem to be a slow-, medium- or fast-growing species? **Investigate** the average growth rate of eucalyptus.
4. **Identify** any possible outliers in this set of data.
5. **Identify** any sources of error that could have occurred in this investigation.

Table 7.1. Sample of eucalyptus heights over 30 years

Age (years)	Height (m)	Age (years)	Height (m)
2	0.7	14	18.6
2	1.1	14	24.9
2	0.5	18	27.3
2	0.9	18	22.6
2	0.8	18	23.1
4	1.5	18	27.2
4	2.0	18	21.8
4	1.3	20	28.4
4	1.7	20	23.5
4	1.3	20	24.1
6	3.6	20	28.2
6	3.8	20	23.7
6	3.3	25	31.4
6	3.4	25	25.9
6	3.5	25	26.6
10	12.8	25	31.1
10	10.6	25	26.1
10	10.8	30	44.2
10	12.7	30	36.3
10	10.2	30	37.5
14	18.7	30	43.6
14	15.5	30	36.6
14	15.8		

7.2. Evaluating and discussing results

The limitations of investigation methodologies and methods, and of data generation and/or analysis

In reporting your investigation, you need to provide a clear interpretation of the results. It is important to compare your data to the findings of others who have carried out similar investigations. The data that you have collected may support the findings of other similar investigations or they may be slightly or very different. Whatever the case, you need to discuss the similarities and differences in the approach to the investigation and also in the results obtained. When using other researchers findings, it is important to cite their work in your analysis.

You should discuss any inconsistency in the experimental process or any errors that may have affected the results. It is useful to recommend any additional or further research that help explain any unexpected results and possible ways to improve your investigation design for future research.

Limitations

Limitations can be considered the boundaries of your investigation. Limitations can exist in the design of your method, how the data is to be collected and even in the analysis of your data. If you are the first person to undertake the investigation, then there will not be any other data for you to draw comparisons against when you are analysing your data.

If you are conducting fieldwork, access to and the type of sampling site might limit the data than can be collected. Also the sample size being investigated can be a limiting factor to interpreting the data that was collected. The equipment used can also limit the quality of the data being collected. If you are conducting an experiment in the laboratory, you could be limited by the number of trials that are being set up. It is essential that identified limitations do not lead to a **biased** set of results.

It is important to acknowledge the limitations of your specific investigation and provide an explanation of how your experimental limitations could be overcome if the investigation were to be conducted again.

Also, you must not apply your findings beyond the limitations of the study. For example, if you study nesting behaviour in caged budgerigars, it would not be valid to apply the findings to wild budgies, because they fall outside the boundaries of the study.

Critical thinking and discussion 7.3

Identify possible limitations in each of the following investigations and **explain** how the limitations could be overcome.

1. A student has set up an experiment to investigate the effect of salinity on the germination of lettuce seeds. They have set up five different concentrations of salinity (including the control) and are using 10 seeds in each trial.
2. A survey on the number of animals using a wildlife corridor is conducted to determine species population numbers in a nature reserve.
3. The water quality of a local bird sanctuary is tested to determine the health of the waterway.

7.3. Writing scientific reports

The conventions of scientific report writing including scientific terminology and representations, standard abbreviations and units of measurement

Ways of presenting key findings and implications of the selected scientific investigation

When communicating your scientific findings, you may choose a report designed to be published, a poster report, a practical report, oral presentation, multimedia presentation or visual representation. Whichever approach you take, your writing should be clear, **concise** and logical. Using **visual aids** and images can help you to communicate your ideas.

Objective writing

Scientific reports should be concise, **objective** and **impersonal**. You should keep your sentences short and not add unnecessary words. Make sure that your writing contains only facts or **unbiased,** educated **inferences**, but no opinions or subjective ideas.

It is common practice to avoid **personal pronouns** ('I' or 'we') in a scientific report, although limited use is becoming more acceptable. These pronouns can be avoided by writing passive sentences that focus on the study rather than who has done it. For example, rather than: 'I noticed that the colour of the lake water changed as the depth increased', you could say: 'The colour of the lake water was observed to change as the depth increased'.

Your report should include important key **vocabulary** that you have learnt about in class. This will help to demonstrate to your teacher that you have a high-level understanding of the topic you are researching.

Visual aids

You should use a range of visual aids when compiling your report. These may include tables, graphs, photographs and sketches. Don't include your raw data or logbook data in the main section of your report.

Well-designed visual aids will reduce the number of words you need and may make your response more engaging to the audience. **Flow charts** can be used to outline your method or a series of steps that may form part of your analysis.

Remember to label appropriately *all* visual aids.

Graphs should have a title, clearly labelled *x* and *y* axes, a relevant scale and gridlines (if necessary).

Tables should have a desciptive title that includes the independent and dependent variables. All columns should have a header (label). Include the units of measurement in the header of each column or row (if applicable); this will avoid having to write the unit of measurement in every cell of your table. Figure 7.7 is an example of a well-labelled table.

Clear title showing IV and DV

Columns labelled; each column shows unit of measurement (mins and °C)

Table 1: Temperature inside model 'greenhouses' over 10 minutes in sun

Greenhouse 1		Greenhouse 2	
Time in sun (mins)	Temperature (°C)	Time in sun (mins)	Temperature (°C)
0	20	0	18
2	21	2	20
4	24	4	21
6	28	6	25
8	31	8	29

Figure 7.7. A well-labelled table

Figure 7.8. A labelled sketch. Credit: Bertrand Letlet

Photographs should be in colour if possible. Include the date that the photograph was taken and briefly describe the photograph in a caption. If you did not take the photograph yourself, always credit the photographer by name.

Sketches should always be drawn in pencil. Include a caption with a brief description of the sketch.

Label your sketches and try to keep them as simple as possible (see Figure 7.8). If necessary, choose an area of particular interest to zoom in on with a bubble.

Use of abbreviations

Abbreviations are shortened forms of words. There are many accepted abbreviations that you can use in your writing, but as a general rule, it is important to write the word out in full the first time you use it in your report. For example:

'This report examines the effect of daily temperature changes on sulfur dioxide (SO_2) levels in an urban environment. In this report, SO_2 is measured in parts per million (ppm).'

Common abbreviations, such as units of measurement for mass or length do not need to be written out in full. If you are not sure whether your abbreviation is 'common' then write it out to be sure that your audience knows what you are referring to in your writing.

Critical thinking and discussion 7.4

1. The following sentences are examples of statements that show poor scientific writing techniques. For each statement, **suggest** an alternative could be included into a scientific report.

Unscientific writing	Scientific writing
The results were bad because they showed ...	
I saw heaps of ants in the nest.	
We thought that the temperature felt hotter than yesterday.	
Tons of turbidity showed up in the tube.	

2. **Outline** the reasoning behind the need for unbiased language in a scientific report.

3. The following statements are classified as verbose. For each statement, **suggest** *one* word that says the same thing.

Verbose	Concise
due to the fact that	
in the event that	
in the vicinity of	

Student activity 7.1 Field sketch

Convert the following photograph into a field sketch. Include a caption, labels and a zoomed-in bubble.

Figure 7.9. Alpine water fern.
Credit: Bernard Spragg CC0 1.0

Table 7.2. Contents of a research poster

Title: Clear and concise question that deals with the investigation
Introduction: Explanation of background concepts
A research-based hypothesis
Identification of variables
Scientific method
Methods: List of equipment, materials and procedures
Clear explanation of steps
Results: Clear and accurate graphical representation of the data
Discussion: Explanation of the link between the investigation findings and the underlying scientific concepts
Evaluation of the procedures, errors and limitations of the experiment
Conclusion: A statement that links the hypothesis with the data collected
References list and acknowledgements

Research poster

What is a research poster?

Posters are widely used in the academic community, and most conferences include poster presentations in their program. Research posters summarise information or research concisely and attractively to help publicise it and generate discussion. The poster is usually some brief text mixed with tables, graphs, pictures and other visual formats. At a conference, there will be a particular session when the researcher stands by the poster display and other conference attendees can come and view the presentation and talk to the researcher.

What makes a good poster?

A good poster:

- makes sure the important information is readable from about 2 m
- has a short title that draws interest
- contains around 300 to 800 words
- has text that is clear and to the point
- uses bullets, numbering and headlines to make it easy to read
- simply but effectively uses graphics, colour and fonts
- has a consistent and clean layout, with plenty of 'white space'
- includes acknowledgements and your name.

The contents of a research poster text are given in Table 7.2. Figure 7.10 is an example of a well-designed poster and Figure 7.11 shows a poorly designed poster.

Practical report

A practical report contains the same elements as found in a research poster (see Table 7.2).

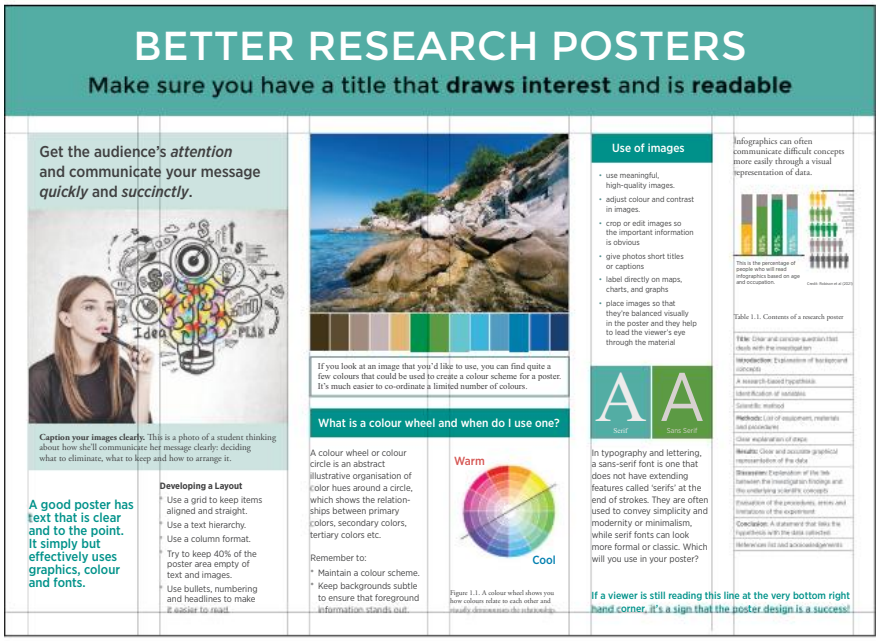


Figure 7.10. Example of a well-designed poster (shown with with a design background grid)

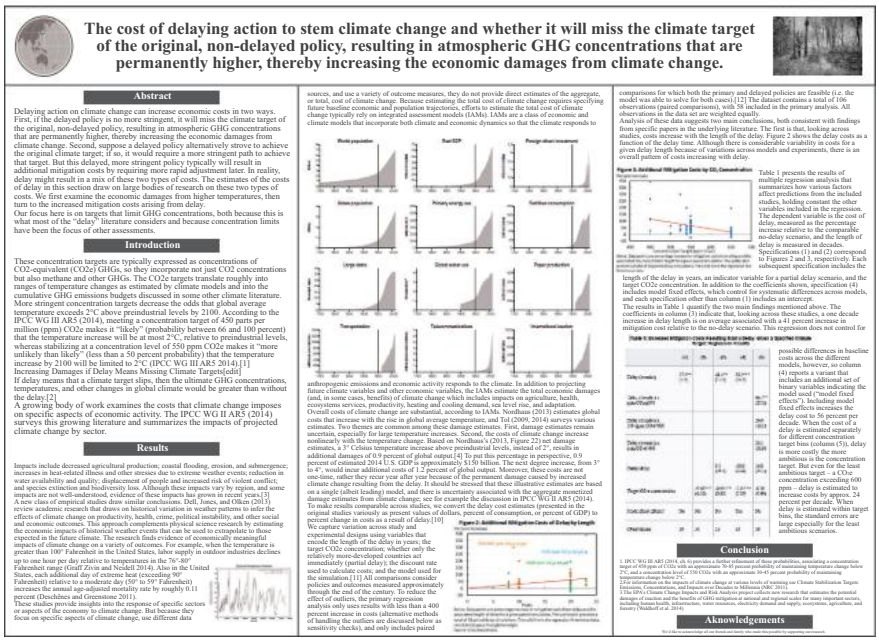


Figure 7.11. Example of a poorly designed poster

Multimedia presentation

A multimedia presentation is a film that combines still images and narration with film clips to produce one moving image. For assessment purposes, your multimedia presentation should run for approximately 3 to 4 minutes and use multiple image sources to illustrate the finding from your investigation.

Much like traditional forms of reporting, a multimedia presentation will have an introduction, explanation of methodology, data-collection methods, results, discussion and conclusion.

To communicate effectively, you should aim to show a new image every 3 to 4 seconds for still images and every 6 seconds for film images, so a film lasting 3 to 4 minutes will need approximately 40 to 90 images.

Images can include photographs of the investigation site, animals observed, data sampling, still images of graphs and tables, moving images of organisms and examples of data collected. All of the images should be accompanied by an informative narration.

EXPLORING SCIENCE 3
Teaching Indigenous students on Country

School of fish: how we involved Indigenous students in our investigation of a 65,000-year-old site

Morgan Disspain, Adjunct Researcher, Southern Cross University, and Lynley Wallis, Associate Professor, Griffith University

This article was originally published in The Conversation, *22 October 2020. https://theconversation.com/school-of-fish-how-we-involved-indigenous-students-in-our-investigation-of-a-65-000-year-old-site-144577*

A recent program for school kids in Kakadu and West Arnhem Land, incorporating traditional knowledge and Western science, is a model for teaching Indigenous children on Country.

The Djenj Project (djenj means 'fish' in the local language) involved teaching Bininj (Aboriginal) children and rangers about fish, and scientific water research techniques, to improve employment opportunities.

As archaeologists, we wanted to find out how fish populations near the 65,000-year-old Madjedbebe archaeological site have changed over thousands of years. Evidence collected from the rock shelter suggests it's one of the oldest sites on the continent.

We wanted to know which fish Bininj inhabitants at the site ate in the past, where and how they caught them, what the environment was like then, and what impact humans and environmental change have had on fish populations.

We needed to gather information about traditional fishing methods and knowledge. We also needed to gather samples of the current fish in the region, to compare them with fish remains excavated from Madjedbebe.

To do that meaningfully, we wanted to bring the community on the journey with us, rather than working in our labs in isolation. Dozens of school children between the ages of seven and 17 were involved in the project. They helped us answer our questions and learnt a lot in the process.

Beyond thinking about our scientific aims and questions, we put community-based benefits at the forefront of the research process. At the heart of the project were the core ideas of respect and two-way knowledge sharing, especially giving senior Bininj people the opportunity to share their knowledge and skills.

What it looked like

The project included about 80 community members from the small townships of Jabiru and Gunbalanya, and surrounding outstations in the Top End of the Northern Territory.

Bininj Elders shared traditional ecological knowledge with Bininj children, rangers (the Djurrubu Rangers of Gundjeihmi Aboriginal Corportion and Njanjma Rangers), and Western (Balanda) researchers. Everyone worked together to prepare teaching resources so the project has long-lasting benefits.

Fishing is a favourite activity for Bininj, so participation in the project was high. While word of mouth was the main way to reach the community about catching fish for the project, we also shared short videos on social media. These explained what we were doing and how people could get involved.

One positive side effect of the project was providing large amounts of fish for the community to eat, promoting healthy eating.

In between the fishing and the eating was the science and the learning. A key aim was to integrate cultural knowledge into school lessons to improve literacy and numeracy skills.

Figure 7.12. Djurrubu Rangers Russo Marimowa and Clarry Nadjamarrek off duty, doing some fishing for the project. Credit: Morgan Disspain

Figure 7.13. Sharni Dirdi, Imogen Mangiru and Zedekiah Nayilibidj at Gunbalanya School got hands on measuring and processing fish. Credit: Morgan Disspain

Figure 7.14. The Djurrubu Ranger team processing fish and extracting their otoliths. Credit: Lynley Wallis

Local teachers interwove The Djenj Project throughout the class curriculum for the entire year. Researchers ran monthly workshops to teach children and rangers how to collect and interpret scientific information from fish, such as species, length, girth and weight, as well as the capture location and the fishing method used.

Fish were then processed to collect otoliths (ear bones), and sometimes their entire skeletons. Otoliths provide valuable information about the fish's life, such as its size, age, season of death, and the water conditions it lived in.

Elders shared traditional knowledge about fish and fishing methods with the children. They worked together to construct bone points to use as fish hooks. They also constructed traditional fish traps, which involved making string from plant fibre.

Groups made trips to the rock art (bim) sites, where Elders shared knowledge about djenj, and the children found, recorded and counted djenj images.

While the Elders shared their knowledge about the local waterways, water monitoring specialists provided training in testing water quality for rangers and children. Children also learnt about the importance of water quality to the health of all living things.

Woven throughout all activities was attention to Indigenous languages, with staff from the Bininj Kunwok Language Resource Centre creating a dedicated language booklet and app focused on djenj. This resource is helping with language maintenance and revitalisation in the Bininj community, as well as providing Balanda with the necessary terms to have productive discussions with Bininj about fish and water.

What we learnt

Students and rangers gained a new appreciation for how much we can learn from our environment. The project also reinforced the rights of Bininj to engage in water and fish management processes.

The project also laid a foundation for future skills and environmental awareness with children (many of whom will go on to join local ranger teams). They have learnt cultural and scientific knowledge about fish, water, archaeology and rock art.

As researchers, we have established modern fish reference collections we can use and have learnt about local traditional fishing methods and ecological knowledge.

The Djenj Project is a great example of how grassroots projects can provide practical benefits for Aboriginal communities, while contributing to scientific research. The model of collaborative teaching and learning from each other can be customised to benefit other communities.

We are planning to do more projects like this in West Arnhem Land over the following years, investigating other species of plants and animals.

Figure 7.15. Bininj Elders Raelene Djandjul, May Nango and Djaykuk Djandomerr and Djurrubu Rangers Martin Liddy and Clarry Nadjamerrek processing fibre to make a traditional fish trap. Credit: Lynley Wallis

Figure 7.16. Students learnt about the fish skeletal system using reference collections created from fish they had captured. Credit: Morgan Disspain

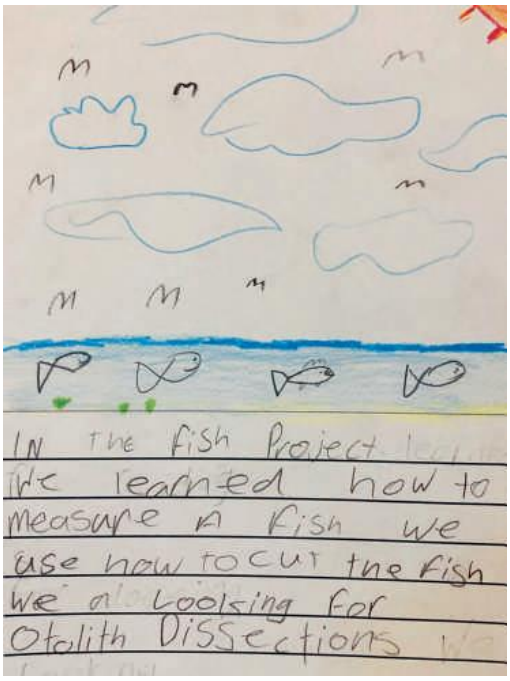


Figure 7.17. The Djenj Project increased science learning on Country. Credit: Gunbalanya school student

Figure 7.18. Djurrubu Ranger Clarry Nadjamerrek making a traditional fish trap. Credit: Lynley Wallis

UNIT 2

What affects Earth's capacity to sustain life?

Even landscapes or ecosystems that appear unspoiled can be adversely affected by pollution emitted from nearby as well as distant sources. The nesting, communication and mating behaviours of certain bird communities can change when exposed to continuous noise generated in human-populated environments. Hazardous waste spills, unsustainable farming practices, strip mining, deforestation and littering may cause soil and water contamination that can lead to poor growth and reduced crop yields, loss of wildlife habitat, water and noise pollution, soil erosion and desertification. The preservation of Earth's life-supporting systems and the management of pollution are interrelated. In this area of study students link the characteristics of pollutants to their impacts on Earth's four interrelated systems, and examine emerging opportunities to mitigate pollution discharge and manage the adverse effects of pollution for living and non-living things.

The selection of learning contexts should allow students to develop practical techniques and undertake fieldwork to assess and monitor air, water and soil quality. Students develop their skills in the use of scientific equipment and apparatus. They perform standard laboratory tests for pollution indicators such as dissolved oxygen and phosphate levels, and select sampling techniques that determine the number and relative abundance of introduced species, such as the use of pond nets or kick sampling. Secondary data for analysis may be used to explore environmental relationships between environmental contaminants and selected aspects of Earth's systems.

Outcome 1

On completion of this unit the student should be able to explain how the chemical and physical characteristics of pollutants impact on Earth's four systems, and recommend and justify a range of options for managing the local and global impacts of pollution.

AREA OF STUDY 7

How can we manage pollution to sustain Earth's systems?

Key knowledge

Area	Section
Pollution effects on Earth's systems	
• chemical and physical characteristics of pollutants that influence dispersal of emissions from natural and manufactured sources	8.1
• the transport mechanisms, persistence, fate and toxicity of pollutants throughout Earth's four interrelated systems	8.2
• the impacts of a range of pollutants on the health and survival of living things in the biosphere, including humans, and on the quality of the atmosphere, hydrosphere and lithosphere with reference to risk, exposure, dosage, tolerance limits, LD50, chronic and acute toxicity, allergies, disruption of system regulation and synergistic action	8.3
Managing pollution	
• the contributions of scientific data, new technologies, regulatory frameworks and diverse stakeholder values and priorities when managing pollution	9.1, 9.2, 9.3
• options for control and treatment of pollution to reduce local and global impacts	10.1

CHAPTER

8

How can we manage pollution to sustain Earth's systems?

CASE STUDY 8.1
Mercury pollution from decades past may have been re-released by Tasmania's bushfires

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https://theconversation.com/mercury-pollution-from-decades-past-may-have-been-re-released-by-tasmanias-bushfires-114603

Tasmania's bushfires may have resulted in the release of significant amounts of mercury from burnt trees into the atmosphere. Our research shows that industrial mercury pollution from decades past has been locked up in west Tasmanian trees.

Mercury occurs naturally in Earth's crust. Over the past 200 years, industrial activities have mobilised mercury from the crust and released it into the atmosphere.

As a consequence, atmospheric mercury concentrations are now three to four times higher than in the pre-industrialisation era.

Mining is the largest source of the global atmospheric mercury, accounting for 37% of mercury emissions. When Europeans first arrived in Australia, there was, of course, no Environmental Protection Act in place to limit emissions from industrial activities. In western Tasmania, where mining has occurred for more than a century, this meant mercury was being released without control into the local atmosphere until changes in technology, market conditions, and later, regulation, conspired to reduce emissions.

Because mercury is also very persistent in the environment, past mining activity has generated a reservoir of mercury that could be released to the atmosphere under certain conditions. This is a concern because even small amounts of mercury may be toxic and may cause serious health problems. In particular, mercury can threaten the normal development of a child in utero and early in its life.

Tree rings can reveal past mercury contamination

How much mercury has been released into the Australian environment and when has remained largely unknown. However, in a new study we show how mercury levels in Tasmania have dramatically changed over the past 150 years due to mining practices. Long-lived Huon pine, endemic to western Tasmania, is one of the most efficient bioaccumulators of mercury in the world. This makes it a good proxy for tracking mercury emissions in western Tasmania. If concentrations of mercury in the atmosphere are high in a given year, this can be detected in the annual ring of Huon pine for that year.

Figure 8.1. Temporal tree rings of Huon pine, revealing historical mercury pollution. Author provided

Mercury pollution from past mining practices in western Tasmania has left a lasting environmental legacy. The sampled trees contained a significant reservoir of mercury that was taken up during the peak mining period in Queenstown. Changes in mercury concentrations in the annual rings of Huon pine are closely aligned with changes in mining practices in the region.

Increased concentrations coincide with the commencement of pyritic copper smelting in Queenstown in 1896. They peak between 1910 and 1920 when smelting was at its height. In 1922, concentrations begin to decline in parallel with the introduction of a new method to separate and concentrate ores. This method required only one small furnace instead of 11 large ones. In 1934, a new dust-collection apparatus was installed in the smelter's chimney, coinciding with the further decrease in mercury concentrations in nearby Huon pine.

Toxic elements or compounds taken up by vegetation can also be released back into the local environment. Bushfires that burn trees that have accumulated mercury may release this mercury as vapour, dust or fine ash, potentially exposing people and wildlife to the adverse effects of mercury. It is estimated that bushfires release 210,000 kilograms (kg) of mercury into the global atmosphere each year. As these fires become more frequent and ferocious in Australia, mercury concentrations in the atmosphere are likely to increase. Mercury released by bushfires can persist in the atmosphere for a year, allowing for long-distance transportation depending on wind strength and direction.

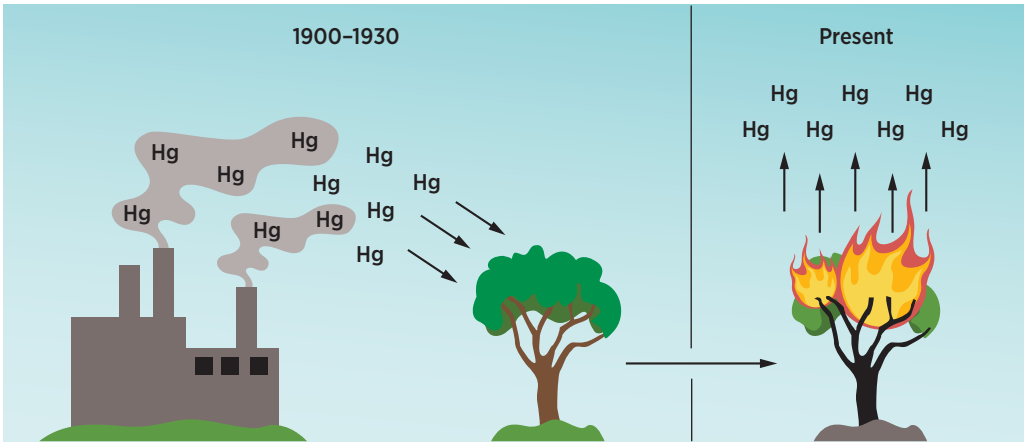


Figure 8.2. Re-release of historical mercury emissions by bushfires. Adapted from image provided by author

This means that mining activity from over a century ago may have regional implications in the near future. The Tasmanian fires in December–February [2019–20] burned almost 200,000 ha, including areas around Queenstown.

It is not currently possible to know how much mercury has been released by these recent fires. Our results simply highlight the potential risk and the need to better understand the amount of mercury taken up by vegetation that may one day be released back to the atmosphere via bushfires.

Although there is no simple way to remove bio-accumulated mercury from trees, the history of mercury contamination recorded in tree rings provides important lessons. Decreased uptake of mercury after upgrades to the Queenstown copper smelter operations demonstrates the positive impact that good management decisions can have on the amount of mercury released into the environment.

To control mercury emissions globally, the United Nations Environment Programme (UNEP) has developed the Minamata Convention on Mercury. Its primary goal is to protect human health and the environment from the negative effects of mercury. Australia has signed the convention but has yet to ratify it. Once ratified, Australia would be required to record sources of mercury and quantify emissions, including those from bushfires.

But to do this, the government must first be able to identify environmental reservoirs of mercury. Our study, the first of its kind in the Southern Hemisphere, shows that the long-lived Huon pine can be used to for this purpose. Further work to determine what other tree species record atmospheric emissions of mercury and other toxic elements in other regions of Australia is required.

Questions

1. **Determine** the science required to understand this case study.
2. **Describe** the types of technology that would assist with understanding or solving issues in this case study.
3. **List** the many stakeholders involved in this case study.
4. Using the definitions presented in 'Stakeholder values' (p 82), **describe** the values and priorities of the stakeholders involved. **Justify** your choice/s.
5. **Identify** the regulatory frameworks used to protect the environment that is described this case study.

8.1. Characteristics of pollutants

Chemical and physical characteristics of pollutants that influence dispersal of emissions from natural and manufactured sources

We often hear about how pollution can have devastating effects on the environment and on human health. We're told that we need to manage our waste better and that we must be careful not to let contaminants enter the environment – but what exactly is a contaminant and how can we distinguish different pollution sources from one another?

What is pollution?

Pollution is defined in the *Oxford Dictionary* as "the presence in or introduction into the environment of a substance which has harmful or poisonous effects". That substance is the **pollutant**. Pollution can occur naturally, for example, the gases released in volcanic eruptions and the gases and fine particles in bushfire smoke. Pollution can also be the result of human activities, such as oil spills or improperly disposing of industrial waste.

There are a variety of sources of pollution, both natural and manufactured. Their impact on the environment depends on how they interact with one another, their characteristics and how they enter the environment (also known as **dispersal**). Note that many pollutants are found in different forms in the air, water and/or soil.

Primary pollutants are substances that are released into the environment directly from a polluting source. The majority are those emitted from the burning of fossil fuels. **Secondary pollutants** are formed by chemical changes to the primary pollutants. For example, nitric oxide (NO) will transform into nitrogen dioxide (NO_2) when it comes into contact with ozone (O_3) in the ozone layer of the atmosphere, reducing the amount of ozone in that stratum.

Atmospheric pollution

Atmospheric pollution (air pollution) can be gases such as carbon dioxide, carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, volatile organic compounds (VOCs) such as benzene and formaldehyde, and particulate matter (PM). Particulate matter is found as solid and liquid particles suspended in the air.

Pollutants released to the air from human activities include dust from agriculture, mining and urban development; suspended particles from vehicles; smoke from bushfires, prescribed burning and household wood-burning heaters; and spray drift from agricultural application of chemical pesticides (that control pest animals such as insects or rodents, plants, plant pathogens and other pests), including herbicides (pesticides that kill or control plants) .

Figure 8.3 illustrates various sources of atmospheric emissions.

Figure 8.3. Sources of atmospheric gases

Water pollution

Water pollution can be attributed to a substance that enters waterways (fresh water and marine) at excessive levels. Human sources of water pollution include illegal discharge from industrial activity, run-off from agricultural fertilisers such as nitrogen and phosphorus, and debris from plastics and other litter.

Terrestrial pollution

Terrestrial pollution (land pollution) can result from an imbalance in natural systems caused by humans. An example of this is salinity levels on the surface of the land. Following land clearing for agriculture, groundwater levels rise and salts that would otherwise be trapped within underground water are brought to the surface. This salt pollutes the land and makes it unsuitable to grow the usual vegetation that supports the usual fauna. Saline soils also harm agricultural practices on farms.

Light pollution

Many towns, cities and industrial activities produce light pollution. An environment that is illuminated at night due to the effects of a city or industrial activity is affected by light pollution. Light pollution can cause animals to become disorientated and is the reason we can sometimes see birds flying at night or Bogong moths massing in large numbers over cities rather than reaching their breeding grounds. Light pollution can also disturb natural rhythms of growth in plants and other organisms.

Noise pollution

Continuous or recurrent noise that is loud enough to be annoying or physically harmful is known as noise pollution. Noise pollution is caused by cars, trucks, rail, industry, machinery operations and boating activities. Excessive ocean noise pollution disrupts marine animals' ability to mate, find food and avoid predation.

Thermal pollution

Thermal pollution is heat from hot water that is discharged from a power plant or factory into a river or lake, where it can kill or endanger aquatic life.

Heavy metals

Heavy metals are particularly toxic and they persist in the environment for a long time, sometimes making their way into the food chain. A heavy metal is a metal with an atomic mass greater than that of calcium, such as mercury, lead, cadmium and arsenic.

Organisms require low levels of many heavy metals (such as iron, manganese and zinc) to maintain health, but many heavy metals are not biologically essential and can cause toxic effects at low concentrations. Lead, mercury and arsenic are all extremely harmful in low concentrations and cause a variety of health effects. For example, mercury at sublethal concentrations may reduce growth, impair reproductive functioning, reduce immune responses and cause neurological impairment in fish and invertebrates.

All heavy metals occur naturally in the environment, and you must consider the background level of toxicants when investigating the levels in an organism. However, human activities have added large quantities of heavy metals to the environment over many years through industrial processes, burning fossil fuels, mining and agriculture. For example, much of the arsenic consumed by humans occurs in the non-toxic organic form arsenobetaine, accumulated by the marine organisms. Human activities, particularly metal smelting, mobilise around three times the natural quantity of arsenic, often in a more dangerous inorganic form.

Waste, contaminants and pollutants

The terms 'waste', 'contaminant' and 'pollutant' are often assumed to mean the same thing, but their meanings are specific and distinct.

Waste is a material, substance or by-product eliminated or discarded as no longer useful or required after the completion of a process. Waste can become a pollutant if not treated properly, but it may not. For example, sewage water is a waste product of sewage treatment, and can be considered a pollutant if its disposal harms the environment, for example, by adding extra nutrients. In Singapore, however, sewage water is treated to a high quality and re-used – so it is not a pollutant as it does not harm the environment.

A **contaminant** is simply a substance present where it does not naturally occur, or a substance found at concentrations above background levels. A **pollutant** is a contaminant that results in, or can result in, adverse biological effects to resident biota. All pollutants are contaminants, but not all contaminants are pollutants.

Practical 8.1
A potential pollutant

Aim

To model a potential pollution event.

Scenario

A truck transporting milk along the Hume Highway had an accident causing 20,000 L of milk to spill and flow down a drain into a nearby stream. Would this be classified as pollution under the various definitions? The likely impact of this scenario can be modelled using a fish tank that is filled with water to which various non-hazardous liquids are added. There will be no animals in the fish tank, but *Elodea* could be added.

Materials

- fish tank
- *Elodea* (optional)
- non-hazardous liquid (for example, milk)
- oxygen meter or datalogger probe to test for biological oxygen demand (BOD)
- dissolved oxygen (DO) probe
- turbidity tube or other suitable device

Procedure

1. Set up a fish tank containing water. Measure the dissolved oxygen levels of the plain water. This will act as the control.
2. Now you will add a non-hazardous liquid such as milk (this is the pollution spill) to make the required concentration of pollutant. Begin with 1% milk:

a) Measure the total amount of water you will put into your tank (for example, 1 L).

b) Calculate the volume of pollutant required to make the required percentage (in this example, 1% of 1 L is 10 mL).

c) Remove necessary volume (in this example, 10 mL) of water from the tank.

d) Add necessary volume (in this example, 10 mL) of milk to the tank.

3. Monitor the biological oxygen demand (see next page), dissolved oxygen and turbidity levels for the 'spill'.
4. Rinse out the fish tank and repeat for 'spill' concentrations of 5%, 10% and 20%.

continued next page

Practical 8.1 (continued)

Test for biological oxygen demand

1. Collect a sample from each concentration of your 'polluted' water and place it in a black, light-proof bottle.
2. Test the DO level of each sample using a data probe and record the result.
3. Incubate the samples for 5 days at 20 °C.
4. Re-test for DO and record the results.
5. Calculate BOD (see table below).

Discussion

1. **Comment** on the quality of your water samples as indicated by the dissolved oxygen.
2. **Identify** the most likely sources of dissolved oxygen in water.
3. **Suggest** what living organisms remove oxygen from water.
4. **Identify** what types of chemical pollutants remove oxygen from water.
5. Discuss and compare your results in the table, and **explain** the effects of the different concentrations of milk on the fish tank system.
6. Prepare a report to determine and **explain** whether you have, or have not, added a pollutant to the fish tank system.
7. As an extension activity, add other non-hazardous chemicals to a fish tank (for example, oil or salt) and test for BOD, DO and turbidity to **investigate** if they are pollutants.

	DO level 1% milk	DO level 5% milk	DO level 10% milk	DO level 20% milk
Day 1 (a)				
Day 5 (b)				
BOD (a − b) =				

Results summary

Substance	BOD	DO	Turbidity
Control (plain water)			
1% milk solution			
5% milk solution			
10% milk solution			
20% milk solution			

Critical thinking and discussion 8.1

Use your knowledge and the information at www.epa.vic.gov.au/your-environment/waste to answer the following questions.

1. **Define** 'waste'.
2. **Explain** the major difference between municipal and industrial wastes?
3. **List** the EPA's waste management hierarchy in the order of most preferable to the least preferable methods of dealing with waste.
4. **List** some of the steps you can take to reduce household waste.
5. **Determine** what percentage of the waste produced in Victoria in 2015–20 was recovered for re-use and recycling.

Data analysis 8.1
Monitoring ozone levels

The Hazelwood coal mine fire began on 9 February 2014 and was officially brought under control on 10 March 2014 after burning for 30 days. During this time, large quantities of toxic smoke were emitted into the atmosphere and blanketed the towns of Morwell and surrounds. The Environment Protection Authority monitored air quality during the fire to obtain information to protect the health of residents.

Several pollutants were measured including ozone. Figure 8.4 shows the ozone levels detected.

1. Analyse the graph and **deduce** an explanation of the of levels of ozone and the time the gases peaked.
2. **Explain** why the EPA monitored ozone during this time.

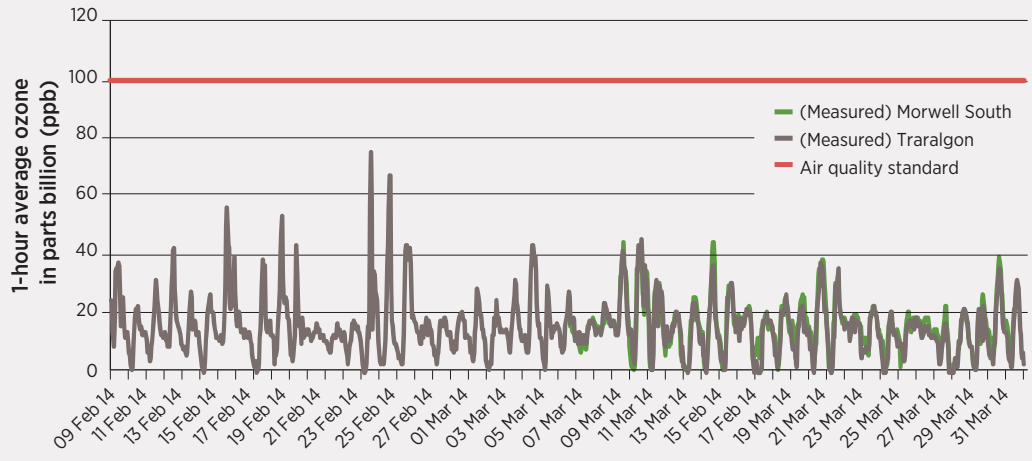


Figure 8.4. Latrobe Valley ozone levels (1-hour average)

8.2. Transport mechanisms

The transport mechanisms, persistence, fate and toxicity of pollutants throughout Earth's four interrelated systems

Many manufacturing processes operating today use a great diversity of chemical substances and release a great variety and quantity of pollutants into the environment. Air and water movements that transport these substances around the country and globe further increase the area affected by pollution. The characteristics of any sort of pollutant or waste determines how it disperses into the environment.

Water is a powerful disperser of pollutants. Water-soluble pollutants are dispersed easily in precipitation, surface water run-off and through aquatic systems, saturated land and groundwater. Water can also transport non-soluble pollutants; for example, rain can wash oil and small particles of rubber from vehicles into waterways.

How atmospheric pollutants disperse is affected by meteorological conditions. Strong winds disperse atmospheric pollutants while the development of secondary pollutants is less likely in cloudy weather. Ground level pollution in urban areas is increased in calm, clear weather when temperature inversions occur (see 'Processes in the atmosphere', p 29).

Managing pollution depends on understanding the types, sources and quantities of pollutants being generated and how they persist in, or are transported around, the environment.

Pollution sources

Pollutants are characterised as coming from either a point source or diffuse sources, and the type of emission affects how easy a pollutant is to manage.

Discharging a pollutant directly to the environment (for example, a factory sending effluent into a creek) is known as **direct pollution**. **Indirect pollution** occurs when a pollutant finds its way indirectly into an environment. An example of this is nitrogen from agricultural fertilisers being carried in run-off from the farm into ditches and local waterways and eventually finding its way to lakes and the ocean.

Point source emissions

Point source emissions come from a single discharge point. This is often a chimney (referred to as a stack) for atmospheric emissions or a discharge pipe for liquid emissions. Because the pollutant is being released into the environment from a single point, it is relatively easy to install pollution-control devices to capture the pollutants or modify the emission stream. Examples are **scrubbers** to 'clean' the gas and **baghouse** filters to trap particulates in air emissions (more details in 'Treating industrial emissions', p 174).

Diffuse source emissions

Diffuse source emissions enter the environment across a broad area, such as fertiliser run-off from agricultural land. Diffuse source atmospheric emissions are divided into fugitive and mobile emissions.

Fugitive emissions escape from an instrument or facility separate to any designated outlets (such as a chimney stack). For example, CSIRO estimates that about 8% of Australia's greenhouse gas emissions are fugitive emissions from fossil fuel mining and production, including coal seam gas. Fugitive emissions are difficult to control through the installation and operation of pollution-control devices.

Mobile emissions come from mobile sources. Motor vehicles are the most common source of mobile emissions. However, unlike fugitive emissions, mobile emissions can be controlled relatively easily by installing pollution-control devices. Although the large number of vehicles creates a diffuse emission source across the state or country, each vehicle is a little point source of pollution.

Pollution sinks

A pollution sink is a process or place that removes a pollutant from the biogeochemical cycle by either storing it for a significant time or turning it into another substance. Examples include:

- nitrites (NO_2^-) reacting with water droplets and precipitating from the atmosphere as nitric acid (known as acid rain, Figure 8.5)
- nitrates (NO_3^-) dissolving in soil water and being taken up by plants and incorporated into proteins – accumulated plant matter is a sink for nitrogen
- carbon dioxide dissolving in water both in oceans and fresh water bodies – the oceans are a major carbon dioxide sink
- atmospheric carbon being taken in for photosynthesis for plant growth and then stored in vegetation or other organic matter – accumulated plant matter is a sink for carbon
- heavy metals settling out in wetlands – wetland sediments are sinks for heavy metals.

The rate at which sinks operate affects how much of the pollutant is removed from the environment over a period of time. Human activity is not only adding greater amounts of some pollutants to the environment, it is also slowing down or decreasing the action of some sinks. Some experts claim we are observing this in action already in that the land and ocean are becoming steadily less effective at removing excess carbon dioxide from the atmosphere.

Pollutant management strategies must consider both where the pollutant comes from and where it ends up when released into the environment.

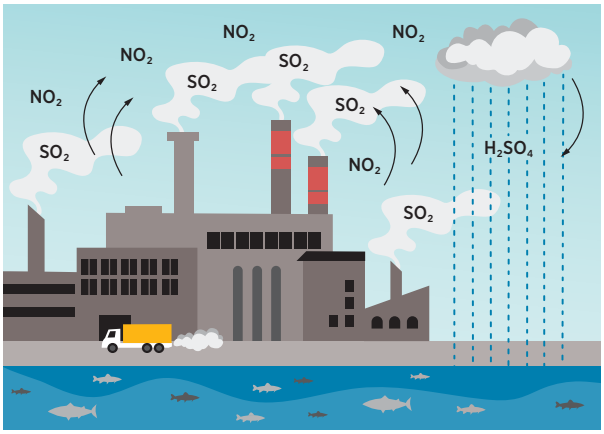


Figure 8.5. Nitrites react with water becoming nitric acids and then fall back to earth as acid rain

Bioaccumulation, biomagnification and bioconcentration

When an organism takes in a substance faster than the body can remove it, the amount of that substance increases in the body over time. This progressive increase is known as **bioaccumulation** and is a normal and essential process for the growth and wellbeing of an organism. All animals, including humans, daily bioaccumulate many vital nutrients, such as vitamins A, D and K, trace minerals and essential fats and amino acids. Bioaccumulation also includes accumulation of substances through respiration, direct contact with air, water or soil, or any other process.

What concerns toxicologists is the bioaccumulation of substances to levels in the body that can cause it harm.

Bioconcentration is a particular type of bioaccumulation: it is the build-up in the body of a chemical taken in directly from the environment, but not through its food, to a concentration higher than the surrounding water or air. This term is usually applied to chemicals that are foreign to the organism and its environment.

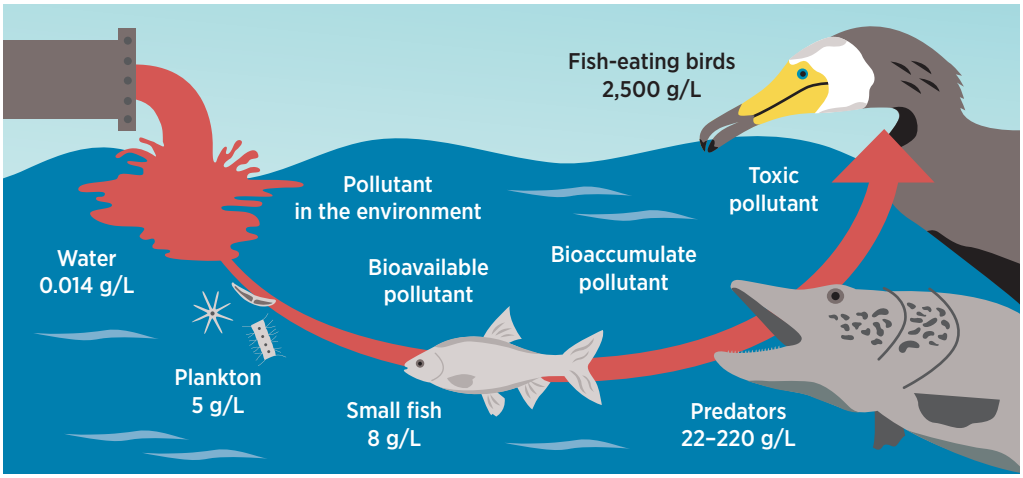


Figure 8.6. Biomagnification of a toxic pollutant in a marine system

Biomagnification is the increasing concentration of a chemical in organisms as you go up the food chain (Figure 8.6). For example, at one location, the insecticide DDT (dichlorodiphenyltrichloroethane) has been measured at a concentration of 10 ppm in soil, 141 ppm in earthworms and 444 ppm in robins that fed on the worms. Biomagnification usually occurs with chemicals that are persistent and degrade very slowly in the environment. This allows the chemical to be accumulated over a lengthy period of time and at each level in the food chain. These chemicals are also usually fat soluble but insoluble in water, which limits an organism's ability to excrete the substance. If the concentration of the chemical passes a certain threshold, it will cause adverse health effects and can lead to death.

CASE STUDY 8.2
Mercury in the environment

Mercury (Hg) is a naturally occurring heavy metal element that is common in the environment. It can be found in three forms: organic, inorganic and elemental (metallic). Although mercury occurs naturally, exposure can cause ill health to humans and serious environmental problems.

Properties and effects

Mercury is the only metal that is liquid at room temperature. It conducts electricity, can kill microorganisms, easily forms alloys with gold and silver, and expands and contracts uniformly with temperature changes. These unique properties make it very useful in manufacturing, mining, hospitals, households, dental offices, laboratories and schools.

Elemental mercury can't break down into less toxic substances, so it persists in the environment. Mercury occurs naturally in Earth's crust and, once released by volcanic eruptions and evaporation, it circulates in and out of the atmosphere until it eventually settles out within soil and water sediments. Elemental mercury is particularly toxic as vapour, but organic mercury compounds can be up to 30 times more toxic.

Methylmercury (an organic mercury compound) is probably the most toxic mercury compound. Methylmercury is formed from the bacterial methylation of inorganic mercury in the environment; this same process is carried out by bacteria in the gills or gut of fish. Methylmercury produces harmful effects at concentrations one-tenth of those of inorganic mercury and makes up over 80% of total mercury found in fish tissue.

Mercury in the environment

Mercury occurs naturally worldwide with trace amounts in most rock, soil, coal, trees, water and air. Natural atmospheric mercury originates from volcanic emissions, forest fires and volatilisation from ocean surfaces. Mercury moves throughout the environment, from air to land and to water (see Figure 8.7).

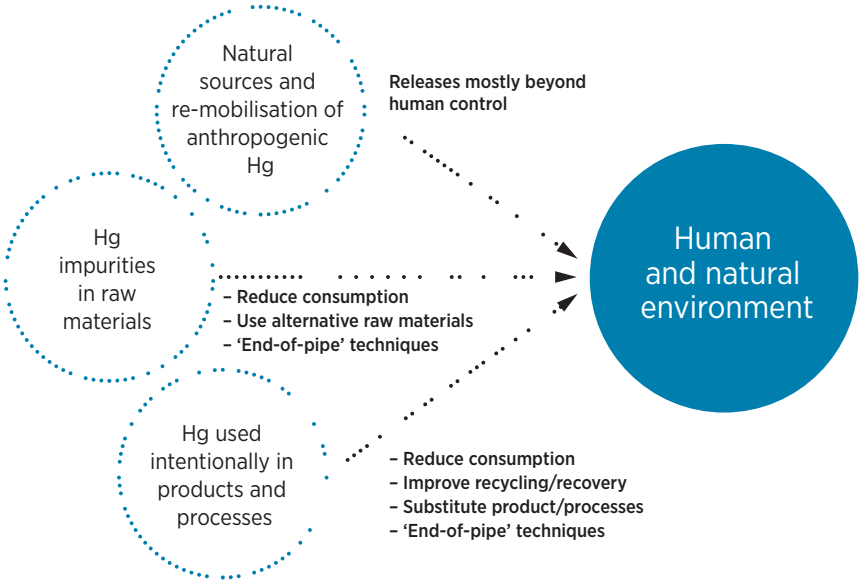


Figure 8.7. Sources of mercury released into the environment and management options

Mercury is rare in Victoria. It is found as metallic mercury (Hg) globules in alluvial deposits and as cinnabar (mercuric sulfide, HgS) in a slate deposit near Jamieson in north-east Victoria. Research by the Victorian Environment Protection Authority has shown that many streams flowing through old gold mining areas have elevated mercury levels in their sediments. The data indicated that old tailings deposits, where mercury was used to separate the gold from ores, have elevated mercury levels and are the source of contamination for these rivers. However, any attempt to remove contaminated sediments would exacerbate the problem.
The mercury contamination of the water is not considered to be a health risk for fish or for humans who either eat fish or drink the water from these rivers.

Increase in mercury concentrations

Mercury has been 'mined' for 2,000 years and, prior to recent research that established its toxicity, mercury was used in a variety of applications including as an amalgam for teeth fillings, in thermometers, as medicine, for hat-making, in paints and in the manufacture of weedkillers. Because it is the only liquid electrical conductor, mercury has been widely used in electrical switches.

Atmospheric mercury levels have increased sharply over the last century as a result of human activity. Most of the increase is from mercury released into the atmosphere as a by-product of the mass burning of coal for power generation and metal smelter operations, such as at Victoria's Alcoa aluminium smelter at Portland, and the incineration of mercury-containing medical and industrial wastes.

Two forms of mercury are released from a power plant during coal combustion: oxidised (or ionic) mercury, which is water-soluble; and elemental mercury, which is not water-soluble. Oxidised mercury can be washed into local water bodies by rainfall. Mercury is also released into water through discharge of industrial waste. Compared with coal from the United States, Australian coal is relatively low in mercury.

Environmental impacts

Mercury that has settled out into the sediment of lakes and oceans does not generally cause problems of environmental exposure. However, dredging or other sediment movement can mobilise the pollutant and raise the exposure threat. Also, elemental or inorganic mercury within sediments can be transformed into organic methylmercury through biological processes. Methylmercury can be directly absorbed from the sediment by small aquatic organisms. It is readily bioaccumulated and passed up the food chain and biomagnified.

Mercury appears to be toxic to most organisms, but selenium seems to reduce mercury's toxic effects. Many marine animals have high levels of selenium, which lets them tolerate relatively high mercury concentrations. Predatory fish, such as large tuna, swordfish, shark and mackerel, can have mercury concentrations in their bodies that are 10,000 times higher than those of their surrounding habitat.

The effects of excessive doses of mercury, especially on humans, are well documented, but less is known about chronic exposure to smaller doses. Such exposure is thought to cause trouble, not only to humans but also to other living organisms, especially with the developing fetus. If this is the case, high concentrations of mercury in an environment could affect the population stability of carnivorous species.

Human health

Mercury is toxic to humans and poisoning can be fatal. Poisoning may result from inhalation of the vapour, absorption of mercury through the skin or ingestion of soluble compounds. Eating fish and shellfish from areas where mercury is in high concentrations is therefore unwise, yet this is the most likely source of exposure for humans.

Mercury accumulates in the meat of fish, but it is odourless and invisible and therefore not easy to detect. Nor can it be avoided by trimming off the skin or other parts of the fish. Once in the human body, mercury acts as a neurotoxin, interfering with, and causing long-term damage to, the brain, kidney, liver and the central nervous system.

Managing mercury

The risk of mercury pollution and poisoning can be minimised by reducing the use of mercury, as well as safely disposing of waste containing mercury. The use of mercury is being phased out in most countries now that research has revealed its toxicity.

At an international level, research is focusing on levels of exposure and the effects of mercury on both wildlife and humans. In addition, industry is examining ways to reduce or even replace mercury in industrial processes. In 2013, many countries agreed on a global treaty to protect human health and the environment from the adverse effects of mercury – called the Minamata Convention on Mercury. Over 120 countries, including Australia, have signed the convention.

The Convention on Mercury commits countries to implement:

- bans on new mercury mines
- the phase-out of existing mines
- control measures on air emissions
- regulations on artisanal and small-scale gold mining.

Data analysis 8.2
Mercury in the food chain

1. **Construct** and draw a food chain based on the mercury concentrations found in each of the organisms in the table below (ppt = parts per trillion).

Table 8.1. Mercury concentration in organisms

Organism	Mercury concentration (ppt)
Dolphin	98,000
Phytoplankton	2,000
Seagrass	14,000
Shrimp	150,000
Squid	0.1
White bait (small fish)	700
Zooplankton	690,000

2. **Demonstrate** your understanding of the terms 'bioaccumulation' and 'biomagnification' by using both terms appropriately to propose an explanation for the levels of mercury found in dolphins.

Practical 8.2
Heavy metal pollution

Introduction

In general, chemicals containing heavy metal ions are poisonous and are a serious form of pollution around mines or industrial sites. This is why abandoned mines and mine waste piles have limited or no plant cover – the heavy metal ions prevent plants from growing. Plants that tolerate the pollution often grow poorly. These plants also absorb the heavy metal ions through their roots and concentrate the metals before passing them on to the animals that eat them.

Aim

To examine the effect of heavy metal ions on the germination of seeds.

Time required

60 minutes

Materials

- Petri dishes or other containers with lids, suitable for growing seeds
- 125 cress or mung bean seeds
- 10 mL copper(II) sulfate solution (0.1 mol/dm^3)
- distilled water
- test tubes in a rack
- 10 mL graduated cylinder
- 1 mL plastic syringe
- paper towel or blotting paper
- glass rod
- marker
- pen
- scissors
- safety glasses

Procedure

1. Cut circles of paper towel or blotting paper to fit the bases of six Petri dishes or containers. Label each dish with your name and the date. Number the dishes from 1 to 6.
2. Use the syringe to add 1 mL of the copper sulfate solution to a test tube. Use the 10 mL graduated cylinder to add 9 mL of distilled water. Mix the solution with a clean, dry glass rod and label the tube '1'.
3. Wash out the syringe with water and use it to take 1 mL of the mixture from tube 1 and put it into a clean test tube. Add 9 mL of distilled water, mix with a glass rod and label it tube 2.
4. Repeat step 3 until you have five solutions, each one with a 10th of the concentration of copper sulfate solution of the previous one (see Figure 8.8).

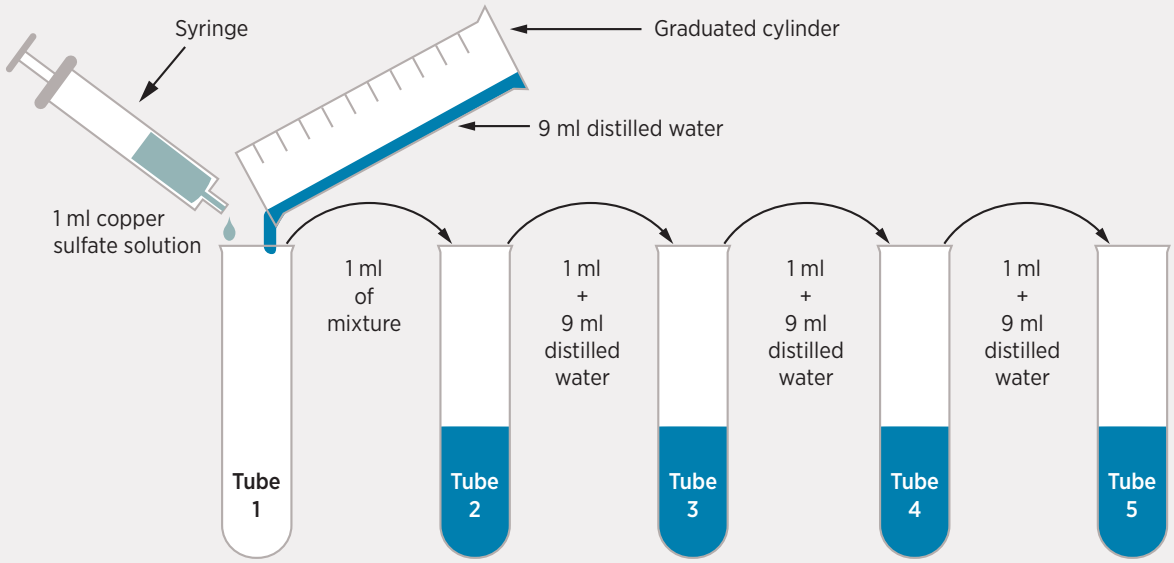


Figure 8.8. Making the series of copper sulfate solutions

continued next page

Practical 8.2 (continued)

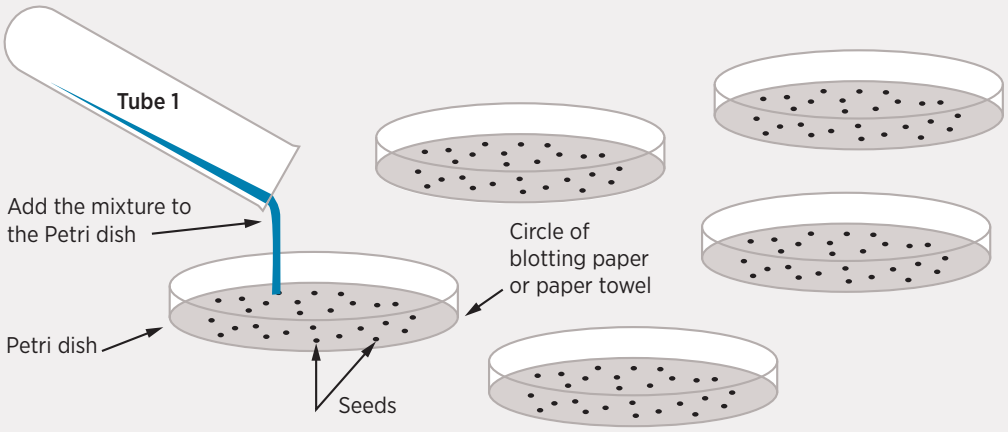


Figure 8.9. Seeds spread out in the Petri dishes

5. Pour the contents of tube 1 into dish 1. Repeat for all the other four tubes until you have five dishes each with a different concentration of copper sulfate solution.
6. Pour 10 mL of distilled water into dish 6.
7. Add 25 seeds to each dish. Spread them out across the paper base so that you can see each one easily (Figure 8.9).
8. Put the lids on the dishes and leave them for at least 48 hours in a dark place or until the seeds begin to germinate. You may need to add a small amount of distilled water to the seeds if they start to dry out. Always add the same amount of water to each dish to keep your experimental conditions constant between treatments.
9. Use the data table below to record the number of seeds that germinate at each concentration of copper sulfate solution every day for 5 days.

	Dish 1	Dish 2	Dish 3	Dish 4	Dish 5	Dish 6
Day 1*						
Day 2						
Day 3						
Day 4						
Day 5						

*Day seeds start to germinate

Analysis

1. Work out the percentage germination for each concentration of copper sulfate solution on day 2.
2. One researcher suggested that copper sulfate pollution delays germination in seeds while another said that it prevented germination completely. Use data from your experiment to decide who is right. Give reasons for your decision.
3. At what concentration does the effect of copper sulfate poisoning disappear?
4. How could you modify your experiment to look at how the pH of the soil affected the toxicity of the copper sulfate solution?

Critical thinking and discussion 8.2

1. **Define** and compare the terms 'bioaccumulation' and 'biomagnification'.
2. **Explain** why some chemicals persist while others degrade in the environment.
3. **Explain** why mercury is considered an extremely harmful heavy metal.
4. **List** the various compounds of mercury and describe the effects they have on human health.
5. Complete the following table to **list** the effects of mercury on humans and the environment.

Effects of mercury on humans	Effects of mercury on the environment

8.3. Environmental impacts of pollutants

The impacts of a range of pollutants on the health and survival of living things in the biosphere, including humans, and on the quality of the atmosphere, hydrosphere and lithosphere with reference to risk, exposure, dosage, tolerance limits, LD50, chronic and acute toxicity, allergies, disruption of system regulation and synergistic action

Scale of environmental impacts

The impact of pollution on the environment can be viewed at three levels:

- **local** – a small-scale impact affecting an area of a few square kilometres (for example, a chemical spill on a road, contamination of a block of land, odour from a factory)
- **regional** – a large yet distinct area of impact (for example, photochemical smog, soil salinity, acid rain)
- **global** – a global and international impact (for example, the greenhouse effect, ozone depletion, acid rain).

Human health and the environment

There is a growing understanding that human health is interlinked with the state and health of the environment. In some circumstances, pollution can be quantified and its impact easily measured, for example, carbon monoxide discharged into a closed environment where people are located. Some pollutants are not easy to quantify, or their impact may be hard to measure, for example, smoke from large bushfires.

Managing environmental health

Government, industry and the general public are increasingly aware of the impact of human activities, consumption patterns and settlement on the state of the environment. We are also beginning to recognise that disruptions to ecosystem functioning, such as that caused by environmental degradation, may lead to new hazards and diseases.

The Australian Department of Health defines environmental health as:

"those aspects of public health concerned with the factors, circumstances, and conditions in the environment or surroundings of humans that can exert an influence on health and well-being."

Furthermore, environmental hazards are defined as those environmental factors which threaten or impair human health in some way. Environmental hazards include contaminated water and food, chemical exposures, polluted air and soil and vector-borne diseases.

Identification of environmental hazards for humans involves establishing relationships between the environmental hazard and human illness. Studies that attempt to identify such causal relationships in a population are investigated in the medical field of epidemiology. Determining what causes an illness is not always easy. Causal relationships are particularly difficult to determine if multiple factors are involved. Illnesses may be caused by a specific environmental hazard and additional contributions from:

- environmental factors (for example, housing, climate)
- demographic factors (for example, socio-economic status)
- genetics
- other exposures (for example, smoking).

In Australia, environmental impacts on human health are generally under the jurisdiction of Australian and state departments of health, while the health of the environment is under the jurisdiction of Australian and state departments of the environment. Environment departments are responsible for ensuring a healthy environment, with the long-term goal of ecological sustainability.

Keeping the environment healthy, or improving the state of the environment, also reduces the risk to human health by removing environmental hazards. Managing environmental impacts on human health, as occurs in the health sector, involves assessing, correcting, controlling and preventing environmental elements that can adversely affect human health.

Student activity 8.1
Legionella in water systems

Legionnaires' disease is a sometimes fatal pneumonia-like illness caused by infection with *Legionella* bacteria. The bacteria are commonly found in fresh or brackish water, coastal waters and moist soil. The conditions in air-conditioning and water-cooling systems, especially when poorly managed, can encourage the bacteria to proliferate. *Legionella* outbreaks infect significant numbers of people and some people may die. Often buildings need to be closed while the bacteria are eradicated and the water-cooling system improved. These events, which can be very costly for the business responsible and the community, can be avoided through good management practices.

Questions

1. **Identify** the environmental hazard in this example.
2. **Explain** the ecological requirements for the survival of this environmental hazard?
3. **Suggest** how this environmental hazard comes into contact with humans.
4. Using the internet, **investigate** appropriate management strategies for this environmental hazard. Develop a brief report of recommendations for a business or industry to assess its environmental risk for this type of environmental hazard.

Student activity 8.2
Environmental hazards and human health connections

In small groups, use a concept map to describe and identify the connections between human health, health of the environment, environmental hazards and pollutants.

Exposure

A pollutant may take a variety of pathways through the environment, and humans may be exposed to a pollutant in a variety of ways. **Exposure** is a measure of how much of a pollutant a person is exposed to in a given amount of time.

Substances can be absorbed into the body in a variety of ways:

- **ingested** via food or drink, then absorbed from the digestive system into the liver or lymphatic system and then into the bloodstream
- **inhaled** via the lungs and then absorbed through the membrane surfaces into the bloodstream
- absorbed via the skin (**dermal absorption**).

Certain pollutants are more likely to be absorbed because of the length of time they stay in the environment, which increases exposure. A substance that does not break down easily is said to be persistent. In contrast, a degradable pollutant breaks down in the environment due to the action of sunlight, soil and water organisms, or reactions with other chemicals. One of the reasons insecticides, such as the organochlorines dieldrin and chlordane, and the heavy metal compound lead arsenate were used as pesticides was their lengthy persistence in the environment.

Some chemicals are excreted from the bloodstream, while others get stored in body tissue. If an absorbed substance is to be stored in the body, it usually binds to proteins or dissolves in fats.

Dosage

Exposure affects the **dosage** a person receives, which is the amount of a chemical absorbed per unit of body weight. Most chemicals, both natural and synthetic, have the potential to be hazardous to human health, but the level of harm depends on the dose. For example, table salt (sodium chloride) is poisonous in large doses (for example, a child eating a box of salt), but a small amount is essential for a healthy life. Long-term intake of salt may contribute to high blood pressure.

The dosage of chemical pollutant a person receives is affected by:

- respiration rate – breathing quickly can allow more of a chemical to be absorbed by the body
- concentration – exposure to higher concentrations of a chemical can cause larger amounts to be absorbed
- frequency of exposure – frequent exposure to a chemical can increase the amount of the substance absorbed
- length of exposure – the amount of time in the presence of a chemical will affect the amount absorbed
- properties of the chemical – some chemicals are more easily absorbed by the body than others
- body weight – a small person who ingests the same amount of a chemical as a larger person actually receives a much higher dose (that is, the concentration of the chemical is much higher in the body).

Toxicity

The effect of a certain dosage of a pollutant depends on how harmful the substance is. **Toxicity** is a measure of the harm (through illness or death) that a substance can cause in humans and other living things. **Acute toxicity** is the adverse health effect from a single dose of the toxic substance. **Chronic toxicity** refers to the adverse health effects of repeated exposure to the material over a relatively prolonged period (generally greater than 1 year).

The **threshold** is the level of chemical exposure below which there is no adverse effect and above which there is significant toxicological effect. The threshold of a pollutant is a key factor in determining its danger to human health. For certain individuals, allergies also play a role in determining the impact of exposure: these people become sensitised to a substance following exposure and then are likely to show increased effects and symptoms even if they receive a lower dosage than someone who is not sensitised.

Scientists use a wide variety of methods to measure and understand the toxicity of substances. It is not legally possible or desirable to test these substances on humans, but data is collected and analysed when humans and organisms are accidentally exposed to a pollutant. Data is also obtained by testing on animals under laboratory conditions. Lethal dose (LD) is the term used to describe the dose of a substance that is sufficient to kill a percentage (usually 50%) of the specified test animal within a set period of time. The smaller the LD50 dose, the more toxic a substance is.

LD50 values are obtained using laboratory animals and results vary widely, depending on the species, sex, diet, season, age and social conditions of the animals. In reporting lethal dose results, the species of animal and the method of administering the chemical are stated and the value is expressed in milligrams (mg) per kilogram of body weight for that animal. For example, 'Dermal LD80 (rabbit) – 37 mg/kg' tells us that the test animals were rabbits, the substance was administered through skin absorption and that the dose required to kill 80% of the population was 37 mg/kg of body weight.

It is important to remember that lethal dose figures refer to acute toxicity (that is, the short-term effects) and therefore do not give an indication of delayed effects, chronic sublethal effects or the cumulative effects of small doses over long periods of time. LD50 tests on animals can't simply be extrapolated to humans, but the results can indicate possible effects.

Emerging issues in health

There are emerging issues that are associated with new risks and hazards for society and the environment. Ozone depletion, genetically modified organisms and electromagnetic fields are examples of new potential hazards and risks.

Since the 1990s, the emerging health issues that have dominated society's attention have been those associated with chronic hazards. Chronic hazards are hazards whose impacts take a long time to materialise. It is generally hard to manage risks associated with chronic hazards as they are often the result of complex interactions involving a number of variables and require long-term monitoring.

Endocrine disruptors

Endocrine disruptors, or endocrine-disrupting chemicals (EDCs), are synthetic (human-made) or naturally occurring chemicals that affect the hormonal systems in animals. Hormones are chemicals that control the balance of normal functions in animals, including reproductive systems.

The first recognised EDC was diethylstilbestrol (DES), a synthetic pharmaceutical product given to pregnant women from 1948 to 1972 to help prevent miscarriages. Naturally occurring EDCs are collectively known as phytoestrogens and are found in soybeans, apples, cherries, wheat and peas.

Environmental endocrine disruptors are endocrine-modifying chemicals that are absorbed into the body from the environment, for example, environmental pollutants such as organochlorides. There is increasing evidence that some pollutants have affected the endocrine systems of certain fish and wildlife, resulting in developmental abnormalities and reproductive impairment. However, the relationship of human diseases of the endocrine system and exposure to EDCs is still poorly understood.

Endocrine-disrupting chemicals may affect the activity of the sex hormones oestrogen and androgen, as well as other hormones such as the thyroid hormones. EDCs generally operate in one of two ways: mimicking a hormone or blocking the activities of a hormone. If the EDC mimics the naturally occurring hormone in the organism, it fools the body into over-responding to the stimulus or responding at inappropriate times. If the EDC acts as a blocker, it may block the effects of a hormone in parts of the body normally sensitive to it. Other EDCs may act by directly stimulating or inhibiting the endocrine system, causing overproduction or underproduction of hormones.

Student activity 8.3
Endocrine disruptors

Using biology textbooks and the internet, research the following information.

1. **Define** 'hormones'.
2. **Explain** what the endocrine system is and what types of organisms have an endocrine system.
3. **Describe** the function of the endocrine system.
4. **Explain** how endocrine-disrupting chemicals affect the endocrine system.
5. **Identify** the stages of development that are most at risk to exposure to endocrine-disrupting chemicals.
6. **Suggest** how endocrine-disrupting chemicals would affect the health of the environment.

Arsenic

Large doses of arsenic and inorganic arsenic compounds can cause death. These substances are highly toxic and are known as carcinogens (cancer-causing substances). Some arsenic compounds are also teratogens; that is, they harm the development of a fetus. Lower levels of exposure may cause nausea, vomiting, diarrhoea, abnormal heart rhythm, damage to blood vessels, decreased production of blood cells and a feeling of pins and needles in the hands and feet. Long-term exposure through contaminated water supplies (many arsenic compounds are water-soluble) has led to stomach disorders, anaemia, skin lesions, and liver and kidney damage. Figure 8.10 provides an overview of arsenic pathways in the environment.

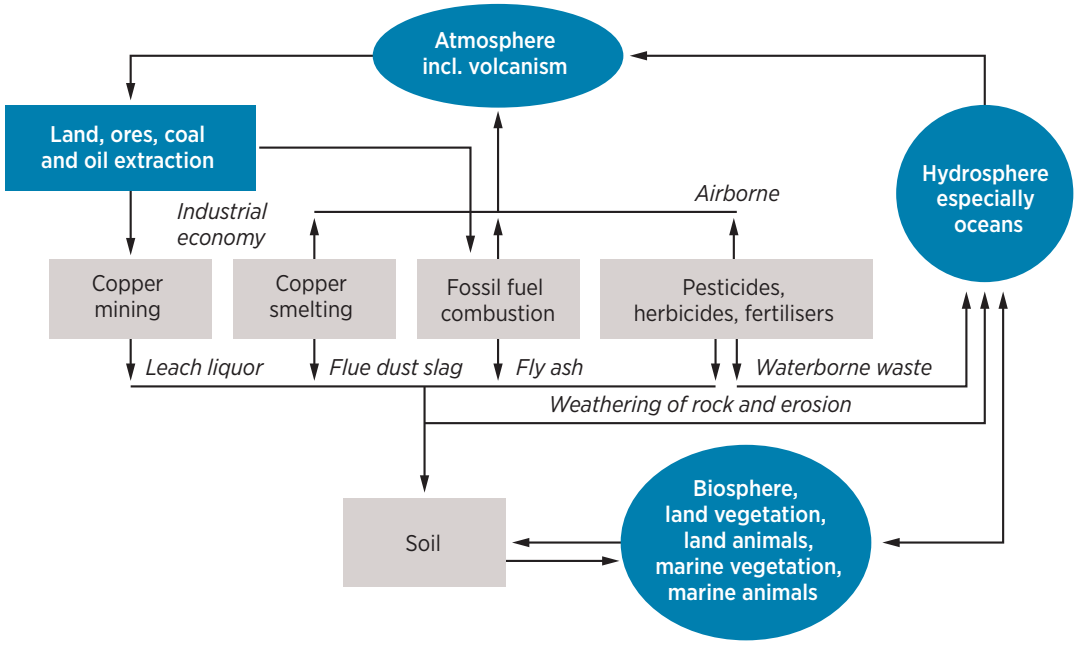


Figure 8.10. Arsenic pathways in the environment

Soil contamination and pollutant transport

The environmental effects of a pollutant will vary from one location to another. In the case of a contaminant entering the soil, the type of soil and ecosystem characteristics will affect its impact. Plant and animal species, hydrogeological conditions and land use all need to be considered when assessing the environmental effects of a contaminant. Figure 8.11 shows where and how soil contamination can affect the environment.

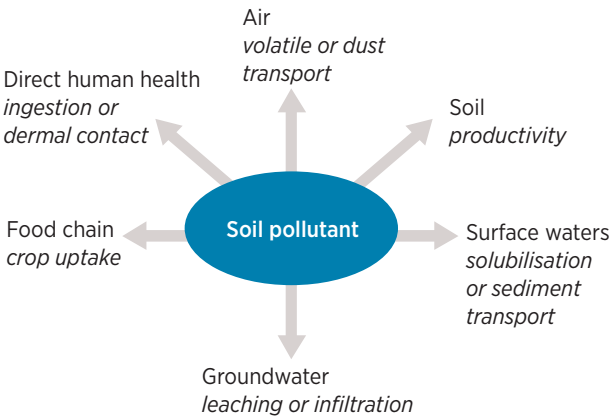


Figure 8.11. Potential impacts from soil contamination

CHAPTER

9

Monitoring pollution

9.1. Environmental indicators

The contributions of scientific data, new technologies, regulatory frameworks and diverse stakeholder values and priorities when managing pollution

Community concern about environmental quality is growing, and the community is demanding that activities affecting water, air, soil and plant and animal life are managed appropriately. More accountability than ever before is expected from those responsible for using and conserving natural resources (including management agencies, industry and individuals). Many countries now have government policies and legislation to protect environmental qualities. These protection policies require environmental monitoring so that we can detect whether environmental qualities are improving, staying the same or declining.

The environment is complex, so determining trends can be difficult. It would be very costly and time-consuming to assess the condition of a particular environment by measuring every variable, and in many cases, we do not yet have the knowledge or tools to do this. It is important, therefore, to identify the key scientific measurements that will help us track environmental change.

Key factors, called **environmental indicators** are identified and measured as a way of assessing the overall condition of an environment. Selecting appropriate environmental indicators lets us assess the effects of human activities, including management responses, on the environment without having to measure every variable. When used appropriately, environmental indicators accurately summarise and communicate key aspects of the functioning of complex environments.

Typical indicators

Environmental indicators are physical, chemical, biological and socio-economic measures that best assess the key elements of a complex system or environmental issue. They can be used to assess components of natural resources and parts of environmental quality.

- A **physical** environmental indicator measures a physical feature of the environment, such as the amount of sunlight reaching the forest floor.

- A **chemical** environmental indicator measures a chemical factor affecting the environment, such as the amount of carbon monoxide gas in the air.
- A **biological** environmental indicator measures a biological component of the environment, such as the number of a certain plant species in a given area.
- A **socio-economic** environmental indicator measures attributes relating to people and society, such as health and wellbeing, employment, government actions such as the setting of environmental regulations, or cost of regeneration projects.

Good environmental indicators reflect an understanding of the links between human activity and its consequence. For example, exhaust from cars decreases air quality in cities, and clearing native vegetation reduces biodiversity.

If the cause and effect are well understood, indicators can be used as an early-warning signal to detect dysfunction in a system. An increase in ozone-depleting gases in the stratosphere provides a warning signal for increased levels of ultraviolet light reaching Earth's surface, the consequences of which are known to be detrimental.

Environmental indicators are commonly used as part of a rehabilitation or restoration monitoring program for environmental problems that are already well advanced, for example salinity.

Indicators used to monitor the environment may be collected via field observation, field sampling, remote sensing or from existing data. Environmental indicators are also useful communication tools, as they can focus and condense the information about complex environments for management, monitoring and reporting uses.

Environmental indicators for air quality

Air quality is determined by the chemical composition of the atmosphere. It affects human health, plant and animal health, ecological systems and aesthetic values. Pollution impacts on the atmosphere come from specific pollutants (for example, lead) and complex combinations of pollutants that produce a secondary pollutant (for example, stratospheric ozone and offensive odours).

Environmental indicators of atmospheric pollution typically concentrate on pollutants that affect the health of people or ecosystems, or damage materials (for example, buildings). Victoria's State Environment Protection Policy for air quality includes carbon monoxide, photochemical oxidants, particles, nitrogen dioxide, sulfur dioxide and lead in its list of Class 1 (common) indicators of air quality.

A good indicator of the health of the upper atmosphere is the concentration of ozone-depleting substances. We know that an increase in the concentration of ozone-depleting substances is harmful to the stratospheric ozone layer. Furthermore, a decrease in concentration shows that efforts to protect the ozone layer are succeeding. We do not need to understand the complex chemistry of stratospheric ozone depletion to measure this indicator, but this understanding helps us recognise the problem and develop effective policy and management strategies to reduce ozone depletion.

Concepts relating to environmental indicators

Ecological niche

A habitat is like the 'address' of an organism – it is the place where it is normally found. The organism's 'occupation' or 'profession' is its **ecological niche** – the description of its structural and functional role in an ecosystem. An organism's niche describes what it does in its habitat, for example:

- Is it a producer, herbivore or carnivore?
- What links does it occupy in the food chain?
- How does it fit in the biogeochemical cycles?

Species that occupy broad ecological niches and feed on many kinds of food are known as **generalists**. Other organisms, which have very specialised ecological niches and feed only on one or very few types of food, are known as **specialists**.

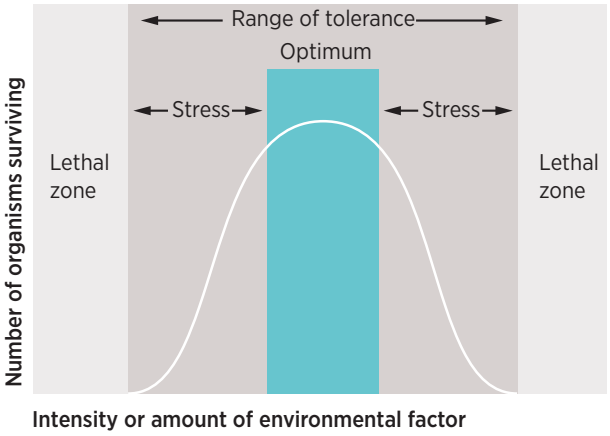


Figure 9.1. Range of tolerance for individuals of a particular species to a limiting environmental factor

The survival of an organism depends on its habitat being in good condition. The health and numbers of this population will be adversely affected if the physical, chemical or biological conditions of its habitat become degraded. If that particular habitat continues to degrade substantially, a species can become rare and ultimately endangered or even extinct.

Range of tolerance

Organisms can live, grow and function normally within a limited range of chemical and physical conditions. The tolerance limit is the point at which a chemical or physical condition becomes harmful to an organism. Every species can survive only within a given range of conditions, but individuals within a population will vary in their tolerance (Figure 9.1).

Species differ in their ranges of tolerance. For example, aquatic **macroinvertebrate** species differ in their ranges of tolerance of environmental pollutants (see 'Aquatic macroinvertebrates', p 165). Stonefly nymphs only survive in streams with very good water quality, while a segmented worm can survive in lower quality water. Therefore, the presence of stonefly nymphs indicates that the water quality of the stream is high. In contrast, the water is likely to be polluted if only segmented worms occur.

Only a few species can tolerate extremes of environmental conditions, such as very hot or very cold temperatures (Figure 9.2).

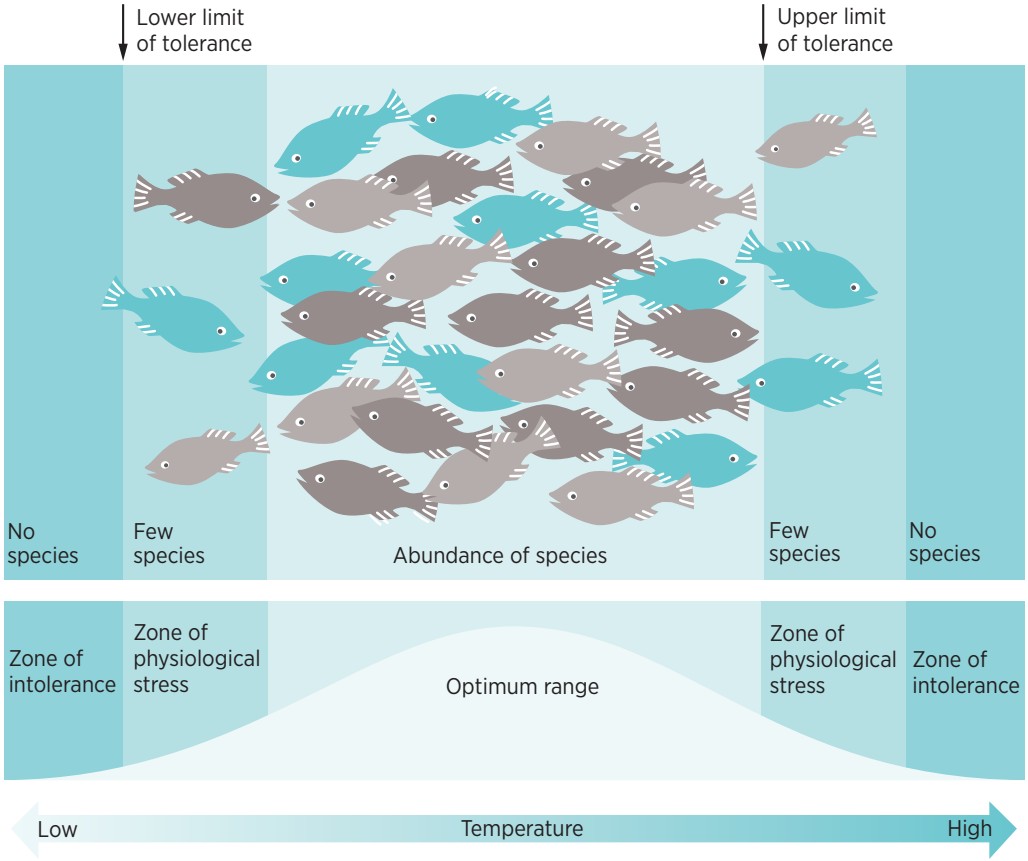


Figure 9.2. Range of tolerance for different species to an environmental factor (temperature)

Threshold

A **threshold** is the point at which a level (or concentration) is reached at which an effect is observed. Many changes in pollution levels and in the landscape occur so slowly that organisms tolerate them until a threshold is crossed and a response is triggered. Threshold levels for organisms vary widely depending on the pollutant, the type of organism, the environment concerned and the stage in the organism's life cycle. Generally, the developmental stage of an organism is most susceptible to pollutants.

A **threshold pollutant** is a substance that is harmful to a particular organism once it reaches a certain concentration, or threshold level. Examples of threshold pollutants include DDT and mercury. The threshold effect helps explain why some pollution and environmental problems seem to have appeared suddenly. Some harmful effects of pollutants may not show up for many years, making it difficult to determine which chemicals are pollutants.

Environmental standards

An important aspect of using an environmental indicator is knowing how to use the measurements to determine whether or not the environment is healthy. Scientists have determined targets, or standards, for many environmental indicators to identify these healthy levels. You can make a scientific judgement about the condition of the environment by comparing measurements of the environmental indicator against this predetermined standard or a known background level or baseline.

The standards for physiological, ecological or environmental conditions might be the acceptable maximum or minimum levels, or a defined range or limit. They may be determined by:

- historic levels of an indicator (levels before human disturbance)
- desired levels (set by a government agency or a monitoring group)
- potential levels and threshold levels (set by known biophysical constraints or from research or measurement data), for example, setting salinity standards for water quality after determining an organism's threshold level.

When standards have been set, monitoring is carried out to measure a given factor to see if it meets the agreed level or standard or to measure the amount of change (if any) from an expected level or standard.

The next two sections contain information on a selection of environmental indicators and standards of pollution and ecosystem health. Many of these examples are from fresh water aquatic ecosystems and can be used to monitor or study a nearby pond, wetland, creek or river.

9.2. Physical and chemical environmental indicators of water quality

Turbidity

Turbidity is a measure of fine particles suspended in the water column. These particles often give water a cloudy appearance. The term is used to describe the quantity of solid material suspended in water arising from, for example, soil erosion and waste discharges. The level of turbidity in a water body is important because it influences the penetration of sunlight. Suspended solids reduce light penetration and so reduce the amount of photosynthesis by aquatic plants and photosynthetic algae and bacteria. Turbidity can affect animals in other ways too. For example, organisms that rely on their sight for finding food may find it more difficult in turbid conditions. In general, higher turbidity is associated with a lower diversity of aquatic organisms.

Turbidity has been identified as one of the major water quality problems in Australia. The Victorian Environment Protection Authority includes turbidity levels as one of its environmental measures. Higher-than-normal levels of turbidity may indicate soil erosion in the catchment. Soil erosion is a particular concern after heavy rain or where there is little or no vegetation cover.

Turbidity is normally measured in NTUs (nephelometric turbidity units) using a nephelometer or by using simpler field-monitoring equipment such as a Secchi disc or turbidity tube.

Table 9.1. Turbidity levels of the Yarra River upstream and downstream of Diamond Creek

	Urban tributaries	Yarra upstream of Diamond Creek	Yarra downstream of Diamond Creek
50th percentile	25	20	30
90th percentile	80	50	80

Turbidity varies naturally between water bodies. Turbidity also varies naturally over time, for example, increasing after heavy rain. Many Australian waterways have naturally high turbidity levels to which many native fish have adapted. The varying natural turbidity levels must be taken into account when using turbidity as an environmental indicator (see Table 9.1).

Light intensity

Light intensity is a measure of the amount of sunlight reaching a surface. Light intensity can be used as an environmental indicator because a decrease in light intensity may reduce the rate of photosynthesis by marine or fresh water plants, reducing their growth and potentially also affecting the animals that feed and hide among them. Light intensity can be measured by a datalogger probe, a light probe or a Secchi disc lowered through the water from the surface to any depth.

Light intensity is often linked to turbidity levels in aquatic ecosystems. Light intensity can also be measured in terrestrial ecosystems to indicate the levels of sunlight entering different 'layers' of the community.

PH

pH directly and indirectly affects biological processes, the rates of chemical reactions and the toxicity of substances. The pH scale is a measure of the acidity or basicity (alkalinity) of water or soil, and ranges between 1 and 14. On the pH scale, 7 is neutral, below 7 is acidic and above 7 is basic (also called alkaline).

As pH is measured on a logarithmic scale, a single unit of change in pH indicates a tenfold change in the environment being measured. Any change of more than 0.5 pH units from the natural seasonal maximum and minimum should be investigated.

The pH of fresh water is usually in the range of 6.5 to 8.2, though wider variations can occur; for example, limestone areas produce more alkaline conditions. Relatively few species can survive in conditions of very high or very low pH values (see Table 9.2).

Table 9.2. pH tolerance of fresh water organisms

Organism	pH tolerance
Bacteria	1.0 to 13.0
Algae	6.5 to 12.0
Carp, cod	6.0 to 9.0
Aquatic snails	7.0 to 9.0
Greatest species diversity	6.5 to 7.5

Soil pH can be used to monitor a range of degradation processes, such as soil acidification, salinity, acid sulfate conditions, alkaline soil conditions, and relationships with soil organisms and plant root diseases. Since soil pH provides information on soil fertility, nutrient availability and biological condition, it can be used by land managers, including farmers, to monitor conditions that could adversely affect farm productivity.

Some plants have high tolerance ranges for pH. Native plants that grow in heathland areas of Victoria flourish in the usually acidic sandy soils in which they grow, whereas a crop of wheat planted into this acidic soil would not survive.

Dissolved oxygen

Oxygen is one of the essential requirements for life in water. Both plants and animals require this element for survival. The level of dissolved oxygen (DO) will vary with:

- water temperature
- salt content
- microorganism abundance
- exposed area of surface water
- turbidity level
- biomass of photosynthetic organisms.

Fresh water with a DO reading of 5 ppm or greater can support a wide variety of organisms. Dissolved oxygen levels between 1 ppm and 5 ppm are sufficient for some living things, but not for most fish. Readings less than 1 ppm indicate there is probably no life in the water.

The release of organic waste into a water body can severely reduce the level of DO. Aerobic bacteria break down these wastes, consuming large quantities of oxygen in the process. Thus, large amounts of sewage or agricultural run-off flowing into a water body can cause the bacterial population to flourish and oxygen to be consumed.

Dissolved oxygen levels in a water body can vary considerably between day and night due to plants photosynthesising during the day and producing oxygen. Monitoring of DO therefore needs to take these diurnal changes into account, either by measuring DO over a diurnal cycle or by measuring at the same time each day.

Biological oxygen demand

The biological oxygen demand (BOD) of water is related to the amount of organic material, such as waste, in the water. Waste produced by plants or animals is broken down by bacteria, which need oxygen for that process, as we saw above. The release of domestic and industrial waste into a water body will increase the activity of the bacteria that break down organic material and increase the BOD of the water. In that way, BOD is an indicator of water cleanliness.

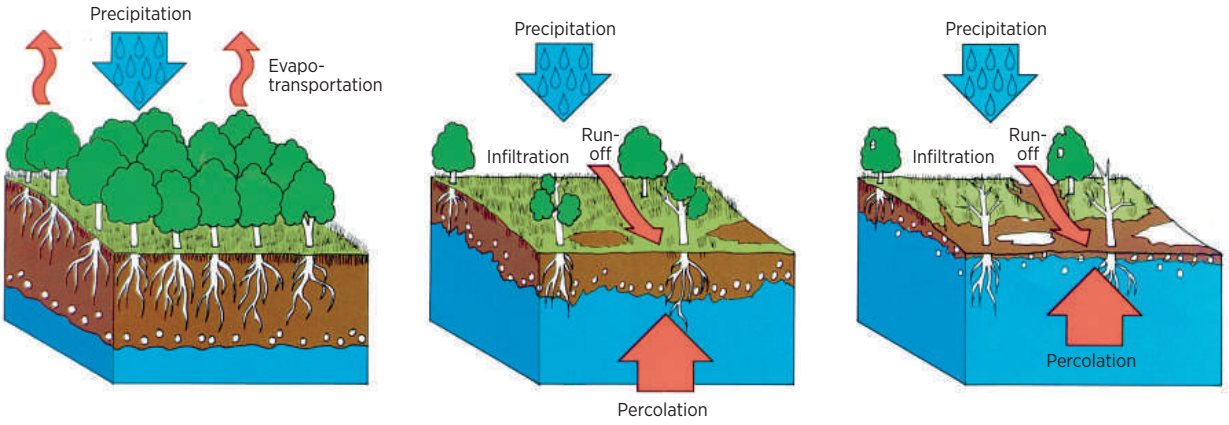
A BOD below 1 ppm indicates extremely clean water, such as that found in pristine river headwaters. A BOD reading of 2 ppm or more indicates that organic pollution of the water is occurring, as the water contains a sufficient level of organic material and organisms feeding on it to lower the amount of dissolved oxygen present.

Salinity

Conductivity measures the amount of inorganic salt materials dissolved in a soil or water sample. Sodium and chlorine are the most common salts, followed by calcium, bicarbonate and other ions. A conductivity probe placed into water, or a soil suspension, measures the flow of electricity between its electrodes. The greater the salt concentration, the higher the conductivity. Salinity can also be measured by evaporating a given amount of the water and weighing the remaining salt. Salinity is measured in micro-siemen units per centimetre (µS/cm) electrical conductivity (EC) or total dissolved salts.

For water to be of an excellent standard for humans to drink, it should have an electrical conductivity reading lower than 800 µS/cm EC.

Many species of plants and animals only survive within certain salinity ranges, so a change in salinity changes the types and relative numbers of species found in an area. Land clearing for agriculture and the irrigation over large areas has caused the water table to rise. In many areas the water table is naturally saline, so as the groundwater rises and flows into streams, it causes the soil and streams to become saline. Salinity that has occurred or increased due to human activity is known as **secondary salinity** (Figure 9.3). Natural salinity, or **primary salinity**, is also common across Victoria and Australia in salt pans, such as Lake Eyre.



Before clearing
Most water is used where it falls. The system is in balance.

After clearing
Saline groundwater rises and is concentrated at the surface by evaporation. Vegetation growth is affected.

Later
Accumulation of salt at the surface kills protective plant cover. The land is open to erosion.

Figure 9.3. Secondary salinity after land clearing

Student activity 9.1
Water quality requirements of different species

Table 9.3 gives upper salinity limits for a range of water uses. Look at the data and answer the following questions.

1. Do all plants and animals require the same level of water quality with regard to salinity levels?
2. What does this suggest to you in specifying standards for different uses?
3. Which species can survive on water with high salinity levels?
4. Which species cannot tolerate high levels of salinity, that is, 1,700 µS/cm EC or higher?

Table 9.3. Upper salinity limits for some water uses

Domestic use	µS/cm EC
Industry	1,667
Paper	250
Petroleum	583
Carbonated beverages	1,417
Irrigation use	
Tobacco	83
Citrus, legumes, garden plants	1,667
Vines, grass, cabbages	2,500
Lucerne, cotton	4,167
Livestock use	
Poultry	5,833
Pigs	7,500
Horses	10,833
Milking cows and ewes	11,667
Beef cattle	18,333
Dry sheep (sheep not feeding lambs)	25,000

Source: Department of Industry, Technology and Resources, 1987, Groundwater Victoria, Melbourne: State of Victoria.

Nutrients: phosphorus and nitrogen

Organisms need phosphorus and nitrogen for their metabolism and growth (see 'Phosphorus cycle', p 37, and 'Nitrogen cycle', p 35). Human activities contribute to increased phosphorus (in the form of phosphates) and nitrogen (in the form of nitrates) levels through the release of domestic and industrial sewage, detergents and fertilisers.

The excess of these nutrients, known as **eutrophication**, can cause a rapid increase in the growth of phytoplankton (algae) and water plants. The increase in algae stimulates an increase in the number of organisms that feed on it, increasing the biological oxygen demand. Consequently, during the night (when photosynthesis does not occur) the oxygen level may be severely depleted, causing many organisms to die. The decomposers quickly break down the remains, resulting in the release of more nutrients to boost the algal bloom. Once the threshold level is reached, the algal bloom suddenly appears. In the extreme, this may result in the water body becoming stagnant and the ecological balance being destroyed.

Because high levels of phosphates or nitrates are useful indicators of possible eutrophication, they are often included in water quality monitoring programs.

Practical 9.1
Presence of phosphate

Aim

To investigate water samples for the presence or absence of phosphate (PO_4).

Materials

- 4 test tubes
- test tube rack
- concentrated nitric acid (HNO_3)
- ammonium molybdate solution
- droppers

CAUTION: Take great care and wear protective equipment for your clothes and eyes when handling concentrated nitric acid. Never add water to acid as this may cause the corrosive liquid to splash up and cause injury. Always add the drops of acid carefully to the water.

Procedure

1. Collect four water samples from your creek or water body. Place the samples in clean jars and label them 1 to 4.
2. Add 5 mL of sample 1 to a test tube.
3. Add 10 drops of concentrated nitric acid (HNO_3) to the test tube and swirl carefully.
4. Add 10 mL of ammonium molybdate solution.
5. Note any colour change that takes place and record the results. A bright yellow precipitate indicates that phosphates are present in the water.
6. Repeat steps 2–5 for the remaining water samples.

Results

Complete a table like the one below with your results.

Water sample	1	2	3	4
Colour change				

Discussion

1. What are your findings for each of the samples based on this information?
2. Which sample had the highest concentration of phosphate?
3. This simple test only indicates the presence or absence of phosphate in a sample.

   Why would more sensitive tests be required to indicate the exact concentration of phosphate in a water sample? Who would use such a test?
4. If a very high concentration of phosphate was found in a water body, what would happen to the biological oxygen demand in the short term? What effect would this have on the dissolved oxygen level in the long term?
5. After periods of heavy rainfall, would you expect the phosphate level of a local creek to be higher or lower than usual? Explain your answer.
6. If no phosphate was detected in a water body, what types of aquatic flora and fauna would you expect to find living in the water? Explain.

Temperature

The temperature of a water body is affected by the depth of the water, flow rate, the surrounding vegetation cover, the time of day and season, and turbidity. Turbidity affects water temperature because suspended soil particles absorb heat from the sun, heating the water temperature in the top of the water column. Lower in the water column, where light is not able to penetrate, the water temperature decreases. This is known as thermal stratification.

Human-induced activites that influence the water temperature of streams and lakes include:

- discharging cold water from reservoirs
- clearing vegetation that shades the water body, which raises temperature
- allowing run-off from bitumen and concrete areas (urban roads, footpaths and car parks), which can be warm and raise temperature
- discharging warm industrial waste water (some industries use water as a coolant and then return the warmed water into the system)
- increasing soil erosion by clearing land or from road and building construction, leading to increased turbidity and warming.

Higher temperatures reduce the concentration of dissolved oxygen in water. The temperature also influences the rate of photosynthesis: as temperatures increase, photosynthesis speeds up and plants grow faster. When these plants die, decomposers consume them and use up oxygen, so an increase in photosynthesis increases the demand for oxygen by other aquatic organisms.

Water temperature affects the abundance and type of organisms found in a water body. Most organisms have an optimum tolerance range, outside which they cannot survive. Even though the temperature may be acceptable for most of the year, a short period of high temperatures can make a water body unsuitable for temperature-sensitive species. Some species have different temperature ranges at different stages of their life cycle. For example, fish larvae tolerate a narrower range of temperature than do adult fish.

Practical 9.2 Temperature

Aim

To measure the temperature of a stream at various depths.

Equipment

- thermometer or datalogger probe

Procedure

Depending on the depth of the stream, different methods may be required. Thermometers may need to be attached to a weighted string so that they can be lowered to various depths.

Results

Record the stream type and location details in your logbook. Copy the results table below and record your temperature measurements.

Depth	Temperature of the water
Surface of water	
Middle level	
Close to the stream bed	

Discussion

1. **Explain** why the water temperature should be measured at different depths.
2. **Explain** what your results indicate about the health of the stream.

Student activity 9.2
Water quality rating and river health

1. Refer to the information in Table 9.4 to determine the health of the river for which test results are reported in Table 9.5. For each test result, determine if the water quality is excellent, good, fair, poor or very poor. Then describe your overall interpretation of the health of the river at the given location.
2. Justify why these tests provide suitable data for indicating the environmental health of a stream.
3. Explain why different water quality rating guideline figures are given for conductivity and turbidity in mountain, valley and plain locations within a catchment.
4. Suggest other suitable data for measuring the environmental health of a stream.
5. Describe possible human activities that could be affecting the health of the river, and suggest ways human impacts could be reduced.

Table 9.4. Example water quality rating guidelines for water quality tests

Test	Excellent	Good	Fair	Poor	Degraded
Conductivity (µS/cm)					
mountain	<30	<90	<150	<225	>225
valley	<80	<240	<400	<600	>600
plain	<100	<250	<500	<750	>750
Turbidity (NTU)					
mountain	<5.0	<7.5	<10	<12.5	>12.5
valley	<10	<12.5	<15	<22.5	>22.5
plain	<15	<17.5	<20	<30	>30
pH (units)	6 to 7.5	5.5 to 6 or <8	8 to 8.5	5 to 5.5 or 8.5 to 9	<5 or >9
Reactive phosphorus (mg/L)	<0.008	<0.02	<0.04	<0.08	>0.08
Total phosphorus (mg/L)	<0.01	<0.025	<0.05	<0.1	>0.1
Nitrates (mg/L)	<0.05	<0.1	<0.2	<0.4	>0.4

Table 9.5. Water quality readings taken in the upper catchment of a river

Conductivity (µS/cm)	30
Turbidity (NTU)	10
pH	5.7
Reactive phosphorus (mg/L)	0.05
Total phosphorus (mg/L)	0.1

9.3. Biological indicators of catchment health

The presence or absence of particular kinds of organisms provides an indication of environmental conditions, so plants, animals and microbes are sometimes used as biological indicators.

Biologists sometimes use plants as indicators of water and soil conditions. For example, the presence of salt-tolerant species, or the absence of salt-sensitive species, indicates that the soil has relatively high salt levels. The presence of species tolerant of waterlogged soils (such as sedges or rushes) indicates that the soil is sometimes waterlogged. Different species of fish may occur in different depths according to their temperature tolerance.

Species with narrow or specific tolerance ranges are more reliable indicators than organisms with wide tolerances. Observations and measurements of changes in the number and types of species present in a given environment can indicate changes in the functioning and condition of that environmental system.

Changes in the health of a catchment will affect the aquatic biological community in its waterways. Catchment health can therefore be assessed by investigating the organisms that live in its waterways.

Stressed aquatic systems often show:

- reduced diversity, especially the loss of sensitive groups and species
- an abundance of pollution-tolerant groups and species.

Bacteria

The bacterium *Escherichia coli* (*E. coli*) inhabits the intestines of humans and other warm-blooded animals. Each day, billions of these bacteria are excreted from every human body. Most strains of *E. coli* do not cause serious disease or illness in people, but *E. coli* is a readily measured indicator of faecal contamination and the likelihood that other pathogenic organisms are present.

Many pathogens (for example, the bacteria that cause typhoid and cholera and the virus that causes hepatitis A) can be transmitted through contaminated water and are linked with faecal contamination. Pathogens are difficult to detect, but *E. coli* is not.

Water run-off, sewer and septic overflows and leaks, domestic and stock animals, and wastes dumped into waterways and bays are all potential sources of contaminants. Contamination of waterways or beaches is most likely after heavy rain and storms due to contaminants being flushed into creeks and drains. Table 9.6 lists the *E. coli* standards used by the EPA for water-based recreation in fresh water.

Table 9.6. Indicators for water-based recreation in fresh water

Trigger	Number of *E. coli* organisms per 100 mL water
Single sample	≤550
Consecutive sample	≤260

Source: State Environment Protection Policy (Waters)

Frogs

Frogs are very sensitive to environmental change because they have permeable skin through which pollutants in their immediate environment can enter their body. Frogs are relatively easy to monitor because they can be identified by their distinctive calls. Commercial recordings of frog calls are available with which to make comparisons.

Fish

The presence of native fish can be used as an ecological indicator of environmental quality. Fish are relatively easy to identify and relatively long-lived, which makes them useful as biological indicator species. However, fish are highly mobile so they can avoid poor environmental conditions by swimming away. Our limited knowledge of native fish biology means that water quality tolerances are not yet known for most Australian fish.

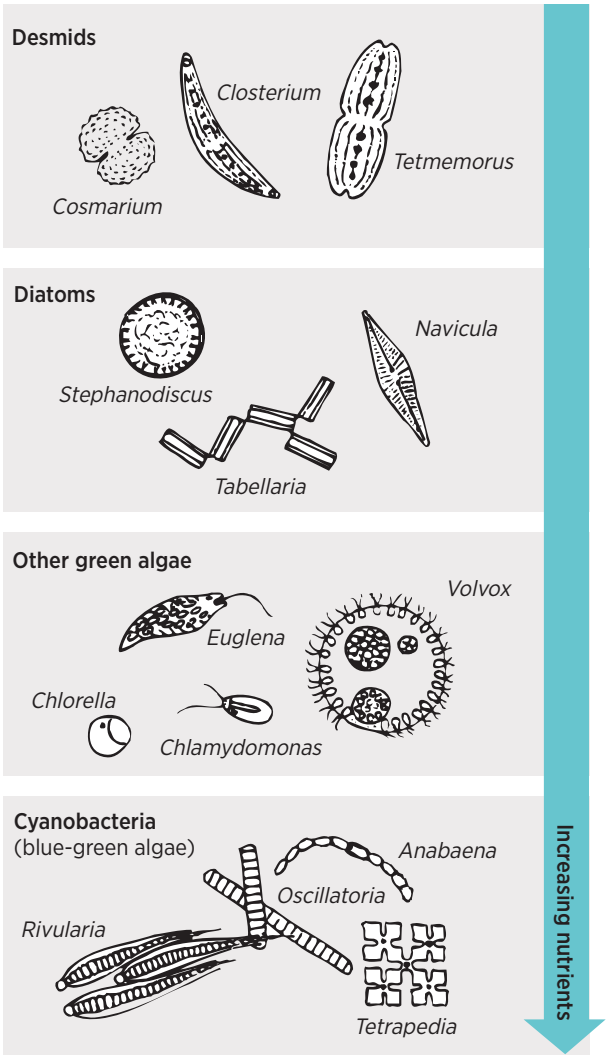


Figure 9.4. Distribution of phytoplankton species

Algae

Phytoplankton (algae) are an indicator of the nutrient levels of a water body. Desmids live in water bodies that are low in nutrients. Diatoms replace desmids as the nutrient levels in the water increase. At higher nutrient levels, green algae and then blue-green algae (cyanobacteria) become the most abundant (see Figure 9.4).

Eutrophication and toxic blue-green algal blooms are a natural feature of Australian water bodies in summer because of the natural decrease in flow rate and increase in water temperature. In recent times, the frequency of algal blooms has increased due to higher nutrient levels in streams (caused by the discharge of industrial and sewage effluent and run-off from agricultural land) and decreased river flows (because of water diversions for dams and irrigation) (see 'Nutrients: phosphorus and nitrogen', p 160). In the extreme, eutrophication may result in the water body becoming stagnant and the ecological balance being destroyed.

Aquatic macroinvertebrates

Aquatic macroinvertebrates used in water quality monitoring programs include worms, nematodes and the larvae of dragonflies, damselflies, mayflies, stoneflies, bugs, beetles and true flies.

Aquatic macroinvertebrates are a very important part of aquatic environments. They make useful environmental indicators because they:

- consist of many widespread groups
- are small and relatively easy to find in a waterway (compared to fish and frogs)
- can be identified to a meaningful level
- live in water for long periods of their lives
- are important in food chains as consumers, including as top predators
- are food for many larger animals, such as frogs, fish and birds
- are sensitive to quite mild pollutants or changes in water quality
- exhibit predictable and easily detectable responses to changes in water conditions.

Measuring the presence and absence of aquatic macroinvertebrate species is a good way to measure the quality of the water and the environmental health of the stream. Macroinvertebrate sampling complements sampling physical and chemical indicators because it detects the presence of most environmental stresses, giving a general indication of the types of pollutants present.

Macroinvertebrates have a lifespan of up to a year and lack mobility, so they are also useful indicators of intermittent pollution. For example, an influx of a toxic waste into a stream may have an impact on diversity and numbers of the macroinvertebrate community that remains evident for several months. In contrast, physical and chemical indicators usually relate to only one variable in the environment

(for example, pH or soluble phosphate levels), and they may not be detected unless they are measured at the specific moment that the chemical enters the ecosystem or the physical condition occurs.

Appropriate biological indicators need to be selected for specific geographic regions. In southern Australia, the presence of stonefly nymphs can indicate high water quality. Stoneflies are mainly cool-region organisms that do not tolerate large increases in water temperature, so the absence of stoneflies in tropical Australian waters is not due to pollution.

CASE STUDY 9.1
Macroinvertebrates as indicators of water pollution

SIGNAL is an index of water pollution developed for eastern Australia. Short for 'stream invertebrate grade number – average level', SIGNAL is based on the tolerance or intolerance of aquatic biota to pollution. Pollution sensitivity grades (1 to 10) have been assigned to common families of aquatic macroinvertebrates found in eastern Australian rivers (Table 9.7).

Table 9.7. Pollution sensitivity of selected macroinvertebrates

Family	Pollution sensitivity grade
Austroperlidae (stoneflies)	10 (very sensitive to pollution)
Leptophlebiidae (mayflies)	8 (sensitive to pollution)
Gomphidae (dragonflies)	5 (moderate)
Janiridae (water slaters)	3 (tolerant of pollution)
Chironomidae (bloodworms)	1 (very tolerant of pollution)

The SIGNAL score is calculated by combining the grades for pollution sensitivity for all the aquatic macroinvertebrate taxa present at the site with ratings for the numbers of each taxon that are present. SIGNAL2, a simpler version, has been developed to allow community groups with limited resources to identify macroinvertebrates to higher taxonomic levels (order, class and phylum).

The SIGNAL2 score for the site can be compared with the objectives for biological indicators for the particular habitat and region as outlined in the State Environment Protection Policy (Waters).

Pollution-tolerant and pollution-sensitive species

Species that live only in unpolluted conditions and species able to survive in polluted conditions can both act as indicator species (Table 9.8). The Victorian EPA uses the presence of key families of aquatic macroinvertebrates as an ecological indicator of the health of aquatic ecosystems. The State Environment Protection Policy for waterways provides a table listing the key families that should be found in different segments of the Yarra River. This list includes stoneflies, mayflies, dragonflies, true flies, caddisflies, beetles, amphipods, shrimps and snails.

Table 9.8. Pollution indicator species

Indicator species	Change in population	Indicator of environmental health
Lichen	Decrease	Air pollution has increased
Stonefly nymphs	Decrease	Water temperature may have increased
Mayflies with protected gills	Increase	Sediment levels may have increased
Caddisflies (filter feeders)	Increase	Sediment levels may have increased
Bloodworms	Increase	Dissolved oxygen levels may have decreased

Soil biota

Soil biota are the plants, animals and microbes that live in the soil. They are sensitive to changes in soil conditions and so are used as indicators of soil health. For example, the presence of an acid-tolerant species of earthworm could indicate a decline in soil pH as healthy soil generally has a pH that is close to neutral.

Nematodes are good indicators of soil health because they:

- are small and widespread (so are easy to sample)
- have a short lifespan and reach their reproductive stage quickly (so respond quickly to changes in food supply)
- have an important position in the detritus food web (so changes in their numbers are likely to affect other soil organisms)
- have relatively stable populations (so any change in nematode population is likely to indicate environmental disturbance)
- have a permeable skin (so respond to pollutants)
- are inexpensive to sample (although expertise is needed in identifying them).

Other biological indicators

Other biological indicators used in environmental monitoring include:

- the population size of a selected animal
- the population size of a specific plant or plant community
- a community diversity index
- the extent of a particular type of habitat
- the occurrence of a particular type of vegetation.

Techniques for investigating responses to pollution

Biomarkers

Organisms living in stressed environments may suffer from effects of a contaminant at levels well below that which will kill them. **Biomarker species** have a low threshold for a particular contaminant. At low levels of contamination, these organisms may show signs of abnormal growth, such as deformities, growth asymmetry or genetic changes. For example, physical deformities occur in some larvae affected by pesticide spray, so the frequency of deformities can act as an indicator of pesticide pollution.

Biomarker techniques depend on sensitive organisms that live in the ecosystem under investigation. Looking for biomarkers may let scientists detect low-level contaminants before the contaminant affects the entire ecosystem.

Bioassays

Bioassays involve exposing an indicator organism to a test material and measuring a response. A well-known example of this is the canary in the coal mine. Canaries are more sensitive than humans are to methane (which can be present in a coal mine), so miners used to watch the canary: if the canary died, methane levels were becoming dangerously high.

This technique has been commonly used over the last few decades, in particular to assess heavy metal concentrations in tissues (heavy metals are harmful to normal, healthy body functioning). Toxicity tests measure effects such as mortality and life history changes. Bioaccumulation tests measure the uptake of contaminants into an indicator species' tissues. Common pesticides sampled using bioassay analysis include DDT, dieldrin, endrin, lindane, aldrin, DDE (dichlorodiphenyldichloroethylene) and HCB (hexachlorobenzene).

9.4. State of the Environment environmental indicators

The Australian Government regularly publishes a national overview of the condition of the Australian environment every 5 years. These State of the Environment reports follow a pressure-state-response model, which asks: What is the environmental pressure? What is the current condition or state of the environment? What response to that condition is required?

The model is used to develop:

- indicators to measure environmental pressures (these describe the extent of human activities affecting the environment)
- indicators to measure the state, or condition, of the environment (these describe the quality or health of the environment and the functioning of important environmental processes; they can be very difficult and expensive to measure)
- indicators to measure societal responses taken in the light of the pressures and state of the environment (these show the range and effectiveness of individual and government actions aimed at reducing or reversing environmental damage or improving conservation of the environment).

The pressure-state-response framework allows information to be organised and presented to define the range of issues to be considered (see Table 9.9). This sophisticated use of indicators should help environmental managers deliver targeted and effective responses.

Table 9.9. Examples of indicators used in National State of the Environment Reporting

a) Atmosphere

Issue	Condition	Pressure	Response
Climate change	Southern oscillation index Daily and extreme rainfall Average maximum and minimum temperatures	Annual total greenhouse gas atmospheric emissions Greenhouse gas emissions by sector of the economy	Cost of drought to government National crop yield
Stratospheric ozone depletion	Ultraviolet radiation flux at the surface	National emissions of ozone-depleting substances in the atmosphere	Destruction of ozone-depleting substances
Regional and urban air quality	Concentration of carbon monoxide Concentration of ozone Concentration of lead Concentration of nitrogen dioxide Concentration of sulfur dioxide Concentration of particles	Emission of air pollutants in urban and regional areas	Number of people included in air quality monitoring Motor vehicle use Hospital admissions for respiratory conditions Compliance with government legislation and regulations Number of local government bodies that monitor and regulate air quality in their region

b) Biodiversity

Issue	Condition	Pressure	Response
Clearing, fragmentation, degradation of native vegetation or marine habitat	Number and extent of ecological communities of high conservation potential	Extent and rate of clearing, or major modification of natural vegetation or marine habitat Location and configuration of fragmentation of remnant vegetation or marine habitat Population size, numbers and physical isolation	Extent of vegetation type or marine habitat type in protected areas Number of protected areas with management plans Resources committed to protected areas Area of clearing officially permitted Area cleared to area revegetated
Genetically modified organisms	Number and extent of genetically modified organisms in the food chain	Distribution and abundance of genetically modified organisms	The number of management plans for genetically modified organisms The amount of funding spent on research into and control of genetically modified organisms

c) Land

Issue	Condition	Pressure	Response
Accelerated erosion and loss of surface soil	Gullying index per major catchment Change in dust storm index relative to number of high wind events	Percentage of cultivated land area with exposed soils by catchment and agro-ecological region Change in area that is impervious as a proportion of total area	Percentage of land managers using agreed best practice by land use and/or catchment Area of forested lands in which the legal framework encourages best practice codes of forest management, and the conservation of special environmental values
Nutrient and salt cycling	Net nutrient balance for major elements (nitrogen, phosphorus and potassium) per year by land use mapped across regions and drainage basins	Sources of phosphorus derived from land activities reaching rivers, by catchment Change in area and location of salinised land, compared across regional catchments	Proportion of each forestry and farming system with stable nutrient balance by major catchment Percentage of urban settlements with and without tertiary waste water treatment, by major catchment

d) Inland waters

Issue	Condition	Pressure	Response
Groundwater	Depth of water table Groundwater salinity	People, stock and crops supported	Borehole capping
Environmental water quality	Nutrient loads Chemical residues	Pesticide exposure Number and volume of point source discharges	Bloom contingency plans Zero phosphate detergents
Physical change	Stream character	Vegetated stream length Riparian stock access	Fenced waterways

e) Estuaries and the sea

Issue	Condition	Pressure	Response
Marine habitat and biological resources	Extent and condition of marine and estuarine habitats Translocated species Native species outbreaks Estimated fish stocks	Coastal zone use Disturbance of marine habitat Total fish catch Introduced species	Marine protected areas Beach stabilisation Coastal care community groups
Water quality	Bioaccumulated pollutants Chlorophyll *a* concentrations	Coastal discharges Marine pollution incidents Nutrient loads and concentrations	Waste water treatment (coastal waters) Implementation of stormwater controls

An indicator may be relevant to more than one theme or issue, or it may appear both as a condition and a pressure. For example, nutrient load is an indicator of the condition of inland rivers, but it is also a pressure on the marine environment.

CHAPTER

10

Managing pollution

10.1. Controlling and treating pollution

Options for control and treatment of pollution to reduce local and global impacts

Strategies to protect the environment, and to prevent further degradation, differ according to the scale at which the environment is being affected – local, regional or global.

Local environmental effects can be controlled by government regulations and by developing individual management plans for polluting facilities.

Regional effects are controlled by developing consistent standards supported by guidelines and codes of practices. Victoria's State Environment Protection Policies are an example of standards to control air and water quality across the state. In Australia, regional effects may require cooperation between two or more states or territories.

Global environmental effects require international cooperation, such as conventions and agreements, to control the problem. Obtaining the support of many countries can be very difficult.

Countries may not recognise a threat, or the need to take action, because it does not fit with their economic and political priorities. An example is the differing level of commitment to international agreements to reduce carbon emissions to control the greenhouse effect. Effective global action requires the support and actions of many individual nations.

Governments must consider more than the environmental controls within their own country. The international community must also address the issue of industries that locate themselves in countries with more lenient (or non-existent) environmental and health and safety laws than their home country. More lenient laws mean that companies can pollute at higher rates than would be allowed at home, saving the company the expense of installing and operating pollution-control equipment and ensuring that wastes are disposed of properly.

A strategy designed to address an environmental problem must first establish its goals. For example, is a particular pollutant, such as polychlorinated biphenyls (PCBs), such a problem that any level in the environment is unacceptable or do we just need to make sure it remains within an acceptable range? Once this fundamental question has been answered, procedures can be implemented that will achieve the environmental protection goal. A complete ban on generating PCB waste may be warranted. Or it may be sufficient to place a levy on the disposal of PCB waste where the cost of the levy discourages manufacturers from producing it.

Regulatory framework for pollution

Before the first modern pollution laws were passed in the second half of the 20th century, it was common for factories to dispose of untreated wastes directly into rivers and streams, and for their chimneys to belch untreated effluent. In the suburbs, many people had incinerators in their back yards and burned leaves and other waste. House paint contained lead and cars used leaded petrol.

As we became more aware of the health impacts of these pollutants, governments responded by passing laws such as Victoria's *Environment Protection Act 1970*, and our air and water quality has improved in many ways since then. For example, in section 39(1) relating to pollution of waters, the Victorian *Environment Protection Act 1970* says:

"(1) A person shall not pollute any waters so that the condition of the waters is so changed as to make or be reasonably expected to make those waters —

(a) noxious or poisonous;

(b) harmful or potentially harmful to the health, welfare, safety or property of human beings;

(c) poisonous, harmful or potentially harmful to animals, birds, wildlife, fish or other aquatic life;

(d) poisonous, harmful or potentially harmful to plants or other vegetation; or

(e) detrimental to any beneficial use made of those waters."

Keeping our air, water and soil healthy is still very important for the community. The Australian, state and territory governments have collaborated on a set of standards, which are outlined in the National Environment Protection Measures (NEPMs) and implemented in state and territory legislation.

Managing pollutants lets us:

- maintain and improve air, water and soil quality
- minimise the environmental impacts of hazardous wastes
- improve sustainability through the re-use and recycling of materials.

Sadly, pollution is sometimes intentional – purposely and wilfully emitted into the environment. Such pollution is less common in countries that have strict pollution legislation; however, intentional pollution can be an issue in international waters or in countries that do not regulate and enforce pollution controls. Neglectful pollution sometimes results from industries or individual companies not adhering to strict pollution regulations, and it can result in increased amounts of pollutants being released into the environment.

Monitoring

A key part of managing pollutants is knowing what pollutants are being produced by industry, agriculture and households. Monitoring emissions plays a significant role in:

- tracking pollutant emissions from a range of sources, across different locations and over time
- evaluating the success of pollutant reduction strategies
- informing environmental planning and management decisions
- sharing information with the community, which can feed into the actions and choices of individuals.

Approaches to reducing emissions

Managing pollution and maintaining or improving environmental quality is an ongoing process of innovation, with new approaches and technologies being devised and applied across the globe. Similar to the 'reduce, re-use, recycle' motto, we can look at approaches to pollution control in a hierarchy from best to worst:

- avoid or eliminate production of the pollutant
- minimise the amount of pollutant produced
- treat the emissions at the source
- safely dispose of pollutants
- remediate or clean up polluted areas.

Avoid pollutants

Avoiding, or eliminating, pollutants is obviously very effective in protecting health and the environment. Generally, however, we are happy to deal with pollutants because of the benefits we get (such as products, food, transport and lifestyle benefits) from the processes that produce them. In some cases, though, the impact of a pollutant is so great it is considered unacceptable. Then we take steps to prevent that pollutant being produced or emitted in the first place.

A chemical banned from agricultural use in most countries because of its adverse health effects is the insecticide DDT. Widely used in agriculture and to control malaria (by killing mosquitoes), DDT was found to have serious health effects on humans and also be toxic to many animals. Many countries took action and banned its use. In Australia it was banned in 1987, 15 years after it was banned in the US. Derivatives of this pesticide are still used in some countries and are causing harm to many people still today.

Another type of pollutant banned from use was CFCs (chlorofluorocarbons) used in refrigeration and aerosol cans. In the stratosphere, CFCs depleted the ozone, causing a hole in the ozone layer that let dangerous levels of ultraviolet light reach Earth. Cooperation from governments around the world in 1987 under the Montreal Protocol led to CFCs first being reduced and then banned by 2000. The ozone hole is slowly diminishing as a result.

Minimise pollutants

Minimising the amount of pollutants emitted is an ongoing effect of good pollution-control legislation. To meet environmental standards, manufacturers may need to substitute materials that are less toxic in their industrial processes. For example, small amounts of lead were once used in the production of steel during the metal coating process. This was replaced with antimony due to environmental and health concerns related to the use of lead.

Technological innovation directed at reducing pollutants is opening up many possibilities:

- Many new technologies are designed to be more energy efficient, which reduces greenhouse gas emissions.
- Advanced instrumentation, such as sensors and meters, can improve control of production processes and reduce waste.
- Outputs that were once considered waste can now be re-used or recycled. This not only prevents them from becoming pollutants, it reduces the need to exploit other resources.
- Chemists are designing new chemicals and processes that can replace more polluting ones. For example, researchers have developed a new process for chrome plating that uses trivalent chromium instead of the traditional, highly toxic form hexavalent chromium.

Nanotechnology, quantum computing and new materials could transform industry, construction and information technology with new capabilities and efficiencies. In the process, old and polluting technologies can be replaced with new, more sustainable and less polluting approaches.

Many technological innovations also apply to pollutant treatment, disposal and remediation.

Treat at the source

Treating waste before it is released ensures that effluent is less harmful to health and the environment than it would otherwise be. Today, industrial processes and products must be designed so that their emissions are acceptable to the community and in line with regulations. A common example of treatment at the source of pollution is the catalytic converter found in car exhaust systems. This device converts toxic pollutants (such as carbon monoxide, nitrogen oxides and hydrocarbons from unburned fuel) into carbon dioxide, nitrogen gas and water vapour.

Treatment measures can be as simple as physical screening or filtering at the point of emission, such as removing rubbish from stormwater or particulate matter from a factory's smokestack. Filters can be more sophisticated too; for example, filters with activated carbon can adsorb gas fumes from air, and biofilters that use microorganisms to break down pollutants in air or water are being used in increasing numbers.

Wastewater treatment is one area in which we can use natural biological processes to help treat emissions. Constructed wetlands, planted with reeds and rushes, can catch a lot of pollutants and excess nutrients from run-off before the water enters a stream. Contaminants can settle out to be stored in the sediments, or converted into less toxic substances through microbial processes. Some new residential and industrial developments incorporate a constructed wetland in their design as part of managing water quality.

Treating industrial emissions

Many industrial activities produce emissions, such as the acidic gases that are the primary cause of acid rain. To control emissions, many facilities are required to install technology that removes the pollutants before the gas is released into the atmosphere as white smoke.

Scrubbers are systems that clean the gas with a substance that extracts the pollutants from the exhaust gas as it passes through a chamber.

Wet scrubbers pass the exhaust gas through a wet mist or pool of fluid. When the pollutant is particulate matter, the wet medium is water, but other liquids are used for different pollutants. For example, liquid calcium carbonate is used to trap sulfur compounds that cause acid rain. The pollutant is attracted to the wet medium, which is removed and stored. One of the disadvantages of wet scrubbers is that this waste, containing the pollutant plus liquid medium, is heavy and produced in large volumes so presents difficulties in disposal and storage.

Dry scrubbers were developed to overcome this problem. They pass gas through a dry medium that chemically reacts with the pollutant to change its composition. The new material is either safe to emit or is removed and disposed or stored.

Electrostatic precipitators uses electrostatic principles to remove dust and other particles from exhaust gas. An electric charge is applied to the gas, which gives the ash and soot particles a negative charge. The negatively charged soot is attracted to positively charged electrodes and removed from the gas into a collecting medium. This medium can be removed and cleaned,
ensuring that ash and soot are not emitted into the environment as a particulate matter pollutant.

Safely dispose of pollutants

For pollutants that can't be avoided, and could cause environmental problems if released, measures must be taken to dispose of them safely. State and local governments have various systems for disposing correctly of hazardous wastes from industry and households. In some cases permits are needed (for example, for disposal of industrial and biomedical waste). Many councils provide collection points for domestic waste oils, household chemicals, batteries and other items that would cause environmental problems if sent to landfill.

On a much larger scale, scientists are tackling the problem of carbon dioxide emissions by investigating whether they could be captured and stored, rather than released from power stations. Carbon capture and storage (or carbon sequestration) may help us reduce greenhouse gas emissions, but the technology is still very young (see 'Carbon capture and storage', p 75).

Clean up polluted sites

It is much better to avoid pollution in the first place, but in some areas the pollution has already occurred. Remediation is often needed at former industrial sites, service stations and refineries, and the sites of chemical spills or pesticide use. Cleaning up polluted sites can be very difficult and expensive. Treatments often require the contaminated soil or groundwater to be processed in some way to separate out and remove the toxic components from the rest. This is most often done on-site, but some remediation involves collecting material and treating it elsewhere. The process of remediation itself, as it involves toxic substances, must be managed carefully to ensure it doesn't cause new environmental problems.

Remediation is another area where we can get help from microorganisms and plants. **Bioremediation** is the process of using organisms to clean up contaminated soil or groundwater. Some plants are 'hyper accumulators' of particular contaminants and can be used to remove pollutants from the soil. For example, Chinese brake fern removes arsenic and Indian mustard removes lead.

While some decontamination happens naturally, bioremediation often involves creating the right conditions (for example, temperature and nutrients) for microorganisms to do their work. The soil or water may need aeration with oxygen, although some bioremediation processes take place in an anaerobic environment. The process may take months or even years, but it is often cheaper and easier than other methods and has a lower risk of environmental damage.

Bioremediation usually uses microbes that are naturally present in the soil, but an emerging field is using genetically modified bacteria to undertake specific clean-ups. For example, *E. coli* bacteria were genetically modified so that they could live in high concentrations of mercury and remove the mercury from the waste. Then the mercury could be retrieved from the bacteria, rather than being released to the air. Another bacterium was modified so that it could degrade crude oil. These processes speed up the rate of decay of these pollutants, minimising or eliminating their harm on the environment.

Australian emission reduction targets

In 2016, the Australian Government ratified the Paris Agreement and agreed to achieving a 26% to 28% reduction in greenhouse gas (GHG) emissions below 2005 levels by 2030. In 2005, Australians' GHG emissions across all sectors were 559.1 million tonnes. The Paris Agreement also requires signatories to commit to strengthening their reduction of GHG emission to restrict global temperature increase to below 2 °C above pre-industrial levels, with efforts to reduce that to below an increase of 1.5 °C. For Australia, this means a rapid decarbonisation of the energy and land sectors, which combined release 527 million tonnes of carbon dioxide equivalent ($MtCO_2$-e) per year (Figure 10.1).

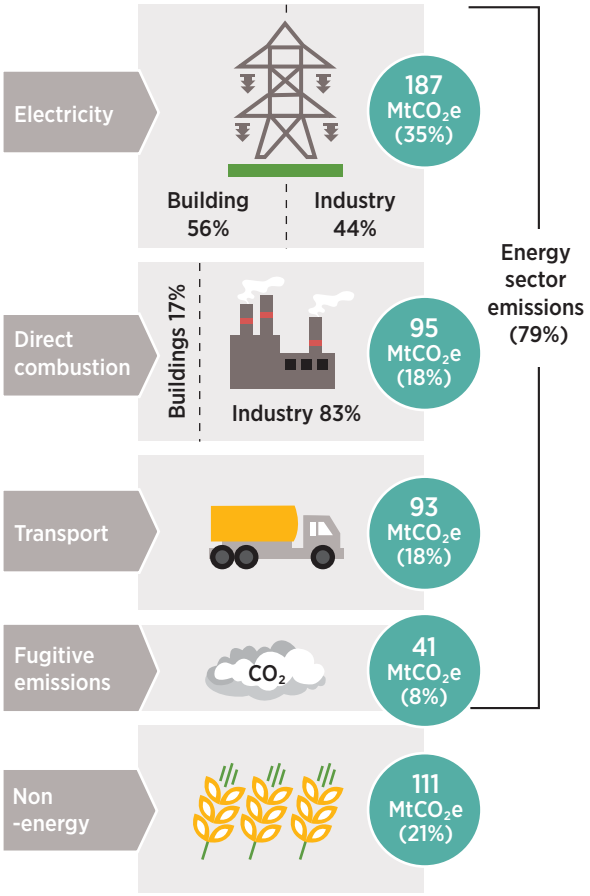


Figure 10.1. The energy and land sectors combined release 527 $MtCO_2$-e per year

Decarbonising and achieving Austalia's greenhouse gas emission goals will require developing and adopting new technologies, such as outlined in Table 10.1.

Table 10.1. Technologies to reduce greenhouse gas emissions

Category	Subcategory	Supporting technologies
Energy productivity	Buildings sector technologies	Technologies supporting energy and emissions reductions in buildings, such as light-emitting diode (LED) lighting; high-efficiency heating, ventilation and air conditioning (HVAC); sensors and controls; high-efficiency appliances; building envelope improvements; and electrification
	Industry sector technologies	Technologies enabling improvements in process heating; materials handling; compression equipment and other industrial equipment such as efficient motors and pumps; fuel switching from coal to gas and from gas/petroleum to electricity; direct use of renewable heat (e.g. solar thermal and biomass)
	Transport sector technologies	Technologies supporting fuel substitution (e.g. electric vehicles, hydrogen fuel cell vehicles, biofuels), improved vehicle efficiency and demand reduction including via mode shifting
Low-carbon electricity	Variable renewable energy (VRE)	Rooftop solar photovoltaic (PV) panels, large-scale solar PV, onshore wind, wave energy
	Biomass	Conversion of biomass to electricity via direct combustion, combustion of biogas produced by anaerobic digestion or biomass gasification
	Concentrated solar thermal (CST)	Concentrated solar thermal power with integrated thermal storage
	Carbon capture and storage (CCS)	Capture, transport and storage of CO_2 into underground rock and reservoir formations. Also includes technologies supporting use of CO_2
	Nuclear	Fission and fusion reactors
	Geothermal	Electricity generation using heat obtained through deep drilling in hot sedimentary aquifers (HSA) and enhanced geothermal systems (EGS)
Other	Hydrogen	Hydrogen production (e.g. thermochemical, electrochemical), storage and transport (e.g. using liquefaction), and consumption (e.g. fuel cells, turbines)
	Fugitive	Technologies supporting reductions in fugitive emissions in coal and oil and gas production, such as ventilation air methane abatement technologies

Practical 10.1
Particulate matter

Engineers use a variety of technologies to measure the concentrations and identify types of particulate matter. Before they can clean up pollutants, engineers first learn everything they can about a pollution site (source). They use this scientific information to design new technologies, such as new fuel types, more efficient engines, and industrial processes and emissions treatments. These designs help to protect our environment and resources from human impacts.

Aim

To demonstrate how pollution is generated from two different processes and explore where pollution is in a local environment.

Materials

Part 1 Incomplete combustion demonstration

- candle
- tin can (soup can)
- matches
- straw
- paper towel or rag
- hot mitt

Part 2 Smog demonstration

- large glass jar
- aluminium foil
- 2–3 ice cubes
- 1 cup of water
- paper
- ruler
- scissors
- matches

Part 3 Building particulate matter collectors

Each group needs:

- 1 small glass jar (spice jar or baby food jar)
- 1 large glass jar (pickle, mayo or mason-type jar)
- petroleum jelly
- masking tape
- magnifying glass
- index card

For the entire class to share:

- chart paper (large, bulletin-board sized)
- coloured paper
- scissors
- transparent tape

Procedure

Part 1 Incomplete combustion

1. Light the candle.
2. Place the bottom of the can directly over the flame for a few seconds. The top of the flame should be almost touching the can.
3. Look at the bottom of the can. Record what you observations in your logbooks. Do you think this is evidence of pollution? Answer in your logbook.
4. Clean off the bottom of the can with a paper towel. Observe the pollution on the towel.
5. Repeat the procedure, but use the straw to gently blow air on the bottom of the can. Be careful not to blow the flame out.
6. Look at the bottom of the can and observe what you see. Write a description in your logbook. Do you see any pollutants? Record your observations and responses in your logbook.
7. Explain in your logbook how the additional air affected the combustion of the candle.

Part 2 Smog demonstration

1. Cut a strip of paper about 15 cm × 1 cm. Fold the strip in half lengthwise and twist it.
2. Use a piece of aluminium foil to make a 'lid' for the jar. Mould it to the shape of the jar opening and then remove it and set it aside.
3. Put some water in the jar and swirl it around until the inside walls of the jar are wet.
4. Put the ice cubes on top of the foil to make it cold.
5. **NOTE: All the parts of this next step must be done very quickly.** Light the strip of paper and drop it and the match into the jar. Place the foil lid on the jar and seal it as tightly as possible. Place the ice cubes back on the middle of the foil lid.

continued next page

Practical 10.1 (continued)

6. Describe what you see in the jar.
   How is it like real smog? How is it different?
   Write your responses in your logbook.

CAUTION: Do not breathe the 'smog'. Be sure to release it outdoors when you are finished with the demonstration.

Part 3 Collecting particulate matter

1. Smear petroleum jelly on the outside of the small jar.
2. Carefully place the small jar inside the large jar.
3. Use the masking tape to make a label for the large jar; include name, date and test site location.
4. Decide on several locations around the school – inside and outside. Think about where visible pollutants may be found. Each group is to have a different collection site. Possible locations include near a road or parking lot, a garage with car exhaust, a sandy/dusty playground, staff room, a stove, the classroom air filter/vent or the school's air intake/vent. Keep in mind that the collectors may have to stay at each site, undisturbed, for a few days.
5. Choose a site for your control and place a jar there – perhaps somewhere that you think will have minimal pollution like inside your classroom or outside. Make sure you can provide a justification for where you have situated the control jar.
6. Make predictions about which area will have more visible pollutants and why. Record your predictions in your logbook.
7. Place jars in the test sites for several days. Check the jars daily and record observations in your logbooks.
8. On the final day of observations, bring the jars back to the classroom for comparison.
9. Observe the amount of pollutants on the collectors.
10. Rank the jars from the one with the fewest visible pollutants to the one with the most, lining them up across a table. Remember to include the control jar. Record this information in your logbooks.
11. Discuss why certain areas have more visible pollutants than others.
12. Remember that these particles are in the air you breathe. Write about how you feel about this in your logbooks.
13. Make a school map on large chart paper. For each test site, cut a jar shape from coloured paper and write on it the ranking, location and number of particles collected (if possible to count). Stick each cut-out jar to the correct location on the map. What conclusions can you draw from the map? Write a few of these conclusions neatly on index cards. Display the map and index card conclusions in a school hallway or main office for others to see.

Alternative collector designs

- Cut rectangular strips from plastic milk jugs or index cards and hole-punch one end to make a hole for a string hanger. Smear petroleum jelly on one side. Leave hanging for a week or more. Be sure to apply a thick coat of petroleum jelly to prevent the jelly from drying out over the course of the experiment.
- Use index cards with a hole cut in the middle (about size of a 20-cent coin). Cover the hole in transparent tape so the sticky side is exposed. Hole-punch one end to make a hole for a string hanger. Make three cards for each site (one for 24 hours, one for 3 days and one for 1 week). Be sure to apply a thick coat of petroleum jelly to prevent the jelly from drying out over the course of the experiment. NOTE: The index cards are not wet-weather resistant, so make sure they are placed in protected areas.
- Experiment with using clear vegetable oil instead of petroleum jelly in the collectors.

Regulatory framework

CASE STUDY 10.1
Hazelwood mine fire and stakeholder values

On 9 February 2014, a grassfire spread to and ignited a coal mine near the rural town of Morwell in Victoria's south-east. The coal mine fire burned for 45 days and caused a thick smoke haze to settle over the town – burning coal produces a number of pollutants including particulate matter. Residents were advised to leave their homes because of the risk of long-term exposure to smoke.

Due to the severity of the fire, Victoria's environmental regulator, the EPA, conducted intensive monitoring of air quality in Morwell and the surrounding areas. This monitoring revealed PM2.5 (atmospheric particulate matter with a diameter of less than 2.5 micrometres) levels to be above the recommended limits in three time periods. Morwell residents reported a number of worrying health effects such as sore and stinging eyes, headaches and blood noses. Most of these effects went away after the fire was controlled. However, there are fears that some community members will suffer long-term health effects.

Figure 10.2. Location of the Morwell mine fire

One group involved in this issue is the firefighters union, who allege that firefighters exposed to the Morwell mine fire are suffering from long-term illnesses such as leukaemia. In response to this, the union has requested they be included in a long-term health study into the effects of the mine fire. Vulnerable groups within the community, namely those with pre-existing respiratory and heart conditions, pregnant women, children and the elderly were particularly susceptible to the health effects of smoke and ash.

Questions

1. In addition to monitoring the levels of particulate matter and other pollutants in the region, the Victorian Department of Health undertook monitoring of the demand on health resources. Why would this information be beneficial to collect?
2. Go to the Hazelwood mine inquiry webpage http://report.hazelwoodinquiry.vic.gov.au/. What were the criticisms of the monitoring program?
3. What was the health response implemented by the Department of Health with the assistance of the EPA?
4. Copy the table below and fill it in to show the multiple stakeholders in the surrounding region affected by the mine fire and their values (refer to 'Stakeholder values', p 82).

	Stakeholders	Values
Social		
Economic		
Environmental		

Critical thinking and discussion 10.1

Complete the table below to identify whether the nominated pollution-control measures are prevention or control?

Management technique	Description	Prevention or control?
Inertial or impingement separators	Separators are primarily used for the collection of medium-size and coarse particles. They concentrate or collect particles by changing the direction of motion of the flowing gas	
Choosing cleaner fuels	Atmospheric particulate emissions can be reduced by choosing cleaner fuels, for example natural gas over coal-fired combustion	
Electrostatic precipitator	A filtration device that removes fine particles using the force of an induced electrostatic field to attract the particles onto the electrodes	
Fuel cleaning	Physical cleaning of coal through washing can reduce its ash and sulfur content	
Wet scrubbers	Use a liquid spray to remove dust particles from a gas stream. These work by introducing the dirty gas stream with a scrubbing liquid – typically water. Particulate or gases are then collected in the scrubbing liquid	

Data analysis 10.1
Particulate matter

Particulate matter (PM10) levels are monitored in Melbourne to determine if the annual standard is met. The EPA collects daily data from monitoring sites and also calculates annual averages. An area will meet the 24-hour standard for PM10 if measurements do not exceed 50 micrograms per cubic metre (µg/m^3) on more than 5 days in a year.

Figure 10.3 shows the PM10 data for Melbourne from 1997 to 2013.

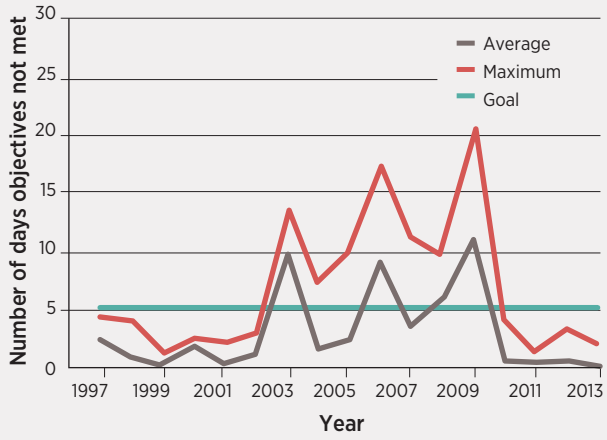


Figure 10.3. Number of days PM10 exceeded 50 µm/m^3 in Melbourne

1. Describe the trend in particulate matter from 1997 to 2013. Ensure you refer to data in your response.
2. What major event in 2009 may have contributed to the large number of days above the standard of PM10?

Go to the EPA Victoria website air quality monitoring data page (https://www.epa.vic.gov.au/EPAAirWatch).

Choose the monitoring station closest to your house or school and another different station of your choice.

Copy the table below and record the level of PM2.5 in the two places for the current hour plus three other time periods in the 48-hour period shown on the website. Make sure your four time periods include two morning times (am) and two afternoon or evening times (pm).

3. Are there any differences in the PM2.5 levels between stations 1 and 2? If so, what might cause this difference?

Day and time	Station 1	Station 2

EXPLORING SCIENCE 4
Pollutants in our air

Common products, like perfume, paint and printer ink, are polluting the atmosphere

Jenny Fisher, Senior Lecturer in Atmospheric Chemistry, University of Wollongong, and Kathryn Emmerson, CSIRO

This article was originally published in The Conversation*, 16 February 2018.*
https://theconversation.com/common-products-like-perfume-paint-and-printer-ink-are-polluting-the-atmosphere-91914

Picture the causes of air pollution in a major city and you are likely to visualise pollutants spewing out of cars, trucks and buses.

For some types of air pollutants, however, transportation is only half as important as the chemicals in everyday consumer products like cleaning agents, printer ink, and fragrances, according to a study published today [16/02/2018] in *Science*.

Air pollution: a chemical soup

Air pollution is a serious health concern, responsible for millions of premature deaths each year, with even more anticipated due to climate change.

Although we typically picture pollution as coming directly from cars or power plants, a large fraction of air pollution actually comes from chemical reactions that happen in the atmosphere. One necessary starting point for that chemistry is a group of hundreds of molecules collectively known as 'volatile organic compounds' (VOCs).

VOCs in the atmosphere can come from many different sources, both man-made and natural. In urban areas, VOCs have historically been blamed largely on vehicle fuels (both gasoline and diesel) and natural gas.

Fuel emissions are dropping

Thanks in part to more stringent environmental regulations and in part to technological advances, VOCs released into the air by vehicles have dropped dramatically.

In this new study, the researchers used detailed energy and chemical production records to figure out what fraction of the VOCs from oil and natural gas are released by vehicle fuels versus other sources. They found that the decline in vehicle emissions means that – in a relative sense – nearly twice as much comes from chemical products as comes from vehicle fuel, at least in the US. Those chemicals include cleaning products, paints, fragrances and printer ink – all things found in modern homes.

The VOCs from these products get into the air because they evaporate easily. In fact, in many cases, this is exactly what they are designed to do. Without evaporating VOCs, we wouldn't be able to smell the scents wafting by from perfumes, scented candles, or air fresheners.

Overall, this is a good news story: VOCs from fuel use have decreased, so the air is cleaner. Since the contribution from fuels has dropped, it is not surprising that chemical products, which have not been as tightly regulated, are now responsible for a larger share of the VOCs.

Predicting air quality

An important finding from this work is that these chemical products have largely been ignored when constructing the models that we use to predict air pollution – which impacts how we respond to and regulate pollutants.

The researchers found that ignoring the VOCs from chemical products had significant impacts on predictions of air quality. In outdoor environments, they found that these products could be responsible for as much as 60% of the particles that formed chemically in the air above Los Angeles.

The effects were even larger indoors – a major concern as we spend most of our time indoors. Without accounting for chemical products, a model of indoor air pollutants under-predicted measurements by a whopping 87%. Including the consumer products really helped to fix this problem.

What does this mean for Australia?

In Australia we do a stocktake of our VOC emissions to the air every few years. Our vehicle-related VOC emissions have also been dropping and are now only about a quarter as large as they were in 1990.

Nonetheless, the most recent check suggests most of our VOCs still come from cars and trucks, factories and fires. Still, consumer products can't be ignored – especially as our urban population continues to grow. Because these sources are spread out across the city, their contributions can be difficult to estimate accurately.

We need to make sure our future VOC stocktakes include sources from consumer products such as cleaning fluids, indoor fragrances and home office items like printing ink. The stocktakes are used as the basis for our models, and comparing models to measurements helps us understand what affects our air quality and how best to improve it. It was a lack of model-to-measurement agreement that helped to uncover the VW vehicle emission scandal, where the manufacturer was deliberately under-estimating how much nitrogen gas was being released through the exhaust.

If we can't get our predictions to agree with the indoor measurements, we'll need to work harder to identify all the emission sources correctly. This means going into typical Australian homes, making air quality measurements, and noting what activities are happening at the same time (like cooking, cleaning or decorating).

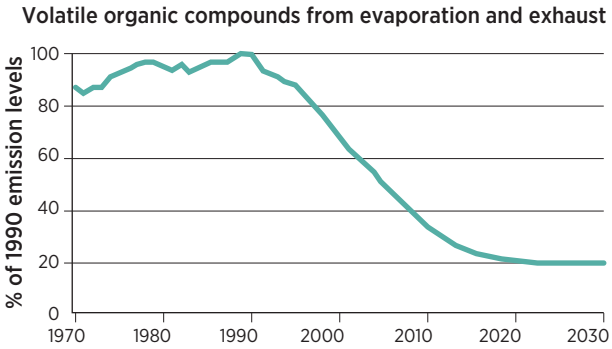


Figure 10.4. Historical and projected trends in Australia's road transport emissions of VOCs. Author provided, adapted from Australia State of the Environment 2016: atmosphere

What should we do now?

If we want to keep air pollution to a minimum, it will become increasingly important to take into account the VOCs from chemical products, both in our models of air pollution and in our regulatory actions.

In the meantime, as we spend so much of our time indoors, it makes sense to try to limit our personal exposure to these VOCs. There are several things we can do, such as choosing fragrance-free cleaning products and keeping our use of scented candles and air fresheners to a minimum. Research from NASA has also shown that growing house plants like weeping figs and spider plants can help to remove some of the VOCs from indoor air.

And of course, we can always open a window (as long as we keep the outdoor air clean, too).

The demand by Earth's inhabitants for adequate, nutritious food and safe water stocks places increasing pressure on our natural resources. Water is critical for healthy, natural and manufactured ecosystems and determines the availability of food crops, livestock and many services that underpin human well-being. The supply of useable water is, however, influenced by both seasonal and long-term climatic variations. Drought conditions have led to changed practices such as seawater desalination, alternative dietary choices and government-imposed water restrictions. Conversely, flooding has led to adaptive responses such as the Gunditjmara Peoples' engineering of local wetland swamps and sink-hole depressions, in order to construct eel traps for farming the eels that migrate annually through the system. In this area of study students examine various approaches for meeting the food and water security challenges facing current and future populations of humans and other species, while minimising negative environmental impacts. Students apply ecological footprint analysis to a selected context and explore options for addressing food and water challenges for a nominated region.

The selection of learning contexts should allow students to develop practical techniques and undertake fieldwork to examine the relationship between natural and human activities and the availability of food and water resources. Students develop their skills in the use of scientific equipment and apparatus. They use food and water calculators, and perform comparative analytical tests related to food and water needs, such as determining the organic matter and water contents of soil from fields with different long-term management systems. Students conduct user surveys to determine food and water usage, habits and attitudes, and design practical responses to environmental challenges such as improving water-use efficiency and managing nutrient-deficient soils.

Outcome 2

On completion of this unit the student should be able to compare the advantages and limitations of different agricultural systems for achieving regional and global food security, evaluate the use of ecological footprint analysis for assessing future food and/or water security, and recommend and justify a range of options for improving food and/or water security for a nominated region.

AREA OF STUDY 2

How can we manage food and water security to sustain Earth's systems?

Key knowledge

Area	Section
Sustainable food systems	
• challenges to supplying adequate and affordable food in regional and global locations that achieve regional and global food security	11.1, 12.1
• qualitative differences between food produced by conventional monoculture and organic monoculture agricultural systems	11.2
Maintaining food and water security	
• options for improving food security that consider organisational, political and structural enablers and barriers to change	12.1
• the use and limitations of ecological footprint analysis, in terms of the sustainability principles of intragenerational equity and the efficient use of resources	13.1
• the ecological footprint of either an individual, local and/or international community or business, or a local or imported raw food and/or food product	13.2

CHAPTER

11

Sustainable food systems

CASE STUDY 11.1
Seaweed for dinner

Phoenix Gardiner, Bachelor of Science student, Deakin University

Sustainability in the food industry has become more prominent as researchers explore innovative ways to feed the hungry and use less resources. Zoe Brittain, a PhD student at Deakin University, is one of those researchers. She is part of the Seaweed Team, a group of academics that research seaweed for commercial use, ecological benefits and education.

Zoe's primary research area is Indigenous uses of seaweed, and her role is to communicate with Indigenous Elders in south-eastern Australia and New Zealand. Her research combines oral histories with academic research, and the knowledge gained could potentially lead to commercial ventures. Her study focuses primarily on seaweed as a food source, but seaweed has many other uses including medicine, vitamin supplements, ceremonies, fire starters and waterproof housing.

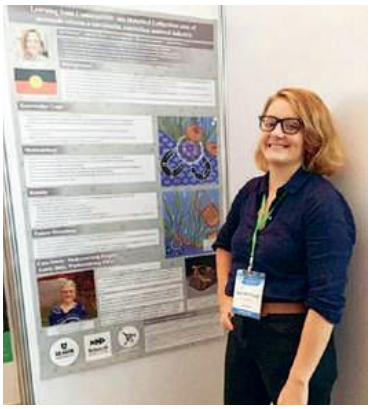


Figure 11.1. Zoe Brittain is a PhD student at Deakin University studying Indigenous uses of seaweed in south-eastern Australia and New Zealand. Credit: Zoe Brittain

Contemporary methods of growing food take up a lot of space, use a lot of water, and contribute heavily to emissions in the atmosphere. Indigenous people, particularly in Australia, have been managing the land and living with it for 80,000+ years; however, their knowledge is rarely used as it is generally in the form of oral histories. In fact, Zoe's research throughout her honours degree was innovative in Australia, and a paper she collaborated on detailing Indigenous seaweed use in temperate Australia was the first of its kind.

Figure 11.2. Zoe educating people at a festival on different edible seaweeds. Credit: Zoe Brittain

Figure 11.3. Indigenous art depicting seaweed and some of its uses. Photo credit: Zoe Brittain

While the belief in Australia is that seaweed is not consumed in amounts comparable to many Asian countries, conversations with Elders has turned this on its head – in only 1 year of collaboration, Zoe learnt about approximately 20 edible species growing from South Australia to New South Wales.

Why is this important?

Seaweed cultivation is much easier to do sustainably than terrestrial agriculture. Seaweed grows in saline water so there is no need for fresh water, and multiple foods can be grown in one spot. This was demonstrated at a seaweed farm in Japan that Zoe Brittain recently visited. The farm grows three sources of food – fish, mussels and seaweed – and each has a purpose. The fish fertilise the water and add more nutrients for the seaweed to grow, and the mussels filter the water to keep it clean. The benefit to a set-up like this is that less space is used, fewer resources are needed and it can be established in any part of the ocean, which minimises harm to sea creatures and their habitats.

Collaboration with Indigenous people is vital in seaweed research in Australia. It increases our knowledge of edible seaweeds, bridges the gap between Indigenous knowledge and academia, and empowers Indigenous people to use and share their skills and knowledge. This can provide an opportunity for commercial ventures in producing and selling seaweed products, which puts money back into the community of those with the skills and knowledge. Seaweed research in Australia is a new and emerging area (see 'Biological sequestration', p 76). It has the potential to improve food security and lessen harmful impacts that traditional agricultural methods produce. In a changing world that is looking seriously at climate change and human impacts, this area of knowledge is vital.

Questions

1. **Determine** the science required to understand this case study.
2. **Describe** the types of technology that would assist with understanding or solving issues in this case study.
3. **List** the many stakeholders involved in this case study.
4. Using the definitions presented in 'Stakeholder values' (p 82), **describe** the values and priorities of the stakeholders involved. **Justify** your choice/s.
5. **Identify** the regulatory frameworks used to protect the environment that is described this case study.

11.1. Food production in Australia

Challenges to supplying adequate and affordable food in regional and global locations that achieve regional and global food security

When Australia was colonised in 1788, food was being sent from Britain to the settlement to feed the convicts and officers. The main goal of the settlement was to become food secure – this was given the highest priority. Within 15 years New South Wales was producing a variety of fruits and vegetables, and sheep and cattle were grazing on the rapidly opening grass plains. Within 40 years of white settlement the colonies had begun exporting food and fibre. By 2020 the farming and fish production market in Australia had grown to around $69 billion dollars annually.

Australia is also an important contributor to global food production, exporting around 60% of the total volume of farm production. Currently Australia is the sixth largest exporter of farm produce, accounting for around 3% of all farm exports globally. Australian farmers feed 25 million Australians and export enough food and stock feed to feed an additional 40 million people globally. Nevertheless, there is always pressure to increase production as many people globally do not have enough food (see Chapter 12 'Food security', p 200)

Agricultural production can grow by increasing the area being farmed or by intensifying agricultural practices on existing farms to increase yields. Intensification is seen as a quick way to meet future food needs; yields can often be increased by adopting better farming practices or through genetic or technological advances. This is already happening throughout plant and animal breeding programs. Livestock farming has seen an increase in larger pig and chicken farms and an increase in feedlot raising of cows and sheep. Feedlots traditionally use grains to feed animals in feedlots so they grow quicker and can be sent to slaughter in a shorter time.

Internationally, livestock have been subject to real or perceived competition for grains between animals and humans. In Australia, however, feed for livestock is sourced from low-quality grains that are not nutritionally fit for human consumption. This ensures there is no competition between humans and livestock for grain consumption.

Impacts of agriculture in Australia

The drive to increase farm outputs and profits has led to many changes to the landscape and significant environmental costs. For example, woodlands and native grasses are cleared and wetlands filled in so there is more land for production. Large open paddocks encourage wind erosion, while large, heavy farm machinery can compact the soil and make it impossible for water to penetrate.

Clearing land for agricultural use has destroyed 90% of the native vegetation from eastern temperate Australia, 5% of our rainforests and 30% of our woodlands. This has caused significant soil erosion and salinity issues. The increased salt load washes into streams and rivers and kills trees, including the iconic river red gums of inland Australia.

Chemical fertilisers and pesticides also contribute to land and water pollution (which affects water quality) and can enter the food chain. Some chemicals and fertilisers contribute to eutrophication of local waterways, killing local aquatic life; they can also drain into larger ecosystems. Soil acidification is another impact, largely caused by farmers' reliance on ammonium-based fertilisers to compensate for the thin and nutrient-poor nature of Australian soils. Poor agricultural practices that increase soil salinity and acidification cost millons of dollars to repair as well as untold environmental costs.

Agricultural irrigation practices see significant amounts of water removed from natural and artificial water systems and used to irrigate crops and to support livestock.

Figure 11.4. Australia produces large qualities of food from a diverse agricultural sector

There is a rising tension within Australia between the amount of water available for agriculture and the amount available to provide environmental flows in river systems that have become critically stressed.

The combined impacts of agriculture – land clearing, soil erosion and reduction of water quality and availability – have also taken their toll on biodiversity in Australia.

Australia's food consumption also contributes to environmental degradation in countries from which we import food. As a wealthy and developed nation, Australia should seek to do no harm with respect to food production. Current market exchanges do not ensure that no other nation is left worse off through Australia's interaction with them, even if that is a desirable outcome. However, there is an opportunity to establish 'ethical trade' with other nations. This is also called fair trade.

There are also costs associated with Australian agriculture's reliance on fossil fuels – in the use of farm equipment, creation of artificial fertilisers and pesticides, and the transport in trucks from farms to supermarkets. A typical Western family of two parents and two children 'eats' approximately 175 barrels of oil each year (27,825 L) when you calculate the fuel used in growing and transporting their food. With the depletion of fossil fuels, supplies of oil-based fuels will decline. This will make it more expensive for farmers to produce food and increase food costs unless we see advances in traditional farming practices or a rapid switch to renewable energy sources.

There is a growing need for agricultural productivity to take into account climate change, nutrition and socio-economic development.

Impacts of climate change on Australian food production

Australia has one of the world's most variable climates, and as climate change begins to affect the agricultural sector there will be challenges to supplying adequate and affordable food.

These negative impacts include:

- increased bushfire frequency and intensity
- increased range and severity of pests and diseases
- higher rates of soil erosion and degradation
- more hot days that lead to livestock stress and a reduction in area available for pasture
- reduced plant production due to salinisation of waterways
- increased distribution of exotic weeds and native woody species.

Possible positive impacts include:

- cooler areas of the continent growing warmer and able to grow more crops
- fewer lambing deaths in warmer winters
- an increase in the ability to grow crops in north-eastern Australia as rainfall increases.

The potential positive impacts do not outweigh the negative impacts of climate change or the damage to the landscape already done.

Australia is predicted to be one of the countries most affected by climate change. This will in turn affect the amount of food that Australia can produce and export.

The Australian Government has attempted to address the declining ability of the landscape to keep pace with growing food needs and decreased yields. It established the Northern Australia Land and Water Taskforce to determine the viability of transforming northern Australian into the next 'food bowl'. The task force reported that while there is an abundance of rainfall in the region, most of the rain falls on the coast and floodplains.

These landscapes have a very limited ability to support agriculture. In addition, the report concluded that the landscape's low elevation and gentle undulation meant there was little opportunity to harvest water run-off in traditional dams. This confirmed what the Wentworth Group of Concerned Scientists had already been saying: sustainable development can only occur if agricultural production conformed to the biophysical limits of the climate and terrain.

Practical 11.1
Do farms damage the environment?

Aim

To look for evidence of damage caused by farm practices.

Time required

1–2 hours for initial survey, 2 hours to take any measurements, 3 hours for research

Materials

- local map of farmland (each group will need a copy of their survey area)
- tracing paper large enough to cover map
- records of the farming area for approximately the last 30 years (for example, photographs, media reports, information from local groups, local library, Google Maps and Google Earth)

Procedure

1. Make a group of three students and nominate an area from the map to survey.
2. If possible, go to the site and observe the area for evidence of environmental damage or landscape change. Record your observations in a table like the one shown below.
3. Back at school, cover the map with tracing paper and transfer the information from the data table below.
4. Gather more data from the other groups so there is information from the whole area on the tracing paper.
5. Fill in more data from the secondary sources such as Google Maps.

Analysis

1. What damage or landscape changes did you observe in your group's area?
2. Describe the pattern of agricultural impacts across the whole map area.

Discussion

1. **Justify** why the farming practices you observed were carried out.
2. **Explain** what might be done to limit the damage.
3. **Suggest** how you would amend any data-collections problems you had, Could you collect any other data?

Group: Evidence of environmental damage or landscape change	Area of map surveyed: Key	Location (e.g. map reference)
Removal of low vegetation	LVR	
Tree removal	TC	
Silo and buildings for machinery and animals	BE	
New crops introduction	NC	
Pesticide use	PU	
Herbicide use	HU	
Waterway pollution (effluent)	WP	
Compaction of soil	CS	
Fertilisers causing eutrophication	FE	

Critical thinking and discussion 11.1

1. Have a look in your cupboards at home. Make a list of the country of origin of foods like rice, flour, lentils and sugar. Calculate the greatest distance a food item has travelled.
2. Ask your parents or grandparents how household shopping has changed over time.
3. Plan a backyard vegetable garden by making a list of your favourite fruits and vegetables. Divide those plants into those harvested in summer, autumn, winter and spring, and compare what you can grow in each season with what is available in the supermarkets in those seasons. Does it match up or can you still buy out-of-season produce in the supermarkets? Determine how this is possible.

Data analysis 11.1
Arable land

Using the data in Table 11.1, make a graph to show trends in the percentage of arable land in Australia from 1995 to 2015 and answer the following questions.

1. **Define** 'arable'.
2. **Explain** what trend your graph shows.
3. **Justify** the trends you were expecting. Did you find those trends?
4. **Suggest** an explanation for the trends shown in the graph.

Table 11.1. Percentage of arable land in Australia used for agriculture

Year	Percentage of arable land used for agriculture
1995	60.313
1996	60.557
1997	60.164
1998	60.370
1999	59.061
2000	59.292
2001	59.318
2002	58.185
2003	57.209
2004	57.288
2005	57.944
2006	56.613
2007	55.380
2008	54.318
2009	53.243
2010	51.882
2011	53.326
2012	52.780
2013	51.627
2014	52.883
2015	47.630

11.2. Conventional vs organic farming

Qualitative differences between food produced by conventional monoculture and organic monoculture agricultural systems

Traditional farming relies on many off-farm resources, such as water, fertilisers, herbicides and pesticides. Traditional farming systems often consist of large-scale monocultures that rely on heavy machinery. While able to produce food conveniently and inexpensively, such farming systems are often unsustainable, either because of the inputs needed or the environmental impacts (which can eventually decrease farm productivity).

In contrast, **organic farming** adopts sustainable practices in all aspects of food production, handling, processing and labelling of food and food products. Organic farming, which occupies less land in Australia than traditional farming, supports a whole-system food management approach that follows ecological principles to promote and enhance biodiversity and biological activity and cycles. In addition to using organic practices on the farm, organic farmers limits their use of off-farm products and minimise farm waste.

Nutrients and soil quality

Traditional farming practice supplies nutrients to crops via synthetic inorganic fertilisers. Organic farming practice delivers nutrients to crops via **green and animal manure**, **crop rotation**, **compost** and the use of **cover crops**. Organic farming promotes healthier soils through till building, which ensures that the soil is not disturbed by ploughing or other activities. Till building is also called 'no-till farming'. In addition, organic farming practices incorporate crop rotation and organic soil conditioning, which build up organic matter and increase microbial activity in the soil. These strategies are not found in traditional farming, in which soils are often planted with the same crop year after year and inorganic fertilisers are routinely used to increase yields. Numerous investigations have concluded that soil in organic management systems is improved compared to soil in traditional agricultural systems.

Organic farms tend to have a more complex soil structure, and increased soil organic matter improves soil structure and stability, water filtration and holding capacity, and diversity in soil organisms. One of the most concerning features of traditional farming practices is the potential for nutrient run-off from the use of inorganic fertilisers, particularly nitrogen and phosphorus. Nitrogen and phosphorus run-off and leaching are significant contributors to waterway pollution.

(a)

(b)

Figure 11.5. A traditional farm (a) and an organic farm (b)

Figure 11.6. Organic soils often have increased biological activity. Credit: designed by Freepik

Figure 11.7. Traditional farms need to replenish phosphorus lost due to run-off. Credit: designed by Freepik

On organic farms, nitrogen is more tightly coupled to the plant–soil–microbes nitrogen cycle. This is due to the increased carbon in the system, which leads to a greater biomass demand for nitrogen. Therefore, the rate of nitrogen mineralisation (conversion of nitrogen by soil microorganisms from organic nitrogen to an inorganic state that plants can easily take up) is much higher in organic farms than in traditional farms – a three-season comparison of organic and traditional tomato farms found the soil in organic farms had 25% higher nitrogen mineralising potential. Thus organic farms do not need inorganic fertiliser and are less likely to leach nitrogen into waterways.

Soils on organic farms also show an increase in phosphorus retention and a better balance of nutrients compared with soils on traditional farms.

A phosphorus surplus can be found within both systems, but organically managed soils have less loss, possibly due to greater microbial biomass generating better nutrient cycling. Traditional farms tend to lose phosphorus in agricultural run-off, which then is replaced by inorganic fertilisers. This demand drives more phosphorus mining, but phosphate reserves are limited and the world is facing a future of phosphorus depletion, limiting the long-term productivity and sustainability of the system.

Organic farming also ensures that soils have a healthy environment that supports a more diverse population of macrofauna (including arthropods and earthworms) and a greater microbial biomass than is found in traditional farming systems.

Practical 11.2
Formation of soil humus

Soil is a mixture of weathered rock particles and humus; humus is the rotting remains of plants and animals found in the top layer of the soil. Soil bacteria break down the humus to release mineral salts such as nitrates and phosphates. Animals such as earthworms help to mix the humus into the soil, while rain can carry humus further down in the soil profile. The nutrients released from the humus (such as nitrate and phosphate) can be taken in by the plants through their roots, helping them to thrive. In this investigation, you will make your own humus and observe the stages of formation.

Aim

To generate humus from organic material.

Time required

30 minutes to set up
6–12 weeks to produce humus

Materials

- wooden, slatted box with an open top (vegetable or fruit box)
- tray or black plastic sheet or sack to cover the top of the box
- brick to hold down the cover of the box
- small hacksaw or hand saw
- organic material such as vegetable waste from a kitchen
- pitchfork
- soil

Procedure

1. Use the saw to cut out the base of the box, leaving an edge. The hole should be slightly smaller than the tray or proposed cover.
2. Find a site with uncultivated soil that is not under a tree or too exposed to wind or rain. If possible, choose a site that gets sun in the morning rather than in the afternoon. The morning sun is not as strong as afternoon sun, so the compost will be warmed without drying out and fungi and other organisms converting the waste will not die from lack of water.

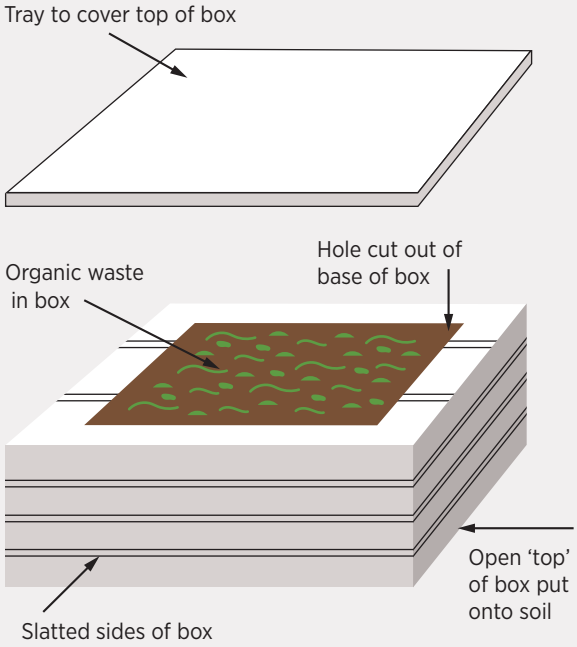


Figure 11.8. Set-up for making humus

3. Use a pitchfork to loosen the soil area.
4. Place the box with the open end down onto the soil.
5. Put a layer of organic material in the box.
6. Place a layer of soil over the material.
7. Now add other organic materials. Do not add meat, bones, stick or tough fibrous vegetation.
8. Add a sprinkle of soil with each layer.
9. Fill up the box to the top, then cover it with the tray or plastic. Put a brick on top to keep the lid on.
10. After 3 weeks, lift the box off the pile of waste and observe the state of your compost. Record your observation in the data table on the next page. Use a pitchfork to turn the material, placing the outside to the middle. Add another sprinkle of soil. Cover the box again.
11. Repeat every 3 weeks until the organic material has broken down into black, crumbly humus.

Box site:	
Organic material added:	
Date	Observations (size, colour, volume, invertebrates present)
1.	
2.	
3.	
4.	
5.	

Analysis

1. Why did your compost box have the following features: slatted sides, a layer of soil and a lid? Why was the site of the box important?
2. What was working in your bin to change the organic matter to humus?

Discussion

1. **Describe** how the organic matter changed over the 12 weeks.
2. **Suggest** ways that the decay could be sped up.
3. **Investigate** in which biome(s) humus forms rapidly. What effect does this have on this ecosystem?

Pest and weed management

In traditional farming, pests, weeds and pathogens are controlled by the use of pesticides. In modern farming times, global pesticides usage has totalled, conservatively, around 2 million tonnes. Herbicides account for around 50% of all pesticides and their use is increasing. Organic farming bans the use of pesticides, so organic producers must choose from the few alternative methods of pest management (mechanical, cultural or physical) that are effective.

Insects and pathogens

Despite the lack of pesticide use on an organic farm, research indicates that herbivore damage is roughly the same on organic and traditional farms. Organic farms have a higher species richness and abundance than traditional farms. This includes birds, predators and parasites – all of which help to control pests – and organic farms typically have fewer pests.

Figure 11.9. Organic farms often use chickens to control insect pests

Research on how insect populations respond to crops grown in inorganic and organic farming systems has found that several pest species (such as aphids) respond more vigorously to crops that have been fertilised with inorganic nitrogen.

It is thought that the lower incident of pest populations in organic farms is due to the increase in beneficial soil fungi and fungal-feeding nematodes as a consequence of increased organic matter in the soil. Pathogens may find it difficult to compete with the many active microbes found within organic farming systems. In contrast, there is little competition in traditional farming systems where microbial diversity within soils is less.

There is no single reason why organic soils have fewer pest species; rather, the organic system of soil conditioning ensures a balance and diversity of nutrients and a reduction in pest problems.

Weeds

Traditional and organic farmers manage weeds in crops very differently. It is interesting to note that organic farms have more weeds in their crops. This could be due to the use of animal manure and animals themselves (such as chickens) that spread viable weed seeds throughout the crop or to less effective pest control methods.

Traditional farmers rely on chemical herbicides, particularly glyphosate. The use of glyphosate in traditional farming exploded in the mid-1990s after glyphosate-resistant crops were developed. Herbicide-tolerant (HT) varieties have been bred for crops such as corn, cotton and soybean. Glyphosate-resistant crops are not affected when sprayed with the herbicide – only the weeds the herbicide is targeting are affected. This reduces the labour required to spray a field of crops in order to reduce the risk to crop yield. HT crops are a technological advantage but cause environmental concern due to the possibility of herbicide leaching. In addition, there is a growing body of evidence to suggest that large-scale use of glyphosate reduces the amount of soil microbes and earthworm populations.

Effective organic methods of weed management involve physical and cultural practices to bury, suppress or remove weeds. Physical weed management is the pulling out of weeds by hand whereas cultural weed management is the ability to understand the strengths and weaknesses of the weed and planting crops accordingly. For example, if there is a problem with a weed that enjoys full sun it would be advantageous to plant a tall crop like corn to shadow the weed and reduce its growing vigour.

Mechanical methods of weed removal include ploughing to turn deep soil over and bury sprouted weeds. However, ploughing disturbs the seed bank, leading to the germination of more weeds. Ploughing also has negative impacts on physical, chemical and biological characteristics of the soil.

Organic farmers commonly suppress weeds by mulching with material that acts as a barrier to weed germination and growth. It is widely accepted that mulching is a more effective weed-suppression method than the application of glyphosate.

Many organic methods of weed removal carry a higher risk of not completely removing all the weeds and so adding to the soil weed seed bank. For example, physical removal of weeds could leave one or two that could grow and flower and so set seed. The same could be said for cultural methods.

Weed suppression on an organic farm will be less effective than the broad-scale use of herbicides in a traditional farming system, and organic farmers need a well-prepared weed-suppression plan. Despite the reduced efficacy, organic weed control has far-reaching benefits including environmental protection, protection of farm workers from exposure to toxic chemicals, and ultimately improved sustainability of the farming production system.

Practical 11.3
Effects of nitrates on azolla populations

Introduction

Grassy parks, green lawns and neatly clipped golf courses owe their vigour and rich colour to fertilisers. Most fertilisers contain three primary nutrients: nitrogen, phosphorus and potassium. After a rain, fertiliser that has not been taken up by plants washes into nearby streams, rivers, lakes and ponds. In these waterways, fertiliser has the same effects on water plants as it did on those terrestrial plants for which it was designed. However, fertiliser levels can accumulate in waterways and cause plant growth to become excessive.

One water plant that responds well to fertiliser is azolla (*Azolla filiculoides*), a widespread fern species that is also native to Australia (Figure 11.10). These plants live in still or slow-moving warm water. An azolla plant does not look much like a typical plant, being just a single lobe or frond (a leaf-like structure). Fronds often grow in clumps with roots hanging below. In this experiment, you will raise azolla in the laboratory and find out how different levels of nitrogen affect its growth.

Figure 11.10. Azolla plant. Credit: bobistraveling CC BY 2.0

Aim

To determine the effects of inorganic fertilisers on a water plant.

Time required

2 weeks

Materials

- Azolla fronds
- 4 Petri dishes
- 25 mL nitrogen solution B, which contains nitrogen at the recommend concentration for lawns and gardens
- 25 mL nitrogen solution C, which contains nitrogen at half the recommended rate for lawns and gardens
- 25 mL nitrogen solution D, which contains nitrogen at twice the recommended rate for lawns and gardens
- 25 mL tap water
- inoculating loop
- magnifying glass or stereomicroscope
- permanent marker or pen
- coloured pencils
- graph paper
- grow lights or access to a sunny window
- science logbook

Procedure

1. Label the four Petri dishes 'A', 'B', 'C', and 'D'.
2. To dish A, add 25 mL of tap water. This will serve as the control in your experiment.
3. To dish B, add 25 mL of nitrogen solution B.
4. To dish C, add 25 mL of nitrogen solution C.
5. To dish D, add 25 mL of nitrogen solution D.
6. Use an inoculating loop to transfer 20 lobes (fronds) of azolla to each Petri dish. A lobe is one plant, although lobes may be growing in clumps.
7. Place the tops on the Petri dishes and set the dishes under grow lights or in a window where they receive plenty of light.

continued next page

Practical 11.3 (continued)

8. Each day for 2 weeks count the number of duckweed lobes in each dish. Record your counts on the data table.

   To count lobes, view the plants using a magnifying glass or a stereomicroscope.

   Count every visible lobe, even the tiny ones that are just beginning to grow from another lobe. For example, Figure 11.11 shows a clump of plants that is made up of four lobes.

   If plant populations are extremely high, draw a four-quadrant grid on a piece of paper (see Figure 11.12) and place the grid under the Petri dish. Count the lobes in only one grid, then multiply your count by four.

9. Graph your experimental findings. Place time (number of days) on the *x*-axis and number of lobes on the *y*-axis. Use a different colour pencil for each Petri dish.

	Number of plants in each Petri dish			
	A	B	C	D
Day 1	20	20	20	20
Day 2				
Day 3				
Day 4				
Day 5				
Day 6				
Day 7				
Day 8				
Day 9				
Day 10				
Day 11				
Day 12				
Day 13				
Day 14				

Analysis

1. What nutrients are found in most fertilisers?
2. How do fertilisers enter waterways?
3. Describe the structure of one azolla plant.

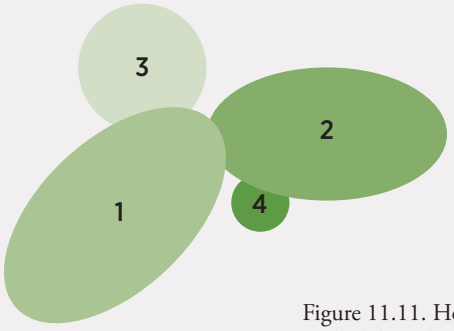


Figure 11.11. How to count azolla lobes: this example has four lobes

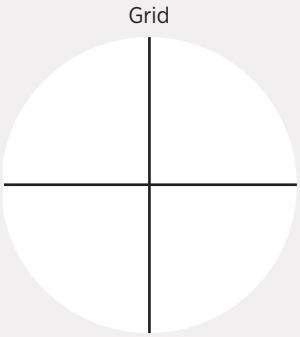


Figure 11.12. A quadrant to be placed under the Petri dish

Discussion

1. In this experiment, in which Petri dish was azolla growth the greatest? **Explain** why.
2. How do you think fertiliser run-off into waterways affects azolla populations? **Explain** your answer.
3. **Suggest** some ways to reduce the problem of fertiliser run-off.

Note to teachers

Make three solutions of nitrogen fertiliser (ammonium nitrate is preferable) at different strengths. To prepare solutions, rinse out three 3 L milk containers. Fill each with water. Label the containers 'B', 'C' and 'D'. To jug B, add the amount of fertiliser recommended on the box or bag. Mix the fertiliser with the water until completely dissolved. To jug C, add half the amount of fertiliser recommended. Mix the fertiliser with the water until completely dissolved. To jug D, add twice the amount of fertiliser recommended. Mix the fertiliser with the water until completely dissolved.

Critical thinking and discussion 11.2

Soil Your Undies Challenge is a citizen science project run by the University of New England, New South Wales, in partnership with Cotton Info. Participants receive a pair of 100% cotton undies to bury. After 8 weeks, participants dig up the undies and observe what type of damage has occurred. The greater the damage, the higher the soil microbial activity.

Find out about the program at https://www.unediscoveryvoyager.org.au/2020/12/14/soil-your-undies-wrap-it-up/.

If you want to, you can do your own Soil Your Undies Challenge.

(a)

(b)

Figure 11.13 (a) Dr Oliver Knox with a well-decomposed pair of undies dug up after 8 weeks in a healthy soil. Credit: Matt Cawood. (b) Undies from a whole range of soils – the degree of decomposition reflect soil health.
Credits: Kieran Meaney, Phil Spark, Oliver Knox

CHAPTER

12

Food security

12.1. Improving food security

Challenges to supplying adequate and affordable food in regional and global locations that achieve regional and global food security

Options for improving food security that consider organisational, political and structural enablers and barriers to change

What is food security?

The term **food security** was originally used to describe whether a country had enough food to meet the **nutritional requirements** of its population. This could be measured by a country's ability to produce enough food to feed the population and achieve self-sufficiency. In Australia, around 15% of the population has experienced food insecurity over the past 12 months – that is around 3.5 million people. Globally, 9.2% of the population (700 million people) were exposed to severe food insecurity.

Food security can be viewed from a regional or local perspective: is enough food available? Food security can also be a measure of household wealth: a household is considered to be food secure if they have the ability to acquire food.

But food being available does not mean that everyone can access that food. Obtaining food security, regionally or globally, does not guarantee a population has access to nutritionally dense foods.

There can be **transitory food insecurity**, caused by seasonal fluctuation of sufficient food, or **permanent food insecurity,** described as long-term lack of access to food due to prolonged war or drought.

In this chapter we will consider food security as described by the 1996 World Food Summit:

"Food security exists when all the people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life".

Global food security depends on a healthy and productive environment; however, the human race is facing challenges to food security due to the declining health of the planet and changing climate patterns.

Challenges to achieving food security

Food security is challenged both by factors that increase demand for food and by factors that reduce production. Even when a country or society has enough food overall, disadvanted people in that society may not have food security; thus, access to nutritious food is also a challenge to security.

Despite growing globalisation, much of the world's population still eats food that is grown locally. Many developing countries are susceptible to food shortages if their production of a certain food declines or if food prices get too high. In those cases, local agricultural production is vital to assure food security.

The amount of local agriculture that can take place depends on the amount of arable (farming) land available, access to seeds and fertiliser as well as favourable farming practices and government policies. Climate also affects the ability of local communities to grow food locally.

Rising demand – population and diet

The demand for food is increasing as the global population rises. The global population is predicted to increase by 1.1% each year (or 86 million additional people in the coming year). This increase will put a significant strain on global food resources on a planet that is already suffering overconsumption and exploitation. Global population increase is not the only issue: cultural diets are changing as well, adding to the strain of meat production. People in countries like China and India, where traditionally animal protein consumption has been low, are consuming more animal protein in their diet. While the Western world is now seeing that a decrease in meat consumption is an effective way to reduce the stress on the global food production chain, any reduction will be filled by other countries' increased meat consumption.

Figure 12.1. Climate change can affect rainfall and reduce agricultural productivity. Credit: designed by Freepik

Climate change

A changing climate will influence rainfall patterns and crop yields. Considering global demand for cereal crops specifically, the food production system of the world is in crisis. In 2011 the United Nations identified that the world's grain reserves had been depleted and were at their lowest level for close to half a century. This is due to the changing landscape from which the global population cultivates food.

It is predicted that climate change will reduce global production of wheat, beef, dairy and sugar by 2–6% by 2030 and by 5–11% by 2050. The 5–11% decrease by 2050 will coincide with the increase in global population from 7.8 billion in 2020 to 9 billion in 2050.

Land degradation

Increasing environmental burdens such as desertification, acidification, salinisation, pollution and erosion have reduced the amount of land available for food production.

Water supply

Water availability is also becoming a problem, with climate change varying rainfall patterns and volume. Growing populations need more water but are facing reduced supply. Groundwater may be available but there are already concerns that aquifers are becoming depleted.

Technological improvements

Advances to existing technologies is favoured by some as a way forward, but different countries need different technologies to achieve food security. In developing countries, strategies can include soil preparation, soil and water management, seed production, weed and pest control, and post-harvest storage. In developed countries like Australia, food security technologies can take the shape of better cultivars of certain plants or the introduction of plants that can produce a higher yield. Technologies or practices that can produce the same amount or greater yield with little or no impact on the environmental condition are often prioritised for development.

Options for improving food security

Food security will be improved by improving food availability (increasing production) and ensuring access for all, including poor individuals and communities.

International aid

As global food insecurity increases, and a higher proportion of individuals have limited access to food, Australia is likely to be asked to assist those nations with contributions of aid. This aid could be in two forms: increased food donations to alleviate hunger or accepting more refugees from nations that can no longer provide food security for their people.

Native cereal crops

Australia has long been a producer and exporter of large volumes of wheat. As can be seen in Exploring science 5 ‘Changing climate has stalled Australian wheat yields: study’ (p 214), a changing climate is reducing the security of future wheat production. It has been recently established that Aboriginal and Torres Strait Islander peoples had been harvesting native grains in Australia long before Europeans introduced wheat. Reintroducing native cereals into farming practices would place less burden on the environment and capitalise on a well-used farming practice. Other native plants can also be introduced into the mainstream food market, such as the desert raisin (*Solanum centrale*) and native yams.

Adapting to new environmental condition

Unpredictable rainfall will be one of Australia’s biggest problems as the climate changes. Australia’s climate is predicted to become drier with large spells of drought followed by heavy, flooding downpours. By genetically modifying plants or adjusting farming practices to reflect an acceptance of climate variability, we will ensure a more secure food market in Australia.

Environmental protection through policy

There has always been conflict between agriculture and environmental protection. As biodiversity dwindles, it is becoming increasingly difficult to avoid having to make compromises between value systems that put human needs before others and value systems that put environmental protection first. There is not one dominant way of thinking in Australia and many different ways are represented and acknowledged.

Not all Australians currently enjoy food security. Pressures on food supply including global demand (due to population increase and diet changes) mean that food prices will continue to increase in the future. Therefore, solutions need to be presented that can balance the need for environmental protection and the need to maintain and increase food security.

Policymakers often favour technological solutions, but these solutions don’t always consider the underlying problems associated with ecological degradation they may cause. Thus, decision-making does not always take into account all social, environmental and economic aspects. Research and development of such technologies may not consider community views until the technologies are being adopted. This gives people limited opportunity to contribute to technological solutions.

Ethical consumption

Ethical consumers are those who consider environmental impacts when buying and consuming food in an effort to improve local and global food security. They will favour food that is:

- sustainably produced
- locally produced
- in season
- free of excess packaging and sympathetic to waste reduction.

These consumers are willing to pay extra for ethically sourced food.

Ethical food consumption in Australia has increased over the past decade in line with worldwide trends. While Australia's ethical food sector (both consumers and producers) is not as well advanced as in Europe or North America, it is more advanced than our Asian neighbours. Even so, it is difficult for consumers to make clear ethical decisions as there is little guidance from government. This means it is up to the ethical consumer to find out about and assess multiple aspects of a particular food production system.

Figure 12.2 The Aquaculture Stewardship Council (ASC) label only appears on food from seafood farms that have been independently assessed and certified as being environmentally and socially responsible. Credit: Aquaculture Stewardship Council

Without government policy requiring transparency in food marketing, food production processes are largely invisible to the consumer. For example, farmed Atlantic salmon is advertised by the industry as more sustainable than wild-caught salmon. Consumers are encouraged to buy brands displaying symbols and statements promoting that they are ethically sourced, sustainably caught or farmed responsibly. It is then left to the consumer to inquire as to the meaning of the varying statements. The Australian Marine Conservation Society reports that every tonne of Atlantic salmon produced by salmon farms requires sourcing 3 t of wild-caught fish as food. This ratio is not considered sustainable, but there is no government policy or guideline that can assist the consumer in straightforward choices.

Student activity 12.1
Global food production

The Food and Agriculture Organization of the United Nations compiles information on global food production and agriculture for 245 countries in its FAOSTAT database. On the Compare Data page (http://www.fao.org/faostat/en/#compare), you can find time series data on a whole range of measures.

Complete the following task. Make five different comparisons for groups, domains, elements and items for two different countries.
See below for an example and fill in the table.

Results table

Countries	Groups	Domains	Elements	Items

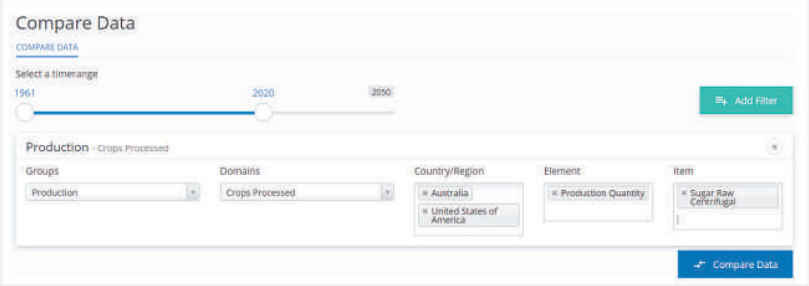


Figure 12.3. Screenshot of the FAO Compare Data page

Critical thinking and discussion 12.1

Using one of the examples from the table below, choose a food system problem to address or choose one of your own.

1. **Describe** any downstream effects of your chosen problem on public health, society, and/or ecosystems.
2. **Identify** factors that contribute to the problem, and choose at one factor that an intervention could act upon.
3. **Design** an intervention, including an achievable goal (be realistic), specific action steps and how the effects of the intervention will be measured.
4. **Identify** allies who could help implement the intervention.
5. Anticipate potential barriers, including groups in opposition to the intervention, and **suggest** how they could be overcome.

	Example 1	Example 2	Example 3
Problem	High consumption of sugar-sweetened drinks	Lack of access to healthy food in the community	High rates of wasted food
Downstream effect	Increased risk of obesity and diet-related diseases	Hunger and food insecurity, higher risk of obesity	Greenhouse gas emission from landfill, wasted resources, missed opportunity to feed people
Contributing factor	Availability of sugary drinks in the environment, behaviour of friends and family, marketing, lack of knowledge about health risk etc.	Poverty, lack of supermarkets or lack of healthy options in stores	Unwillingness of stores to stock 'ugly' products, large portion sizes, plant waste etc.
Intervention	Develop a campaign to change school policy in selling sugary drinks	Develop a plan for a farmer's market and present it to local government	Measure the amount of wasted food at school and offer a prize to the class with the lowest amount
Potential allies	Teachers, school leadership, Parents and Friends Association (PFA) members, local doctor etc.	Local farmers, community leaders, not-for-profit organisations working to promote food security	Teachers, parents, canteen
Potential barriers	School's reluctance to give up revenues from sales of sugary drinks which might be funding sporting teams and clubs	Available land may be designated for other uses (e.g. real estate development)	Might require permission from school administration and may encounter resistance from canteen

CHAPTER

13

Ecological footprint

13.1. Ecological footprint analysis

The use and limitations of ecological footprint analysis, in terms of the sustainability principles of intragenerational equity and the efficient use of resources

Sustainable development was described in 1987 by the World Commission on Environment and Development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

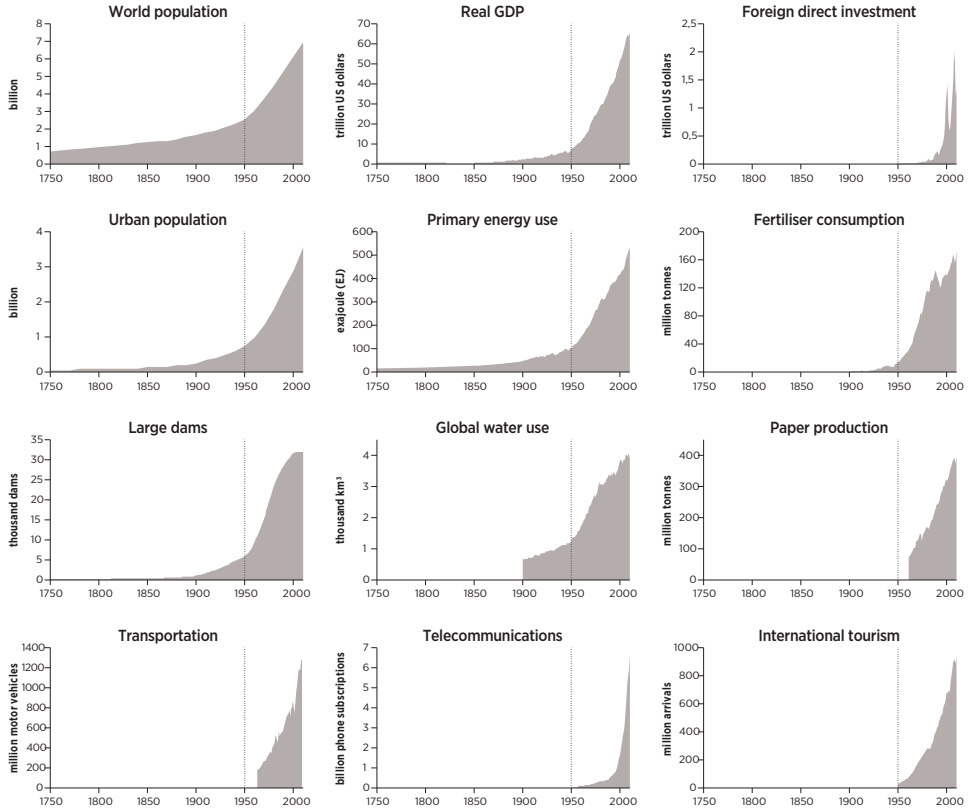
For more than three decades, work has gone into identifying key issues surrounding the economical, ecological and social application of sustainable development. This work quickly identified that sustainable development cannot be achieved without a central focus on sustainable consumption patterns. For example, an article featured in the journal *Nature* found that the most concerning threats to the 8,500 threatened or near threatened species on the International Union for Conservation of Nature Red List of Threatened Species (IUCN Red List) were overexploitation and agriculture.

Human impacts change the globe

In their 2018 *Living Planet Report,* Worldwide Fund for Nature (WWF) observed that we live in a world that is rapidly changing due to increased consumption and our ever-increasing demand for energy, land and water. Overconsumption is the single biggest factor driving the planet into a new time on the geological clock: the Anthropocene. We have reached an epoch where the impact of humans will forever be recorded in the geological timeline of planet Earth.

The rapid increase in measures of human activity beginning in the 1950s (see Figure 13.1) is called the 'Great Acceleration' and has brought many benefits to our society. For example, an increase in technology has meant that clean water is available to more humans than ever before. There is a strong connection between the advancement of humans and an overall rise in health, wealth, food and security.

Socio-economic trends



Earth system trends

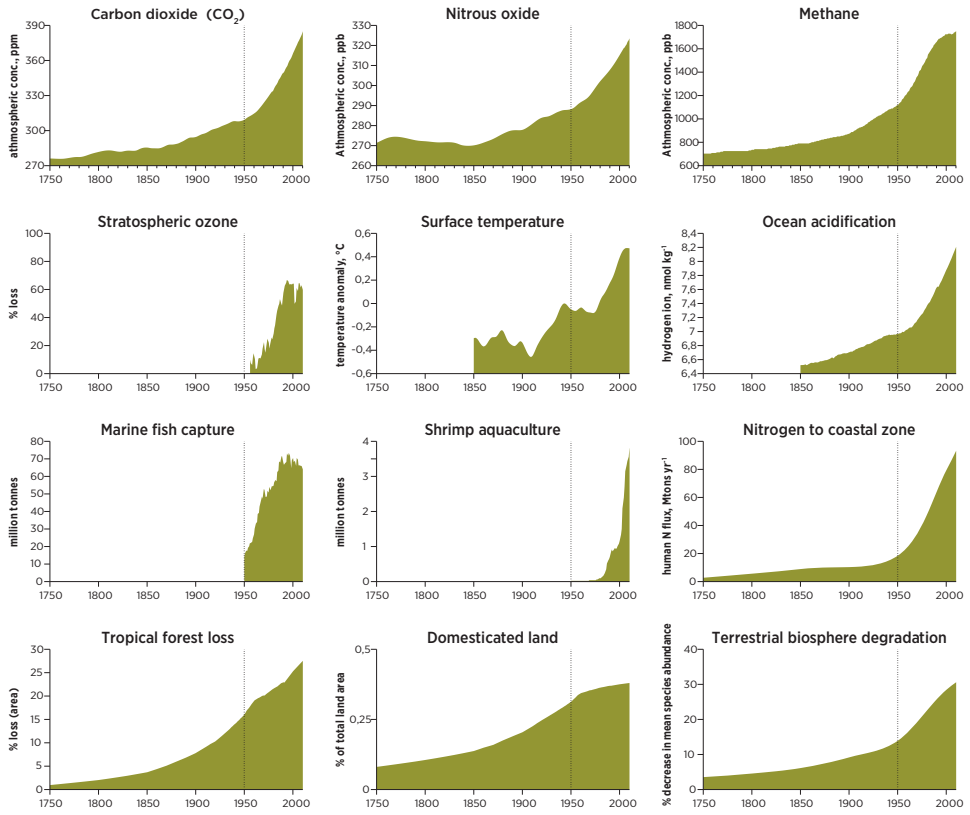


Figure 13.1. Records beginning in 1750 show a consistent trend upwards from the beginning of the Industrial Revolution, and particularly from 1950, in all socio-economic and Earth system trends

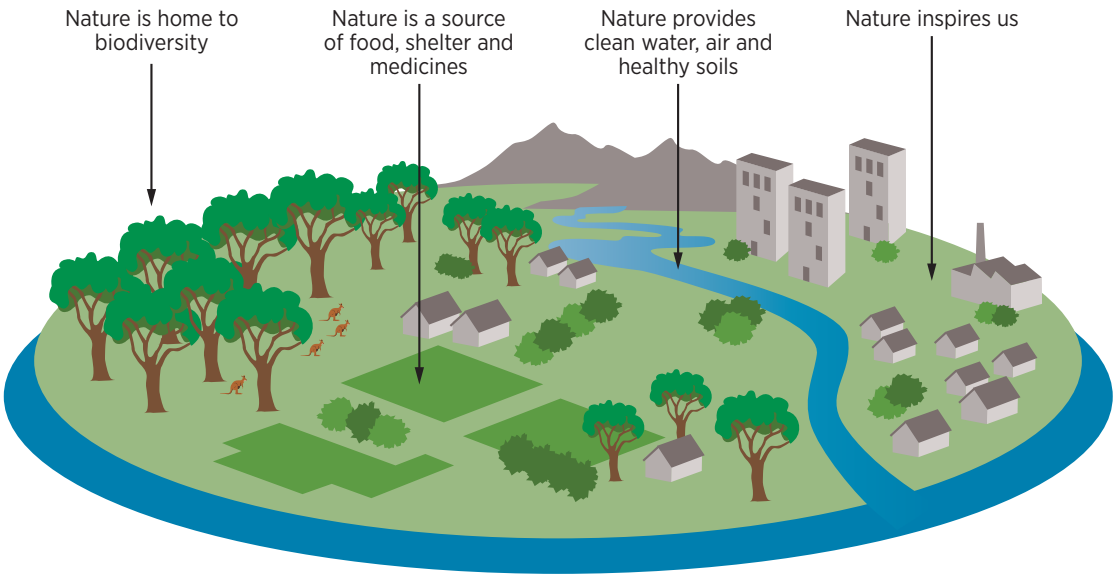


Figure 13.2. The importance of nature to people: nature provides us with vital goods and services

At the same time, however, human activities have disrupted natural systems and negatively affected Earth's four systems: the biosphere, atmosphere, hydrosphere and lithosphere. These systems provide a variety of ecological services (Figure 13.2). A decline in the natural world will signal a decline in resources available to all living things and therefore a decline in overall health, wealth, food and security. To reverse this declining planet health, we need to address overconsumption of all resources.

Calculating our ecological footprint

The demand a person or population makes on resources and services provided by natural ecosystems is known as their **ecological footprint**. Thus, the ecological footprint is one way to measure our consumption of natural resources or overexploitation.

Calculations of ecological footprint take into account the type and source of food consumed, other goods consumed and services used and the natural resources that have gone into them, the carbon dioxide emitted to provide these goods and services, and other wastes produced. People's ecological footprints vary due to differences in their lifestyles, consumption patterns and the infrastructure supporting their activities.

The ability of an ecosystem to renew the resources that have been used is called **biocapacity**. If a resource is consumed faster than that resource can renew itself, then that resource is considered overconsumed.

Ecological footprints and biocapacity are both measured in global hectares (gha) – a unit of averaged productive land. Comparing the ecological footprint of the global population against the biocapacity of the planet provides a measurement of humanity's ability to live within its means. Through better technology and practices, biocapacity has grown globally over the past 50 years by 27%, but this is not enough to keep up with demand. Humanity's ecological footprint over the same 50 years has grown by 190%! Figure 13.3 shows that our ecological footprint well exceeds Earth's biocapacity.

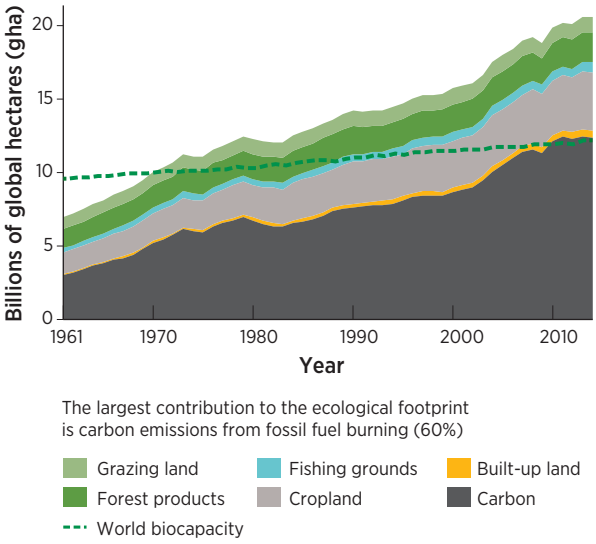


Figure 13.3. World ecological footprint of consumption by area types in global hectares 1961–2014

Figure 13.4. The biocapacity of Australia is reducing and measures need to be taken to preserve it for future generations

Most regions, and in fact many nations, cannot produce all the resources they need so they depend on neighbouring regions and countries for trade. Therefore, a country's ecological footprint includes production and consumption of its own goods and services plus imports from other countries, and excludes exports.

The Global Footprint Network provides an open data platform that analyses the ecological footprints for all nations. In 2016, the Global Footprint Network recorded Australia's ecological footprint as 6.6 gha per person and our biocapacity as 12.3 gha. Looking at the current ecological footprint vs the biocapacity, Australia seems to be in good shape. But if Australia's ecological footprint is compared to the global average (a mere 1.6 gha per person), it is clear that Australians enjoy a much larger slice of Earth's biocapacity that the average person does.

In addition, the biocapacity per person in Australia is trending down and is much closer to the ecological footprint than it was 20 years ago. In 1987, Australia's ecological footprint was 6.54 gha per person (similar to the 2017 figure) and the biocapacity was 19.26. Thus while the ecological footprint has been more or less stable over that time, the biocapacity of the country has reduced. Unless measures are taken to preserve our biocapacity, it will be overtaken by our ecological footprint in time.

Ecological footprint calculators have limitations and should be used with caution as they do not give a full overview of global environmental challenges. Ecological footprint calculators use average values and can't take into detailed consideration different types of land use. For example, over 40% of Australia's biocapacity is taken up by land that is growing and actively absorbing carbon from the atmosphere. However, to absorb the amount of carbon being emitted by Australia would require an additional 62 million hectares of carbon-absorbing land. Thus, while ecological footprint calculators and measurements of biocapacity are a reasonable guide and provide a useful comparison, they are built on assumptions and simplification and therefore have limits in their scientific application.

Data analysis 13.1
National footprints

Head to the Global Footprint Network and explore the data on national footprints and biocapacity (https://data.footprintnetwork.org).

1. Explore the data available for 10 countries. Rank those 10 countries in order of fastest to slowest biocapacity depletion.
2. Think about what the fast-depleting countries have in common and make an inference as to why these countries are (or will be) exceeding their biocapacity.
3. Complete the following activity to illustrate agriculture and biocapacity.

If Earth was an apple

Materials

- apple
- knife
- paper towel

Procedure

1. Water: Take an apple and think about the apple as Earth. Now cut the apple into quarters and remove ¾, leaving ¼. The ¼ is how much of Earth is not covered with water.
2. Polar icecaps, high mountains: With the remaining ¼ of the apple in your hand, look at it and cut it in half again. Remove ½ of the 'dry' Earth surface because this area is either under polar icecaps or in high mountain ranges and so not able to produce food, fibre or wood. You will now have about ⅛ of the original apple in your hand.
3. Too hot, too cold, too wet, too dry, too shallow: With the remaining ⅛ of the apple in your hand cut it into quarters again, removing ¾ of the ⅛ to represent the remaining Earth surface that is too hot, too dry, too wet too cold, too shallow to raise food, fibre or wood. You should have 1/32 of the original apple left in your hand.
4. Skin of Earth: With the 1/32 of the apple in your hand remove the skin of the apple. The skin of the apple represents the soil that is available to raise all the food, fibre and wood on the face of Earth.

Data analysis 13.2
Calculate your carbon footprint

Head to the Global Footprint Network Ecological Footprint calculator (http://www.footprintcalculator.org/) and calculate your carbon footprint. Then answer the following questions.

1. Were there any items calculated that surprised you? Explain why they surprised you and why you think they needed to be included.
2. Many of the items gave you the option of completing the calculation with more accuracy. Why do you think accuracy is important?
3. Research the greenhouse gas output from a cow and a pig and determine which animal produces more greenhouse gas. Did the answer surprise you?

Critical thinking and creative thinking 13.1

1. Does the 'If Earth was an apple' exercise make a difference to your earlier inferences as to the biocapacity of different countries around the world?
2. Describe what would happen to Earth's biocapacity if extreme weather events became more frequent.
3. Write a poem that appeals to the community to stop wasting food.

13.2. Calculating a product's carbon footprint

The ecological footprint of either an individual, local and/or international community or business, or a local or imported raw food and/or food product

Every product has an impact on the environment, and one of the key factors determining a product's sustainability is its **carbon footprint**. A carbon footprint is one aspect of the ecological footprint – it focuses on the greenhouse gases emitted in the production, use and disposal of the product. Understanding the carbon footprint of products helps you reduce emissions effectively through determining where in the manufacturing or life cycle of a product the carbon footprint can be reduced.

A carbon footprint can be calculated as impact per year or per use; for example, a car's carbon footprint can be measured per year of ownership after manufacture or per kilometre travelled. A shampoo bottle can have a carbon footprint based on the liquid inside as well as the bottle or also include the hot water consumed in the shower. No carbon footprint calculation will ever be perfect – it is always a best estimate based on the data you have.

Determining a product's carbon footprint allows organisations to determine the impact of the products and services they supply. If the calculation is made at the manufacturing level, it gives companies the opportunity to make design improvements to reduce emissions. Companies can also market their product as a better environmental choice than a rival product.

Some products and business are easier than others to determine the carbon footprint of. To calculate a carbon footprint you will need to source a variety of primary and secondary data. That data should be assessed using the following five criteria:

- relevance – how helpful is the data in completing the calculation?
- completeness – is all the data available?
- accuracy – how well does the data represent the true nature of the carbon impact?
- credibility – is the data from a source that has credibility and is true and believable?
- timeliness – how up to date is the data?

CASE STUDY 13.1
Basic carbon footprint calculation for a business

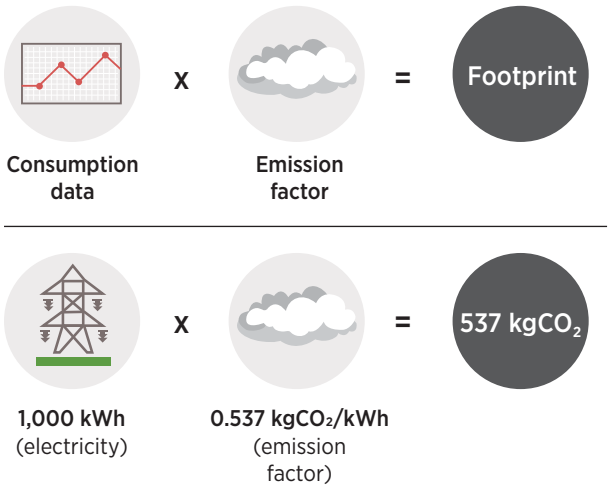


Figure 13.5. Basic carbon footprint calculation when exploring the carbon footprint

When exploring the carbon footprint of a business, a number of elements can be investigated. In this case study, we will determine the carbon footprint of a trucking business by using a simple calculation that multiples the **consumption data** (the electricity, petrol, diesel oil or any other energy consumed in the manufacture or transport of a product) with the **emissions factor** (a predetermined amount reflecting the emissions created by difference types of fuel consumption). The fuel combustion emission factor is modified by the **energy content factor**, which accounts for different types of solid fuels having different energy outputs.

In the following example, the solid fuel is bituminous coal, which has an energy content factor of 27.0 gigajoules (GJ) per tonne and an emissions factor of 90 kg of carbon dioxide equivalents (CO_2-e) per gigajoule.

So if a manufacturing plant uses 20,000 t of bituminous coal in production, the carbon footprint calculations is:

$$\text{Carbon footprint } (CO_2 \text{ output}) = \frac{\text{consumption data} \times \text{energy content factor} \times \text{emission factor}}{1{,}000}$$

$$= \frac{20{,}000 \text{ t} \times 27.0 \text{ GJ/t} \times 90 \text{ kg } CO_2\text{-e/GJ}}{1{,}000}$$

$$= 48{,}600 \text{ t } CO_2$$

As another example, if a freight company consumes 10,000 kL of automotive diesel, the carbon dioxide emission is:

$$\text{Carbon footprint } (CO_2 \text{ output}) = \frac{\text{consumption data} \times \text{energy content factor} \times \text{emission factor}}{1{,}000}$$

$$= \frac{10{,}000 \text{ t} \times 38.6 \text{ GJ/t} \times 69.9 \text{ kg } CO_2\text{-e/GJ}}{1{,}000}$$

$$= 26{,}981 \text{ t } CO_2$$

Table 13.1 shows energy content factors and emissions factors of some of the most common solid and liquid fuels, which you can use in a carbon footprint calculation.

Table 13.1. Fuel energy content factors and emission factors

Fuel combusted	Energy content factor (GJ/t)	Emission factor (kg CO_2-e/GJ)		
		CO_2	CH_4	N_2O
Solid fuels and coal-based products				
Bituminous coal	27.0	90.0	0.04	0.2
Sub-bituminous coal	21.0	90.0	0.04	0.2
Anthracite	29.0	90.0	0.04	0.2
Brown coal	10.2	93.5	0.02	0.3
Coking coal	30.0	91.8	0.02	0.2
Coal briquettes	22.1	95.0	0.08	0.2
Coal coke	27.0	107.0	0.03	0.2
Coal tar	37.5	81.8	0.03	0.2
Dry wood	16.2	0.0	0.1	1.1
Biomass (municipal and industrial materials)	12.2	0.0	0.8	1.0
Liquid fuels and certain petroleum based products for stationary energy purposes				
Diesel oil	38.6	69.9	0.1	0.2
Gasoline (other than for use in an aircraft)	34.2	67.4	0.2	0.2
Kerosene (other than for use as fuel in an aircraft)	37.5	68.9	0.01	0.2
Avgas (gasoline used in an aircraft)	33.1	67.0	0.2	0.2
Biodiesel	34.6	0.0	0.08	0.2
Heating oil	37.3	69.5	0.03	0.2
Ethanol (as fuel in internal combustion engine)	23.4	0.0	0.08	0.2

Source: National Greenhouse and Energy reporting (Measurement) Determination 2008 (Schedule1)

Life cycle analysis

Life cycle analysis (LCA) aims to quantify all environmental impacts of a product over its entire life cycle. Most attention is given to consumer products, but life cycle analysis may also be applied to services and policies. A life cycle analysis should cover the entire life cycle of the product, from extracting raw materials, through manufacturing, distribution and use to disposal. For all stages, life cycle analysis identifies:

- materials used (and their source and processing)
- energy use
- water consumption
- the types and quantities of discharges (including wastewater).

Life cycle analysis improves the information base for decision-making by assessing the impact of energy and material use and waste discharges. This information can be used to adopt alternative materials or methods to reduce the product's environmental impact. Life cycle analyses should consider aspects including ecological health, human health and resource depletion. The basic steps in a life cycle analysis are:

1. **Goal definition:** decide the purpose and conduct of the study and the product, service or policy to be analysed.
2. **Inventory:** identify the systems or stages in the life cycle to be analysed and all inputs from, and outputs to, the environment.
3. **Impact assessment:** convert the inputs and outputs into their contributions to environmental problems, which gives you an environmental profile of the product, service or policy.
4. **Improvement:** evaluate alternative strategies that could reduce lifetime environmental impact.

Student activity 13.1 Calculating emissions

A truck carries 100 television sets (weighing 5.8 kg each) to a shop 120 km away and returns empty. The round trip takes 2.5 hours. The next day, the same truck carries 10 television sets (also weighing 5.8 kg) to the same shop in the same length of time. The truck's emissions equate to:

- 0.25 kg of carbon dioxide per kilometre
- 0.12 kg of carbon dioxide per minute at average speed
- 0.1 kg of carbon dioxide per tonne/kilometre.

Using the data above, calculate the carbon dioxide emissions attributable to transporting one television set each day based on:

- distance
- time
- load.

Based on your results, where would you focus your attention in terms of trying to reduce carbon dioxide emissions from the transport component of this company?

Data analysis 13.3
Coffee roasting in UK

A company wanted to understand the climate impact of cultivating coffee beans in tropical regions, shipping them to the UK, roasting the beans using natural gas, and packaging them ready to be distributed to business customers (such as coffee shops) within the Oxford area.

The primary data obtained for the coffee roasting operation included:

- Amount of natural gas required to roast enough green beans to obtain 1 t of medium-roasted beans = 1,680 kWh
- Weight of aluminium foil bag to package 1 kg roasted beans = 31 g
- Weight of aluminium foil bag to package 3 kg roasted beans = 52 g
- Proportion of aluminium bags wasted in packaging operations = 2%
- A 20% weight loss occurs when roasting beans, so 1.25 t of green beans is required to obtain 1 t of roasted beans.

Several assumptions were made to fill data gaps:

- Average distance green beans are transported via Tillsbury Docks to Oxford is 5,000 km by sea and 500 km by road.
- Given that the bag for packaging 1 kg of coffee weighs 31 g and the bag for packaging 3 kg of coffee weighs 52 g, on average 1 t of coffee is packaged in bags weighing 48 kg.
- Average transport distance for coffee delivery is 120 km.

Table 13.2. Consumption and emission factors for activities involved in producing coffee

Input/activity (unit)	Emission factor ($kgCO_2$-e/unit)
Roasting beans (kWh)	0.227
Growing green beans at farm (t)	4,200
Average UK truck (tkm)	0.301
Average bulk carrier (tkm)	0.004
Aluminium foil (kg)	10
Aluminium foil to landfill (kg)	10.2

Using this example of coffee production, calculate the carbon footprint for a product of your choice. For emission factors relevant to your topic that are not given in Table 13.1, you will need to search in the scientific literature.

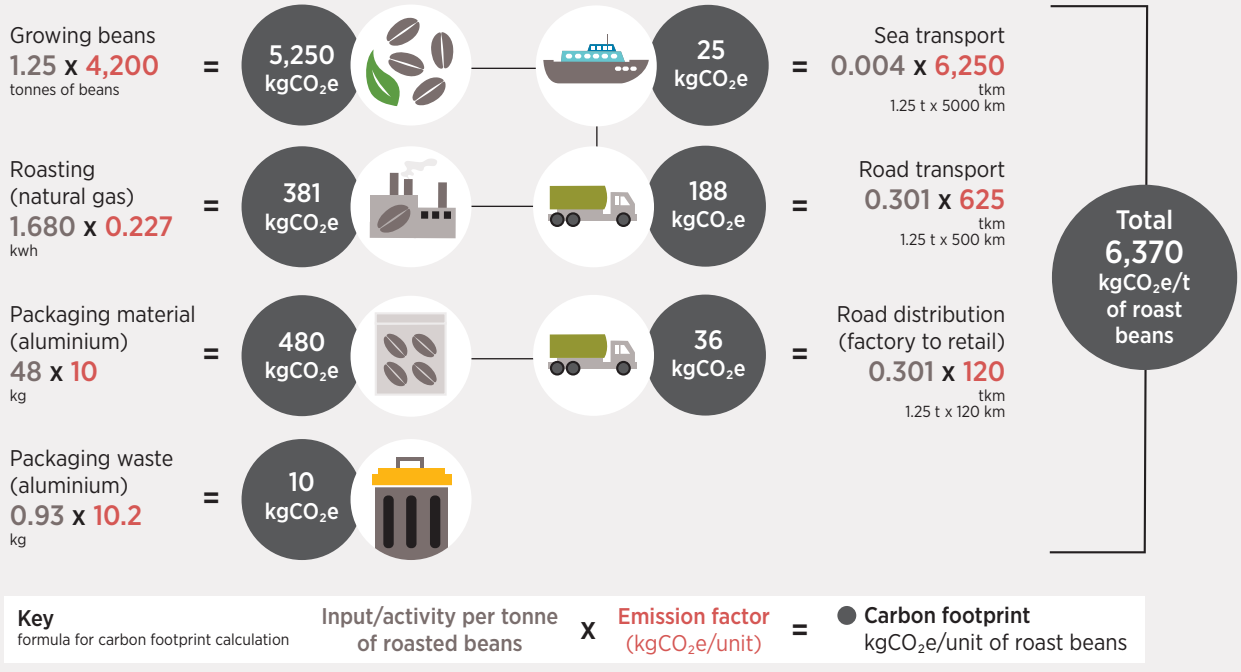


Figure 13.6. Calculating the carbon footprint of coffee beans

EXPLORING SCIENCE 5
Changing climate has stalled Australian wheat yields: study

Zvi Hochman, Senior Principal Research Scientist, Farming systems, CSIRO; David L. Gobbett, Spatial data analyst, CSIRO; and Heidi Horan, Cropping Systems Modeller, CSIRO

This article was originally published in The Conversation*, 25 January 2017.*
https://theconversation.com/changing-climate-has-stalled-australian-wheat-yields-study-71411

Australia's wheat yields more than trebled during the first 90 years of the 20th century but have stalled since 1990. In research published today [25 January 2017] in *Global Change Biology*, we show that rising temperatures and reduced rainfall, in line with global climate change, are responsible for the shortfall.

This is a major concern for wheat farmers, the Australian economy and global food security as the climate continues to change. The wheat industry is typically worth more than A$5 billion per year – Australia's most valuable crop. Globally, food production needs to increase by at least 60% by 2050, and Australia is one of the world's biggest wheat exporters.

There is some good news, though. So far, despite poorer conditions for growing wheat, farmers have managed to improve farming practices and at least stabilise yields. The question is how long they can continue to do so.

Worsening weather

While wheat yields have been largely the same over the 26 years from 1990 to 2015, potential yields have declined by 27% since 1990, from 4.4 t/ha to 3.2 t/ha.

Potential yields are the limit on what a wheat field can produce. This is determined by weather, soil type, the genetic potential of the best adapted wheat varieties and sustainable best practice. Farmers' actual yields are further restricted by economic considerations, attitude to risk, knowledge and other socio-economic factors.

While yield potential has declined overall, the trend has not been evenly distributed. While some areas have not suffered any decline, others have declined by up to 100 kg per hectare each year.

We found this decline in yield potential by investigating 50 high-quality weather stations located throughout Australia's wheat-growing areas.

Analysis of the weather data revealed that, on average, the amount of rain falling on growing crops declined by 2.8 mm per season, or 28% over 26 years, while maximum daily temperatures increased by an average of 1.05 °C.

To calculate the impact of these climate trends on potential wheat yields we applied a crop simulation model, APSIM, which has been thoroughly validated against field experiments in Australia, to the 50 weather stations.

Climate variability or climate change?

There is strong evidence globally that increasing greenhouse gases are causing rises in temperature.

Recent studies have also attributed observed rainfall trends in our study region to anthropogenic climate change.

Statistically, the chance of observing the decline in yield potential over 50 weather stations and 26 years through random variability is less than one in 100 billion.

We can also separate the individual impacts of rainfall decline, temperature rise and more carbon dioxide in the atmosphere (all else being equal, rising atmospheric carbon dioxide means more plant growth).

First, we statistically removed the rising temperature trends from the daily temperature records and re-ran the simulations. This showed that lower rainfall accounted for 83% of the decline in yield potential, while temperature rise alone was responsible for 17% of the decline.

Next we re-ran our simulations with climate records, keeping CO_2 at 1990 levels.

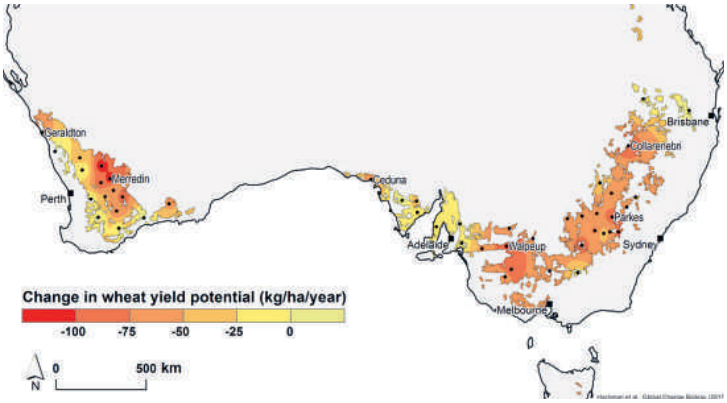


Figure 13.7. The distribution of the annual change in wheat yield potential from 1990 to 2015. Each dot represents one of the 50 weather stations used in the study. David Gobbett, Zvi Hochman and Heidi Horan. Author provided

The CO_2 enrichment effect, whereby crop growth benefits from higher atmospheric CO_2 levels, prevented a further 4% decline relative to 1990 yields.

So the rising CO_2 levels provided a small benefit compared to the combined impact of rainfall and temperature trends.

Closing the yield gap

Why then have actual yields remained steady when yield potential has declined by 27%? Here it is important to understand the concept of yield gaps, the difference between potential yields and farmers' actual yields.

An earlier study showed that between 1996 and 2010 Australia's wheat growers achieved 49% of their yield potential – so there was a 51% 'yield gap' between what the fields could potentially produce and what farmers actually harvested.

Averaged out over a number of seasons, Australia's most productive farmers achieve about 80% of their yield potential. Globally, this is considered to be the ceiling for many crops.

Wheat farmers are closing the yield gap. From harvesting 38% of potential yields in 1990 this increased to 55% by 2015. This is why, despite the decrease in yield potential, actual yields have been stable.

Impressively, wheat growers have adopted advances in technology and adapted them to their needs. They have adopted improved varieties as well as improved practices, including reduced cultivation (or 'tillage') of their land, controlled traffic to reduce soil compaction, integrated weed management and seasonally targeted fertiliser use. This has enabled them to keep pace with an increasingly challenging climate.

What about the future?

Let's assume that the climate trend observed over the past 26 years continues at the same rate during the next 26 years, and that farmers continue to close the yield gap so that all farmers reach 80% of yield potential.

If this happens, we calculate that the national wheat yield will fall from the recent average of 1.74 tonnes per hectare to 1.55 tonnes per hectare in 2041. Such a future would be challenging for wheat producers, especially in more marginal areas with higher rates of decline in yield potential.

While total wheat production and therefore exports under this scenario will decrease, Australia can continue to contribute to future global food security through its agricultural research and development.

Environmental scientists work towards new understanding and insights that can yield innovative solutions to everyday and complex challenges in local, national and global contexts. Making connections between the work of others and their own learning enables students to explore and to compare responses to current and future environmental problems and challenges.

In this area of study students investigate a contemporary example of how science is influenced by, and responds to, the needs and priorities of society in managing a selected pollutant of interest and/or in securing water or food. Students select and explore a recent discovery, innovation, issue, advance or case study linked to their knowledge and skills developed in Area of Study 1 and/or Area of Study 2. Stimulus material for the investigation could include announcements of recent discoveries, an expert's published point of view, an interview with an expert, an online presentation, an article from a scientific publication, public concern about an issue, 'green field' research leading to new technologies, or changes in government funding for environmental science purposes such as maximum sustainable yields in fisheries or the social impacts of resource extraction.

Students apply critical and creative thinking and scientific inquiry skills to prepare a communication to: explain the relevant scientific concepts; identify the sociocultural, economic, political, legal and ethical implications of the selected endeavour for society; and critically examine how science has been used to contribute to addressing the impacts of natural and human activities.

Outcome 3

On completion of this unit the student should be able to investigate and explain how science can be applied to address the impacts of natural and human activities in the context of the management of a selected pollutant and/or the maintenance of food and/or water security.

AREA OF STUDY 3

How do scientific endeavours contribute to minimising human impacts on Earth's systems?

Key knowledge

Area	Section
Scientific evidence	
• the distinction between primary and secondary data	14.1
• the nature of evidence and information: distinction between opinion, anecdote and evidence, weak and strong evidence, and scientific and non-scientific ideas	14.2
• the quality of evidence, including validity and authority of data and sources of possible errors or bias relating to those who benefit and those whose health or livelihood is impacted	14.3
• methods of organising, analysing and evaluating secondary data	14.4
• the use of a logbook to authenticate collated secondary data	14.4
Science communication	
• scientific concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations	14.1, 14.5, 14.6
• the characteristics of effective science communication: accuracy of scientific information; clarity of explanation of scientific concepts, ideas and models; contextual clarity with reference to importance and implications of findings; conciseness and coherence; and appropriateness for purpose and audience	14.5
• the use of data representations, models and theories in organising and explaining observed phenomena and environmental science concepts, and their limitations	14.6
• the influence of sociocultural, economic, legal and political factors, and application of ethical understanding to science as a human endeavour	14.7
• conventions for referencing and acknowledging sources of information	14.8

CHAPTER

14

Evaluating evidence and communicating science

CASE STUDY 14.1
Chickens in fancy dinner suits

Invasive species have been an issue in Australia since early colonisers arrived and brought European animals to Australian shores. One of the most destructive of these was foxes, originally brought to Australia for the purpose of hunting. Foxes quickly multiplied and caused severe damage to Australian native fauna. Dr Patricia Corbett, as the head of the Middle Island – Maremma Penguin Project, knows only too well how damaging foxes can be.

This project was established in response to a local population of little penguins that resides on Middle Island, a small island just off the beach in Warrnambool, Victoria. After calling this island home for some time, a devastating event occurred that almost wiped out the entire colony. Between 2000 and 2005, foxes decimated the penguin population by swimming to the island during breeding season and killing large numbers of penguins. During this time the population decreased from 800 returning penguins to only four, which meant the colony was categorised as locally endangered.

Figure 14.1. Maremma dogs are guarding penguins on Middle Island. Credit: Warrnambool City Council CC BY 2.0

Terrestrial fox control, including baiting and catching, was well underway through the Warrnambool council, but this was not controlling the foxes. No one knew how to help these penguins until a third-year student at Deakin University was chatting with a local chicken farmer. The farmer, Alan 'Swampy' Marsh, was known as an eccentric character with some innovative ideas; he had for example been using Italian sheepdogs, maremmas, to protect his chickens from foxes. When the student told Swampy the issue they were having with foxes, he responded with the idea of trying out maremmas on the island; after all, "penguins are just chickens in fancy dinner suits". This was the beginning of the Middle Island Project.

Figure 14.2. Little penguins.
Credit: JJ Harrison CC BY-SA 3.0

Figure 14.3. Maremma guardian dog Tula.
Credit: Warrnambool City Council CC BY 2.0

The very first maremma to be trialled on the island was the famous Oddball, who has been dubbed as the saviour of the penguins. However, she was only on the island for a trial period of four weeks to establish whether using maremmas was a viable option. Oddball proved that having dogs guarding the penguins was an effective method of deterring foxes, but she was too devoted to her human companions to be a permanent part of the program. Rather than continuing to use maremmas that were used to living on a farm, the program bought some puppies that could be trained from an early age to think of the island as their territory and the penguins as the animals they were guarding. Since becoming the head of the program, Corbett has been the main dog trainer and organiser of the dog's shifts.

Throughout the summer the dogs stay overnight on the island for five out of seven days, and throughout the winter they are taken to the beach to mark their scent each day. Over time, the foxes became smarter, and more management and new ideas were needed from Corbett and her team. This has led to increased monitoring of early arrivals of penguins and increased presence of the dogs, even when it seems impossible to access the island. Through increased monitoring and presence from the dogs, the penguin population has increased; the count in 2017 stood at 182 birds and continues to stay steady.

This program is one of a kind and paves the way for new research with maremmas and other dogs. An example close to the Middle Island Project is the restoration of the eastern barred bandicoots near Hamilton, Victoria. Maremmas are being trained to take care of the bandicoot territory while steering clear of the animals so that the bandicoots do not get scared (as dogs are predators). Corbett suggests that this is a new area of study in Australia that could be used for much more, including crop protection and the discovery of endangered or invasive species. It is an exciting area of research that holds a lot of potential for the future.

Figure 14.4. Middle Island.
Credit: philip.mallis CC BY-SA 2.0

Figure 14.5. Maremmas returning from Middle Island.
Credit: Warrnambool City Council CC BY 2.0

14.1. Primary and secondary data

The distinction between primary and secondary data

Primary data is data that is collected by the investigator themself from firsthand experiences through experiments or fieldwork. The advantages of using primary data are that the data is specific to the investigation and there should be no question as to the quality of the data because the investigator has control of the data collection. Also, it is possible to make note of, and obtain, any additional data and information during the study that may be of assistance when analysing and interpreting the results.

Secondary data has been collected by someone else in different studies, surveys or experiments. Secondary data can provide you with information to help you start your own investigation, and it also provides data for you to compare with your own findings. The advantage of using secondary data is that the research has already been done, but there is no guarantee that the data is of good quality. Also, unless stated in the research, it is hard to know if the secondary data was collected under comparable conditions to the data collected from primary sources.

Student activity 14.1
Primary and secondary data

Complete the table below to check your understanding of primary and secondary data.

Point for comparison	Primary data	Secondary data
Definition		
Main source		
Data time		
Level of control over data		
Collection time		
Specific to researcher needs		
Accuracy, reliability and validity		

Research project B.1
Topic and data sources

In this area of study, you will conduct an investigation, using secondary data, into how scientific endeavours have contributed to minimising human impacts on Earth's systems. Your teacher will explain the details of this task.

1. Decide what sort of topic you are going to investigate. Record the topic in your logbook.
2. Decide on the sources of secondary data that you will use. Record your ideas on secondary sources in your logbook.

14.2. Types of evidence

The nature of evidence and information: distinction between opinion, anecdote and evidence, weak and strong evidence, and scientific and non-scientific ideas

When gathering data for your report, you will have access to lots of information. Gathering a variety of information will make you informed, and the way that you think about and process this information will create good ideas, and therefore allow you to produce a high-quality report. However, not all information is evidence.

The *Cambridge Dictionary* defines **evidence** as "anything that helps to prove that something is or is not true". Your ability to distinguish weak from strong evidence will depend on how critically you can analyse the data.

Using a variety of different sources of secondary data will help to validate your research. Different sources can include journals and periodicals, encyclopedias, textbooks, non-fiction books and the internet. Figure 14.6 shows you a guideline to determining whether evidence from different sources is weak or strong. The strongest evidence is good-quality scientific evidence (that is, evidence that has been generated by a large group or is supported by multiple sources).

The pyramid in Figure 14.6 shows the hierarchy of scientific evidence, from weakest at the base to strongest at the peak.

The pyramid shape demonstrates the amount of evidence you need at each level – a lot of weak evidence or a smaller amount of strong evidence.

Sources of evidence listed in the square in Figure 14.6, such as anecdotes and fake news websites, are all non-scientific. Unfortunately, a lot of information posted online is unscientific and written by people who don't (or can't) distinguish strong from weak evidence (even if they *think* they do).

To assess the quality of online data, first see who has published it. Look at the site's url – a '.gov' site will have reliable information, while a '.org' site may be credible, depending on the organisation behind it. Many science publications are now found online, such as *Cosmos* magazine and *National Geographic*. Do your research: find internet sites that are run by science organisations, or literary organisations, not just a person or organisation who has created a page to voice their own agenda or opinion.

Your own beliefs or view can sway the evidence that you try to collect and the way you interpret evidence. It is important to be as objective as possible in collecting and analysing evidence.

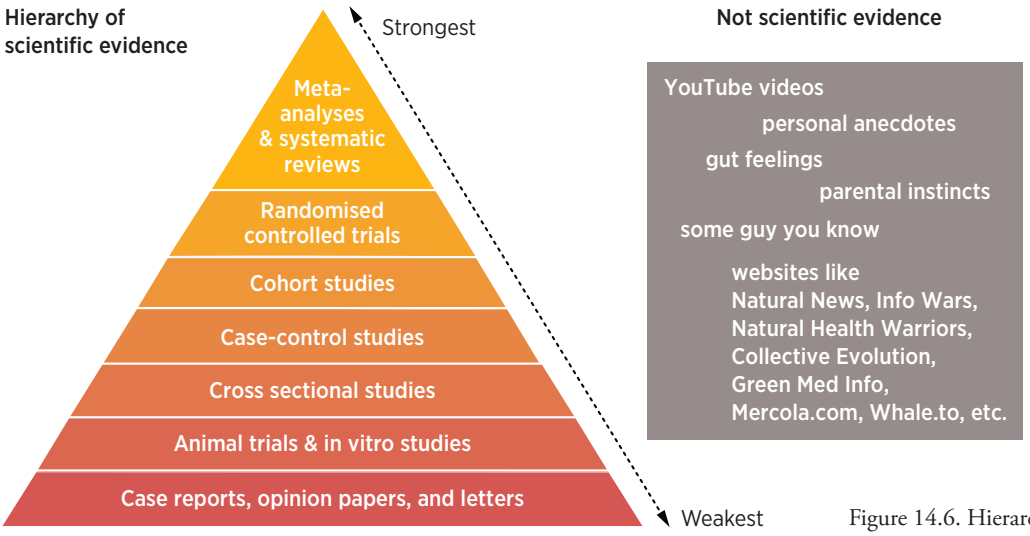


Figure 14.6. Hierarcy of scientific evidence

Research project B.2
Ensuring strong evidence

At this step in your investigation, it is important to ensure that you base your data on strong scientific evidence, rather than media-based opinions or weak evidence.

As you gather data for your investigation, ask yourself the following questions.

1. How do I distinguish between true and false information?
2. How am I going to determine if this evidence is from a credible source?

Student activity 14.2
Opinions and evidence

Complete the table below in your workbook by reading each idea in the first column. In the middle column you should write your current belief or opinion about the idea.

In the final column, outline the evidence you have to support your own current belief.

An example has been done for you for the first idea.

Idea	What do I currently believe?	Evidence for this belief
February 2020 recorded the hottest ever sea temperatures on record in the Great Barrier Reef (GBR) ecosystem	'True! I believe that sea temperatures are rising and the 2020 summer showed the hottest ever GBR recorded sea temp'	My teacher showed us a graph created by the Bureau of Meteorology. I have read an article on *The Conversation* about bleaching on the GBR
Animal agriculture is responsible for 91% of all Amazon rainforest destruction		
Climate change is contributing to the worst extinction event since the extinction of the dinosaurs 65 mya		
2.7 billion people live in areas that experience severe water scarcity issues		

14.3. Assessing evidence quality

The quality of evidence, including validity and authority of data and sources of possible errors or bias relating to those who benefit and those whose health or livelihood is impacted

Scientific evidence comes from a variety of sources, including research findings and expert opinion. In 6.4 'Data quality and investigation validity' (p 112) you learnt about how to ensure a scientific investigation is valid. Well-designed and carried out research based on scientific principles will minimise biases and take into account sources of error (see p 117). Scientific papers published in peer-reviewed journals have been evaluated by other scientists to make sure they are scientifically rigorous and of high quality. The meta-analyses and systematic reviews that are at the top of the hierarchy of scientific evidence shown in Figure 14.6 look at lots of different published research studies on the same topic to see if their findings are consistent, and thus are extremely strong evidence.

People who are very skilled and experienced in their field can provide expert opinions based on their professional knowledge. However, experts should not give opinions on areas outside their expertise. For example a staff member from a zoo could provide expert options on animals in a zoo context, but could not give expert evidence on domestic pets.

Scientific evidence can also be affected by bias – either deliberate or accidental. An example of scientific bias is a researcher who deliberately removes data that does not support the study's hypothesis. Bias can also benefit certain groups. For example, if more research funding is granted to conservation studies of mammals than of insects, then insects may be less well managed. The case study below looks at unintentional errors and bias in the study of wolves that have led to a well-ingrained cultural misunderstanding of wolf behaviour.

CASE STUDY 14.2
Hierarchies in wolf packs

An example of scientific evidence that was accepted despite limited validity is that of the concept of 'alpha' wolves – a lead male and a lead female – in a wolf pack. Swiss animal behaviour scientist Rudolph Schenkel described the concept in an article he published in 1947 called 'Expression studies on wolves' based on his study of wolves during the 1930s and 1940s in the Zoo Basel, Switzerland. Schenkel described how the dominant male and female wolves in a pack constantly controlled the behaviour and reproduction of the other pack members, and he drew parallels with domestic dogs. He concluded that dogs and dog-like animals (such as wolves) that live in packs have a structured social hierarchy with the alpha male and female constantly competing against other pack members to maintain ultimate authority them.

Although Schenkel studied only captive wolves, his work became the foundation for more studies and more widely published results. Wildlife biologist Dave Mech used Schenkel's and other studies as the basis for his PhD research, again with captive wolves, this time in Isle Royale National Park in Michigan. In 1970 Mech published a book called *The wolf: the ecology and behaviour of an endangered species* in which he coined the term 'alpha wolf'.

Dave Mech is a highly respected expert in wolf behaviour and was the Chair of the IUCN Wolf Specialist Group from 1978 to 2013. This status meant that his research was widely accepted and underwent little scrutiny or questioning. But again, findings from captive animals were being extended to apply to all members of the species. Scientific research was being applied beyond the limitations of the study (see 'Limitations', p 120), even influencing how people trained domestic dogs.

It was not until 1999 that Mech and others corrected their misunderstanding of wolf pack structures.

In his article published in the *Canadian Journal of Zoology*, 'Alpha status, dominance and division of labor in wolf packs', Mech correctly describes wolf pack structure as observed in wild wolf populations. It turns out that wolves actually live in family structures: the parents are the dominant animals and the subordinate animals are the children. In contrast, the captive wolves from the initial studies were unrelated adults that lived together and therefore behaved in a way not found in wild packs. Mech has spent most of the rest of his career, and numerous published articles, debunking the idea of alpha males that his and others' research constructed.

Research project B.3
Validity of scientific research

When analysing scientific research for validity you can ask yourself the 'who','what', 'when' and 'why' questions.

- Who wrote, published or made the source?
  - Is the author's personal perspective obvious in the source?
  - Is the author a member of a particular group, religion or organisation?
- What type of source is it?
  - Was the source created at the time of the research or after?
- When was the source written, published or made?
  - How old is the source?
  - Is it written by the person who conducted the research or by another person afterwards?
  - Is the source a complete account of the research or does it partially describe the research?
- Why was the source written or published?
  - Was it produced to entertain, persuade or argue a point of view?
  - Does the creator have anything to gain for producing the source?
  - What other research might have been happening at the time that could have influenced the source?

Use the table below to assist in your decision-making and analysis of scientific sources to help construct your investigation.

Research topic:			
Hypothesis:			
Sources	**Pros and cons**	**Category of source**	**Reference**
Source 1			
Source 2			
etc.			

14.4. Organising data

Methods of organising, analysing and evaluating secondary data: logbooks

The use of a logbook to authenticate collated secondary data

When you have found a source of information that you could use for your investigation, you need to take notes. Don't simply copy slabs of information from the source material. While you can quote from material to back up your statements, your investigation should be written in your own words. Record your notes in your logbook. A table is often a good way to to organise the data (see Table 14.1).

If you are investigating several ideas, then it's best to create a separate table for each idea. In the table, you will need to summarise the information (for example, in brief dot points) and record the source of the material so that it can be correctly referenced in a list at the end (see 14.8 'Referencing sources', p 231).

When you have collected data and information from a number of sources, you will need to go back through your notes to validate the information. If you find a number of different reputable sources have provided similar, if not the same, information, then it is safe to assume that the information is valid and would be good to use. If some information contradicts the rest, it does not mean that it is not valid; it may just mean that you will have to look for more sources to help validate this information if you want to use it in your investigation. The greater number of reputable sources you can find that provide the same or similar information, the more confidence you can have that the information is valid.

Table 14.1. Example of logbook table for collection of secondary data

Topic/concept:

Source	Notes	Validity
1.		
2.		

14.5. Science communication

The characteristics of effective science communication: accuracy of scientific information; clarity of explanation of scientific concepts, ideas and models; contextual clarity with reference to importance and implications of findings; conciseness and coherence; and appropriateness for purpose and audience

A scientific research report should follow the general structure of:

- introduction – this first paragraph should introduce the topic, including why the topic is of importance
- body paragraphs – each paragraph should cover one main idea. If you are switching to another idea or concept, start a new paragraph. Avoid very long or very short paragraphs and make sure you are providing evidence for any statements being made
- conclusion – this should summarise main findings and also relate to the title of the investigation. It can also include any potential future research.

Scientific research should be written in an objective and unbiased style and should not switch between first- and third-person narrative. It is important to decide on the audience and the purpose of the presentation.

Is the audience going to be young children, teenagers, adults? Does the audience have a science background? Do they already know about the topic you are presenting? Is the investigation presenting the findings of an experiment or fieldwork? Is it an informative piece of writing? These questions will help decide the tone and level of language used in your presentation and also the way it is presented.

Through your recording of research notes in your logbook, you should have established the valid information you are going to include. It is now a matter of writing the notes you have taken into concise and coherent sentences and paragraphs. Make sure your information makes sense and it flows well from one lot of information to the next.

If you include diagrams, tables or graphs, refer to them in the text. For example: 'Figure 14.7 shows that atmospheric carbon dioxide levels increased in the 50 years to 2010' or 'Atmospheric carbon dioxide levels increased in the 50 years to 2010 (Figure 14.7)'. Only include such visual elements in your report to validate and enhance the information you are providing, not simply as decoration.

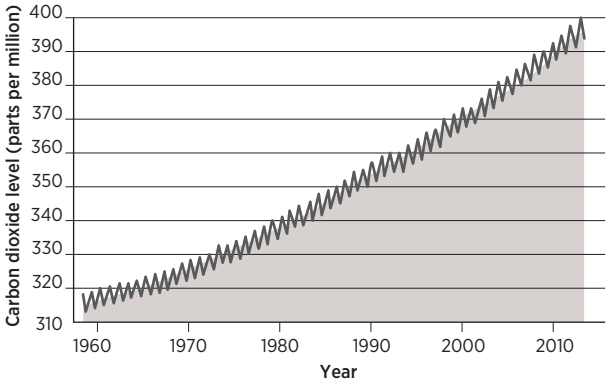


Figure 14.7. Monthly carbon dioxide levels

14.6. Representing data

The use of data representations, models and theories in organising and explaining observed phenomena and environmental science concepts, and their limitations

As you saw in 'Modelling Earth's weather' (p 92), data representations and models are commonly used in explaining weather patterns and systems all around the world.

Scientists use data modelling to predict and visualise large-scale changes to one aspect of the environment, such as weather patterns, sea level or forest distribution.

You may choose to present data models when explaining the science behind your chosen topic (see the example in Figure 14.8). Other data representations that you may choose to include are graphs or tables that you create yourself after analysing various sources of valid secondary data.

You may also choose to create an infographic display when organising large chunks of your secondary data. Infographics are visual representations of data that use graphs and images to convey a concept (see Figure 14.9). Creating an infographic may allow you to break down and simplify some of the information in your secondary data.

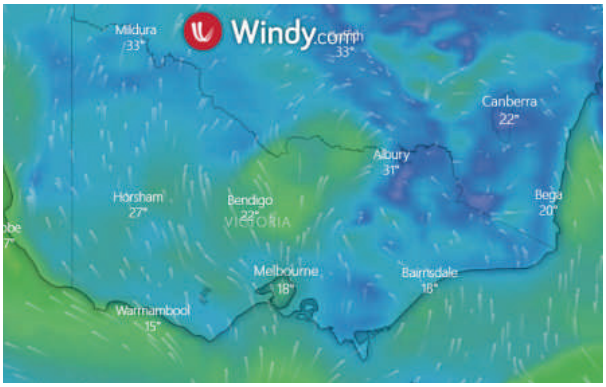


Figure 14.8. Websites like windy.com use data modelling to predict weather patterns. Credit: Screenshot from windy.com © OpenStreetMap contributors

When choosing how best to represent the data you collect, remember the advice discussed in 7.3 'Writing scientific reports' (p 121) on visual aids to representation.

Finally, remember the advantages of presenting data in the form of scientific diagrams and drawings. Although you are analysing secondary data in this task, diagrams and photographs may be suitable representations of the information (see Figures 14.10 and 14.11).

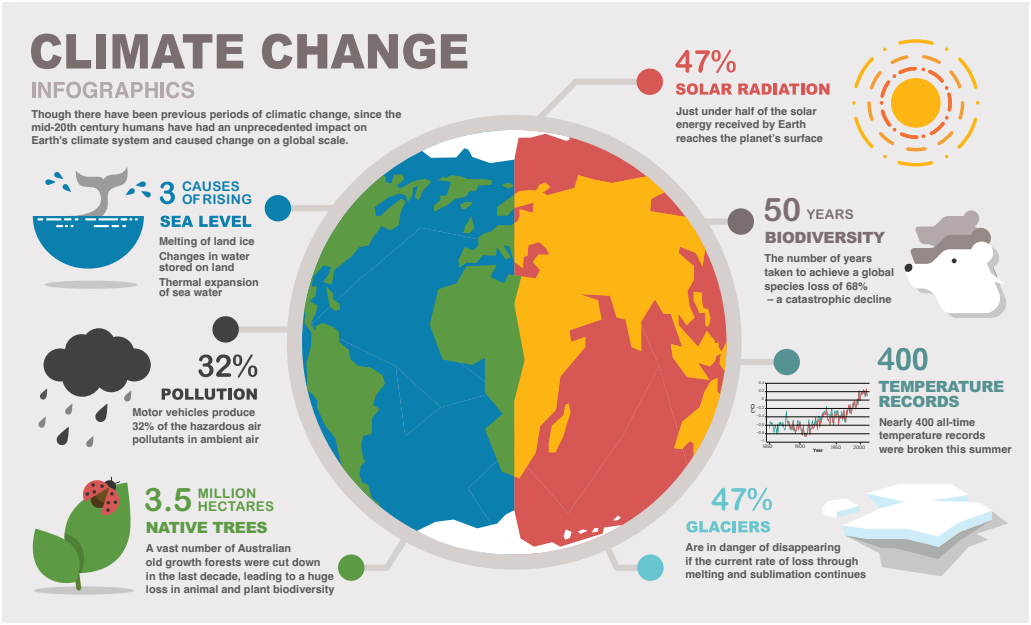
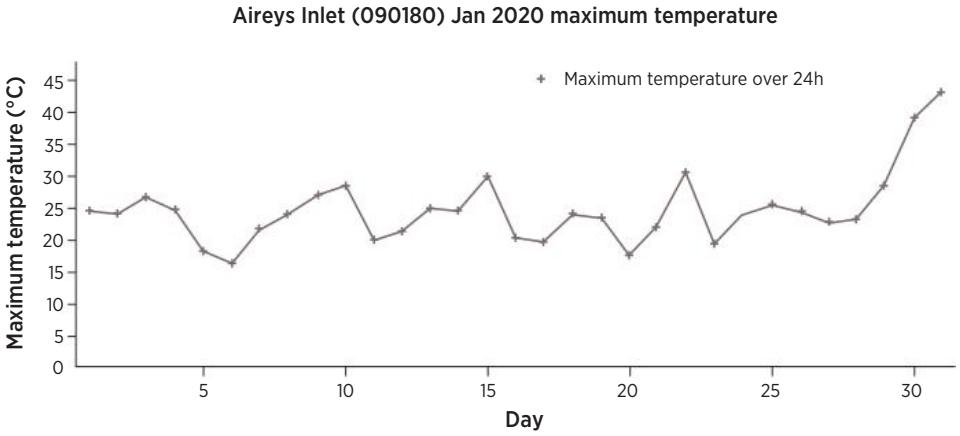


Figure 14.9. Infographics break down and simplify complicated messages into visually engaging bursts of knowledge



NOTE: Data may not have completed quality control.

Figure 14.10. Graphs can allow us to organise large amounts of statistics or observations into easy-to-analyse information

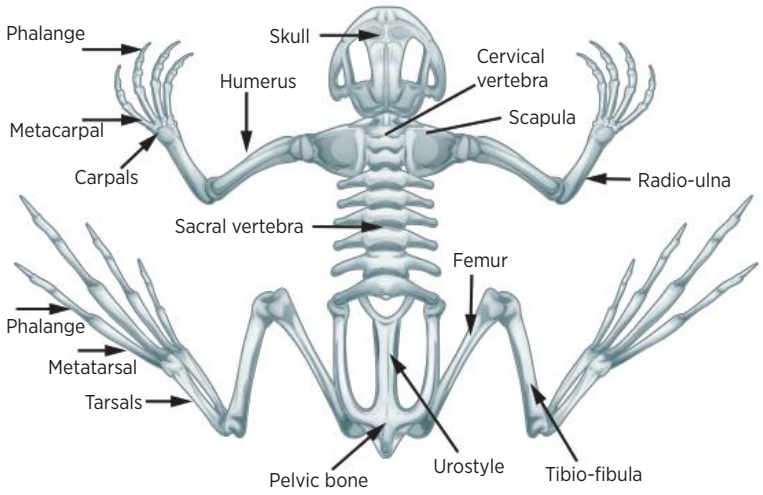


Figure 14.11. Scientific diagrams can be used to explain and display concepts even when you are analysing secondary data. Credit: designed by Freepik.com

14.7. Social, economic, legal and political considerations

The influence of sociocultural, economic, legal and political factors, and application of ethical understanding to science as a human endeavour

Science as a human endeavour explains the nature of science, how science is shaped and how science shapes society; it serves to describe the intentions of science. By posing questions and investigating using evidence, science constructs the most robust theories to explain aspects of the natural world. These theories are not fixed and change as new evidence becomes available. New evidence can be generated by new technologies or new ways of thinking and doing – each of these helps society to advance. These technologies and new ways of thinking are influenced by the dominant society of the time. Remember that once people thought Earth was flat and that smelly air caused diseases. Cultural, legal, economic, political and ethical factors all shape the direction of scientific endeavour as a process.

Sociocultural

Sociocultural influences are those that are directed by the dominant social culture of the time and reflect the priorities of that culture. During the 1950s, 1960s and 1970s, humans made significant advance in space travel, culminating with the Moon landings. There were several reasons that science focused their energies on space during this time, including international competition and new technologies developed during the Second World War. More recently, advances in renewable energy technologies and environmental remediation reflect the dominant societal culture's awareness of global climate change.

Economic

Science has great economic value, including the ability to develop new technologies which then drive manufacturing, employment and economic growth. Technological advances have played a major role since the industrial revolution when products were first produced on a mass scale made possible by the invention of the steam engine. Development of modern technologies and development of modern cultures often go hand in hand. The economic impacts of scientific endeavour are not limited to the production of technologies but can be broadened out to other areas where science has posed questions and produced knowledge to assist in understanding. One example of this is in agriculture – by better understanding soil structure and microbial activity, farmers can produce higher yields with less harmful techniques.

Legal

The law has a large part to play in the advancement of science and science has a part to play in the application of the law. As science does not exist outside of cultural understandings, there is a need to regulate and monitor aspects of science that can influence the direction of a society. For example, biomedical advances such as genomics or engineered babies raise issues that are addressed by strong laws ensuring the integrity of human behaviour. In many aspects of society, human behaviour is regulated and enforced by legislation, such as the regulations controlling pollution that we saw in 10.1 'Controlling and treating pollution' (p 171). Legalisation is often shaped by the political party in power and reflects that party's agenda and priorities, including ethical concerns.

Ethics

Most formal scientific research is practised within established ethical guidelines, often set at a national level. Ethical guidelines in Australia cover treatment of animal and human research subjects as well as the ethical use of data collected from research subjects.

Student activity 14.3
Science as a human endeavour

By completing this activity, you will get a better understanding of the different aspects of science as a human endeavour. To complete the task you need to think about one issue from two different points of view: the dominant culture and a minority culture.

Choose an environmental science issue such as water pollution or the concept of peak phosphorus. With that issue in mind, answer the following questions from the two points of view.

1. Is the issue important today and will it still be in 20 years? Justify your response.
2. How did scientists come to generate their understanding of the issue?
3. What kind of experiments could have been conducted?
4. What ethical implications would have been considered in conducting these experiments?
5. Can you describe the use of the knowledge generated by studying the issue and how that knowledge can be used by various forms of society?
6. Is there a need to develop laws to regulate this issue in society? Justify your response.

14.8. Referencing sources

Conventions for referencing and acknowledging sources of information

All information that you collect from secondary sources should be referenced in your report. Both in-text citations and a reference list at the end of your report are an essential way of acknowledging the ideas of other people that you have included in your report.

Cite your secondary source in the text by including the author's name (or names) and the date of publication at the point where you have discussed their work in you own words. If you are using a direct quote from a secondary source, you must use quotation marks to show that the idea is someone else's exact words. Again, cite the original document and add the number of the page that the quote is taken from.

When compiling your reference list at the end of your report, remember to list each reference in alphabetical order, by name of author. If you use more than one source by the same author, then list these in order of their published date.

Some other hints for an appropriate reference list:

- Leave a full line between each reference.
- Make sure every in-text citation has a full reference listed at the end of your report, and that each reference in your list is cited somewhere in the report.
- Start your reference list on a new page at the end of your report.

As a general rule, scientific papers use Harvard -style referencing (also known as 'author–date' system), but some research fields tend to use other methods (for example, using footnotes or endnotes). Journals each decide their preferred way of setting out Harvard-style references.

Table 14.2 below shows some examples for both in-text citation and the end of report reference list.

Table 14.2. Examples of Harvard-style citation and referencing

Source type	In-text reference exemplar	End of text reference list format
Online article or web page	February 2020 showed the highest average monthly ocean temperatures on record on the Great Barrier Reef (Hughes and Pratchett, 2020).	**Author (s), date published, 'title of article', URL address (date accessed)** Hughes, T and Pratchett, M, 2020, 'We just spent two weeks surveying the Great Barrier Reef. What we saw was an utter tragedy', https://theconversation.com/we-just-spent-two-weeks-surveying-the-great-barrier-reef-what-we-saw-was-an-utter-tragedy-135197 (accessed 8 August 2020).
Book	Through interspecies association, trees gain benefit from taking part in the forest ecosystem, therefore increasing chances of survival (Suzuki and Grady, 2018).	**Author(s), date, *title of book*, publisher, location** Suzuki, D and Grady, W, 2018, *Tree: A Life Story*, Greystone Books Ltd, Vancouver.
Journal article (with more than three authors)	Molyneux et al. (2012) states that the country of Timor Leste is dominated by a central mountain ecosystem.	**Author(s) date, 'title of article', *journal title*, volume number, page number** Molyneux, N, Rangel da Cruz, G, Williams, RL, Anderson, R and Turner, NC, 2012, 'Climate change and population growth in Timor Leste: implications for food security', *Ambio,* vol. 41, pp. 832–840.

Both Microsoft Word and Google Docs have tools that can help you use the appropriate formatting to reference your work. The important part is ensuring that you are making it clear to your teacher that the ideas you have used are not your own. Plagiarism is a serious issue in VCE and learning how to cite your sources is a valuable skill.

Student activity 14.4
Citing a source

1. Create a table like Table 14.2, and reference the following sources:

a. this text book

b. an article from National Geographic website: https://www.nationalgeographic.com

c. a journal article.

EXPLORING SCIENCE 6
The detective work behind the Budj Bim eel traps World Heritage bid

Ian J. McNiven, Professor of Indigenous Archaeology, Monash University

This article was originally published in The Conversation*, 8 February 2017.*

https://theconversation.com/the-detective-work-behind-the-budj-bim-eel-traps-world-heritage-bid-71800

Last month [January 2017] Prime Minister Malcom Turnbull visited the Gunditjmara community of southwest Victoria to announce that the federal government had included the Budj Bim cultural landscape on its World Heritage Tentative List. It was, he said,

"the first area [in Australia] exclusively listed for its Aboriginal culture and heritage and it is absolutely an appropriate recognition of its significance and its values."

So what warrants the area's inclusion on UNESCO's esteemed World Heritage list? At its core, this is a story about the Gunditjmara and their continuing relationship with the Budj Bim cultural landscape. It is also a story about how the Gunditjmara have successfully fought to overturn European misunderstandings of the complexity and sophistication of their culture and history.

This story of misunderstandings begins with an 1841 expedition to southwest Victoria by the Chief Protector of Aborigines, George Augustus Robinson.

On July 9 1841, to the north of Gunditjmara country at a swamp near Mount William, Robinson reported:

"an immense piece of ground trenched and banked, resembling the work of civilized man but which on inspection I found to be the work of the Aboriginal natives, purposefully constructed for catching eels."

Figure 14.12. GA Robinson.
Credit: Tasmanian State Library/wikimedia commons

Robinson estimated that the system of channels measured "some thousands of yards" (2 km) in length and covered an area of "at least 15 acres" (six hectares).

His findings were not what early settlers of the colony wanted to hear. Colonial settlement was about removing nomadic savages, not tillers of the land. The evidence was either ignored as an inconvenient truth or dismissed as evidence of "irrigation" by a superior race of cultivators living in Australia prior to the coming of the Aborigines.

It took another 135 years for more appreciative European eyes to examine the scale and complexity of western Victoria's Aboriginal fishery.

Investigations in the 1970s

In the 1970s, Dr Peter Coutts of the Victoria Archaeological Survey carried out site surveys at Lake Condah (Tae Rak), the centrepiece of the Budj Bim cultural landscape. Lake Condah is very different to the marshy plains near Mount William. It is a rugged lava flow terrain of basalt rises, swampy depressions, and waterways formed as a result of the eruption of Mount Eccles (Budj Bim) at least 30,000 years ago.

Coutts and his team found what local Gunditjmara people had long known about – extensive Aboriginal fish-trapping systems comprising hundreds of metres of excavated channels and dozens of basalt block dam walls constructed over innumerable generations before European contact. Coutts estimated that the volume of basalt blocks moved measured in "the many hundreds of tonnes".

Determining how the Budj Bim traps operated was made difficult after European alteration of Lake Condah's water flows through installation of drainage channels in the 1880s and 1950s. Luckily, heavy winter rains in 1977 revealed how some Aboriginal-made channels fed water and eels into natural depressions that Coutts termed "holding ponds". In addition, numerous C-shaped basalt block structures, averaging 3–4 metres across and representing house foundations – possibly clustered into villages – were recorded in the same area as the fish traps.

Coutts hypothesised that the fishing facilities were up to 3,500 years old, based on radiocarbon dating of habitation sites in the region such as earthen mounds and shell middens. Reconstruction of ancient water levels in Lake Condah by pollen expert Leslie Head revealed that while some traps could have operated 8,000 years ago, most traps corresponded to water levels of the past 2,000 years.

Working at the same time as Coutts was Harry Lourandos, a PhD researcher from the University of Sydney. Lourandos examined Robinson's journals in detail and investigated a huge Aboriginal fish trap at Toolondo, 110 km north of Lake Condah.

Here again was further evidence of Aboriginal people digging an earthen channel (some 3 km long) to move eels into a swamp to dramatically increase their range and availability. Lourandos' excavations revealed that it was up to 2.5 m wide and over a metre deep.

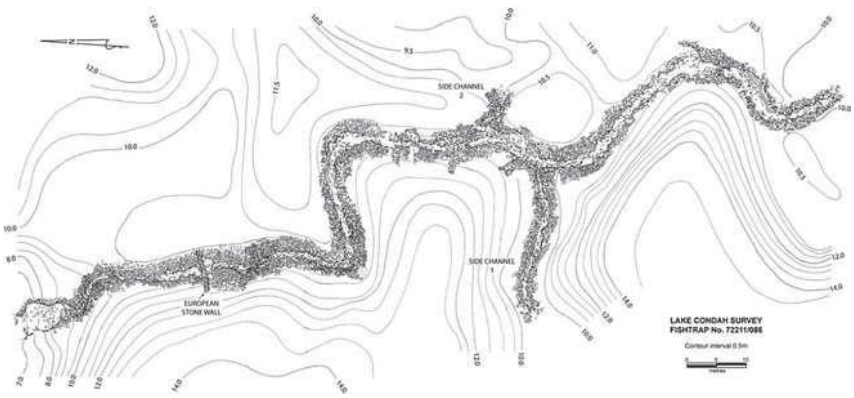


Figure 14.13. A 200-metre-long fish trap channel mapped by Peter Coutts's team at Lake Condah. Credit: Victoria Archaeological Survey

A “lump” of redwood buried within infill sediments at the base of the channel was radiocarbon-dated to 200 years, indicating a minimum date for last use of the site. An original construction date for the channel has yet to be determined.

Aware of Coutts’s Lake Condah holding ponds, Lourandos had the intellectual foresight to call the Toolondo and Mount William facilities for what they were – eel “farms” associated with eel traps.

3D computer maps

In the 1990s and 2000s, Heather Builth, a PhD researcher from Flinders University, worked closely with the Gunditjmara to create sophisticated 3D computer maps of channels and basalt block dam walls and fish traps along Darlot Creek (Killara) at the southern end of the Budj Bim cultural landscape.

Builth computer-modelled water levels and revealed that these stone features were constructed across the lava flow to form a complex system of artificial ponds to hold floodwaters and eels at different stages of growth.

These holding ponds allowed eels to grow in a restricted and protected area and be available to the Gunditjmara for much of the year. Critically, increasing the availability of the eels centred on improving eel survival, given that the eels breed in the Coral Sea. Builth described this complex network of ponds as “aquaculture”.

The most recent insights into the Budj Bim fishing facilities concern their antiquity. Over the past decade, I and students from Monash University, in collaboration with the Gunditjmara, have excavated Muldoons trap system at Lake Condah, which flood sediments had partly buried over the years.

Radiocarbon dating of tiny charcoal fragments within these sediments produced surprising results. One channel was built at least 6,600 years ago, while a dam wall was added 500 years ago. Not only had we discovered the world’s oldest known stone-walled fish trap, but also the longest-used fish trap in the world.

3D computer modelling by Tom Richards as part of this PhD research at Monash indicated that the Muldoons dam was used to pond water and fish. This pond provides the earliest available date for Gunditjmara aquaculture.

Not simply hunter gatherers

These large-scale fishing facilities and associated aquaculture ponds rupture traditional representations of Aboriginal people as simply hunter gatherers.

Rather than living passively off whatever nature provided, the Gunditjmara actively and deliberately manipulated local water flows and ecologies to engineer a landscape focused on increasing the availability and reliability of eels.

Figure 14.14. The funnel-shaped start of Muldoons trap system, Lake Condah.
Credit: Ian McNiven

Manipulation of the landscape involved stone structures (such as traps and channels) dating back at least 6,600 years. Eel aquaculture facilities (ponds and dam walls) pre-date contact with Europeans by many hundreds (and possibly thousands) of years.

As Lourandos pointed out more than three decades ago, and Bruce Pascoe reveals in his recent award-winning book *Dark Emu*, differences between hunter gatherers and cultivators, and foragers and farmers, are far more complex and blurred than we once thought.

The Budj Bim cultural landscape provides an outstanding example on a world stage of the scale, complexity and antiquity of a well-preserved Aboriginal fishery that continues into the present. And it is an exceptional example of Aboriginal environmental manipulation and management that blurs the distinction between foragers and farmers.

Over the next year or so, the Victorian Government will prepare a formal World Heritage nomination spearheaded by the Gunditjmara for submission to UNESCO's World Heritage Committee.

The committee's evaluation of the nomination will be thorough. It will compare Budj Bim to similar types of places around the world. The case is strong, but it will be a number of years before the committee makes a final decision.

Budj Bim is a living cultural landscape and a strong focus for Gunditjmara heritage, identity and spiritual well-being. It is time for this remarkable heritage to be shared with the world. As senior Gunditjmara elder and longtime Budj Bim World Heritage listing advocate Denis Rose has said:

"It's one of those secrets that are a bit too well kept, I suppose. But we are involved in tourism and we do want to get people out on country a bit more and have access to properties to get a better understanding of Gunditjmara culture."

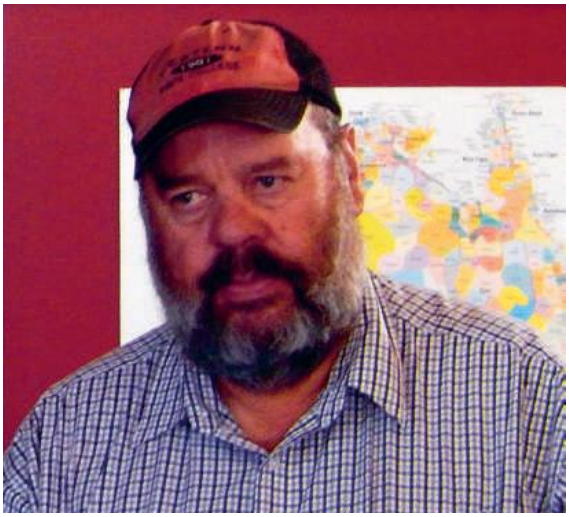


Figure 14.15. Denis Rose. Credit: Ian McNiven

So what will you see if you go there? Hundreds of Gunditjmara stone-walled fishing facilities and stone house foundations are located along the 30 km length of the area. However, in many cases, these low-lying sites are on private land and are hard to see through the long grass that covers much of the lava flow.

To experience these sites firsthand, visit the Tyrendarra Indigenous Protected Areas for a self-guided tour. Or for a Gunditjmara guided tour of the area and access to the large and clearly defined fishing facilities at Lake Condah, contact Budj Bim Tours. (And if smoked eels take your fancy, the Gunditjmara have plans to augment their eel fishery to commercial levels.)

Australia has come a long way since G.A. Robinson's recordings of Aboriginal social and technological complexity were sidelined.

Resources

Online

Environment Education Victoria has many resources useful to teachers and students of Environmental Science. Go to the Resources page https://www.eev.vic.edu.au/resources and explore the links.

Books

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Figure 3.9
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