CHAPTER 1
Natural hazards

1.1 Overview

1.1.1 Introduction

In this topic, you will examine different types of natural hazards and the zones in which they are most likely to occur. These include **atmospheric hazards**, such as severe storms and cyclones; **geomorphic hazards**, such as landslides and mudslides; and **geological hazards**, such as earthquakes and volcanic eruptions.

You will also learn about the processes and patterns of natural hazards, and why they are sources of risk. By analysing data and information you will assess why some hazards seem more common, predictable or frequent, while others occur seemingly randomly.

Finally, you will apply your understanding of natural hazards to examine their potential impacts and how different communities might be able to minimise the damaging effects they have on people, property and the environment.

FIGURE 1.1 Volcano Fuego in Antigua, Guatemala in 2018

1.1.2 Key questions

- What is a natural hazard?
- Where do natural hazard zones occur and why?
- What are atmospheric, geomorphic and geological hazards?
- What factors affect the severity of impact of a natural hazard?
- What factors affect a community's response to a natural hazard?
- What factors affect a community's vulnerability to the risks of a natural hazard?
- How are people in developed and developing communities affected differently by natural hazards?
- How do people in developed and developing communities respond to natural hazards?

Activity 1.1: Reflecting on your knowledge of natural hazards

How much do you know about natural hazards? Reflect on your own experience and knowledge of natural hazards to answer these questions.

1. What natural hazards commonly occur in Australia? Which hazards present a risk in the region where you live? Are there patterns that you can identify for when and where these hazards occur?
2. What do you know about the causes of the natural hazards that occur in your area? How might these causes explain patterns of when and where they occur?
3. What kinds of natural hazards present less of a risk in Australia, but are a significant risk in other parts of the world? Why might Australia be at less risk from these types of hazard?
4. If you had to rank natural hazards in order of highest risk to lowest risk, how would you arrange them? What criteria would you use to determine what was more or less of a risk (e.g. severity, frequency, loss of life, property or environmental damage)?

1.2 Natural hazards

1.2.1 Hazards and disasters

A **natural hazard** is any extreme geophysical event that has the potential to cause harm to people, other living things, property and the environment. They can occur in the Earth's crust, on the surface of the Earth or in the atmosphere, and are created by powerful forces that generate high levels of destructive energy. Because of the dynamic nature of the Earth, natural hazards occur almost everywhere and affect all parts of the **biophysical environment**: natural, managed and built.

A natural event becomes a hazard when its **magnitude** (size), speed of onset, duration or frequency create serious risk to people and have the potential to result in considerable damage. These hazards create **risk** (exposure to some form of dangerous situation). When individuals and comunities are at risk, they have to assess how to manage and lessen the affects of that risk for their communities and the local area.

Natural hazards can cause death or injury to people as well as damage buildings, property, infrastructure, crops and farmland. When a hazard is responsible for many deaths, loss of homes and will cost huge sums of money for repairs and compensation, it is called a **natural disaster**. Natural disasters may involve extensive disruption that requires a long-term recovery plan. For example, the 'Black Saturday' bushfires in Victoria (2009) became Australia's worst fire disaster when 173 people lost their lives and more than 400 people were injured. In 2017, Cyclone Debbie caused a small number of fatalities in Queensland and New South Wales, mostly due to floodwaters. The cyclone's destructive winds and heavy rainfall also caused economic damage, with an estimated cost of more than $1.5 billion in Queensland alone, including economic damage of approximately $150 million to the mining industry and about $150 million to the sugar industry.

1.2.2 Hazard zones

The term **hazard zone** is used to identify areas at risk of being affected by a specific hazard or hazards, and to indicate which areas are at greater or lesser risk. For example, areas that have been flooded or are at high risk of flooding due to the location of drains will be identified and outlined in a local council's urban flood map. This kind of hazard zone map would be used in urban land-use planning or by insurance companies when they are calculating premiums for clients.

Hazards and risks can also change over time. For example, hazard zones are declared around active volcanoes when the risk of eruption is assessed to be greater. When Mt Agung erupted in Bali, Indonesia, in 2017, people were evacuated from the area surrounding the base of the volcano to a distance of 12 km – any closer was considered a high-risk zone for ash and rock fallout. Because these volcanoes have a history of releasing toxic fumes and **pyroclastic clouds** (hot clouds of gas and debris from the volcano), the distance needed to be substantial. There was also the risk of lahars (mudflows) forming because of the heavy tropical rainfall.

1.2.3 Risk management

When humans are faced with the risks of natural hazards, they engage in **risk management** strategies, or ways to prevent or mitigate the risk or its effects based on the known consequences of the hazard.

Risk management includes a number of different elements. **Prevention** is about stopping a hazard from occurring. **Mitigation** is about reducing or eliminating a hazard's force or level of impact if it does happen. **Preparedness** refers to actions taken by communities so they can maintain an ability to respond to, and recover from, natural hazards if they occur. This involves strategies such as planning, community education, information management, communications and developing warning systems.

Activity 1.2: Assessing hazards

Examine figure 1.2 carefully to answer the following questions.

FIGURE 1.2 Road covered by floodwater

Source: Bill Dodd

Explain and analyse a ground level image

1. Describe the features of the natural hazard in figure 1.2.
2. Identify the factors that might have contributed to this hazard occurring. Consider the biophysical (living and non-living things), managed (human-controlled), and constructed (built) features of the environment.
3. Look closely at figure 1.2. Based on the visual evidence, what kind of event might have created this hazard?

Apply your understanding and propose a response

4. Might this hazard happen again? What steps could be taken to eliminate or control the risk permanently?
5. What possible scenarios might unfold if a person with children in their car attempted to drive through the water?

Synthesise the information

6. If you managed road safety for the local council in this area, what actions would you take to mitigate the risk this hazard poses in both the short-term and the long-term? Propose two strategies you could employ and justify why they would help to reduce the risk.

1.3 Types of natural hazards

Because of the way they form and how and where they happen, natural hazards are grouped into categories. Some hazards fit into several categories because they are caused by a combination of processes.

Atmospheric hazards occur in the atmosphere. These include severe storms, tropical cyclones (typhoons and hurricanes), tornadoes, blizzards, wind storms and drought (these may also be referred to as climatological – related to weather).

Geological hazards are natural events that occur in the Earth's crust, such as a volcanic eruption, earthquake or tsunami.

Geomorphic hazards are events on the Earth's surface, such as avalanches, landslides, mudslides (mass wasting). These may be triggered by natural or human processes, for example, by an earthquake or torrential rain, or by land clearing on mountain slopes.

Climatological hazards occur due to the climatic conditions of an area, such as bushfires, droughts and heatwaves. In each of these examples, the hazard is made worse by severe deficiencies of water over a prolonged period.

Hydrological hazards are extreme events with a significant water component, such as flash flooding due to storms, cyclones, ice melt or storm surges and tsunamis (which are hydrological hazards, caused by geological processes).

1.3.1 The systems approach

Examining the locations, processes and effects of natural hazards is best done using a systems approach. A **system** is any network of objects, places, events or organisms that work together as a whole. If a change occurs in one part of the system, that change will often affect the balance and operation of the whole system.

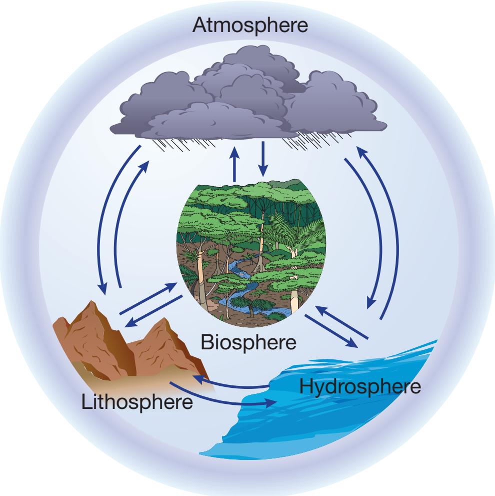
There are two basic types of systems, closed and open, depending on the exchange of energy and matter. **Closed systems** have boundaries, which allow the system to exchange energy with its surroundings, but not matter. An example of a closed system is an oven, which allows energy to enter and keep things warm, but does not allow heat to escape and warm the room. An **open system** is one that can exchange both matter and energy across its boundaries. A river catchment is an example of an open system because both matter, especially water and energy (in the form of sunlight and long-wavelength radiation), enter and leave the system.

The Earth is made up of four interconnected systems, which form the biophysical environment: three non-living and one living. These are:

- the **lithosphere** (the Earth's core, mantle and crust)
- the **atmosphere** (the mix of gases surrounding the Earth)
- the **hydrosphere** (the Earth's water, such as oceans, rivers, lakes and glaciers)
- the **biosphere** (the Earth's living things – plants, animals and organisms, also called the **ecosphere**).

Hazards can occur in any of the Earth's systems. Because they are connected, energy is easily transferred within and between them. For example, solar energy reaches the Earth and warms the land (lithosphere) and water (hydrosphere), and each of these can warm the atmosphere; seismic wave energy from tectonic plate movement and earthquakes can cause landslides and buildings to collapse, and an earthquake below the ocean can lead to a tsunami.

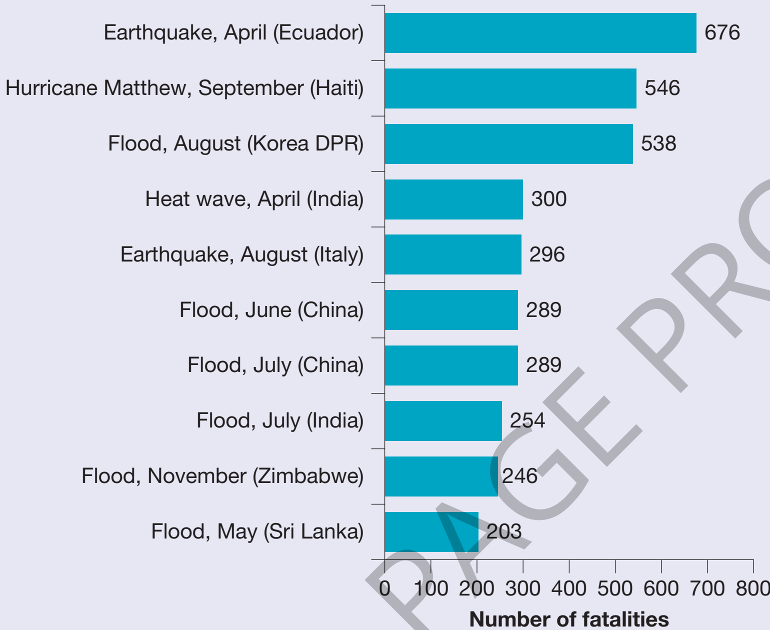
FIGURE 1.3 The Earth's physical systems



Activity 1.3: Impact of hazards

Examine figure 1.4 carefully to answer the following questions.

FIGURE 1.4 Natural disasters (2016) with the highest number of fatalities



***Source**:* Guha-Sapir D, Hoyois Ph., Below. R. Annual Disaster Statistical Review 2016: The Numbers and Trends. Brussels: CRED; 2016

Explain and fatality data

1. Based on the data in figure 1.4, indentify what type of hazard caused the most fatalities in 2016.
2. Identify the three non-living systems of the Earth where the natural hazards listed in figure 1.4 occurred.
3. Group the hazards according to the systems in which they occurred. Which system was responsible for most deaths?

Analyse the data and apply your knowledge of hazard zones

4. Research the natural disasters listed in figure 1.4 online. Using spatial technology or a print map of the world, shade the areas affected by these disasters, using colour to show the different types of hazard.
5. Based on your map data, do certain types of hazards seem to occur in specific regions or areas? Write a short paragraph to describe the geographic patterns you can identify.
6. Create a table showing the natural disasters that occurred around the world during the last year. Sort the data into a table showing the types of hazard, the location of the event and the number of fatalities. Does the data support your answer to question 6? Explain in a paragraph whether your assessment is supported by recent catastrophic hazards.

Resources

Weblink: Reliefweb Updates: Current disaster responses

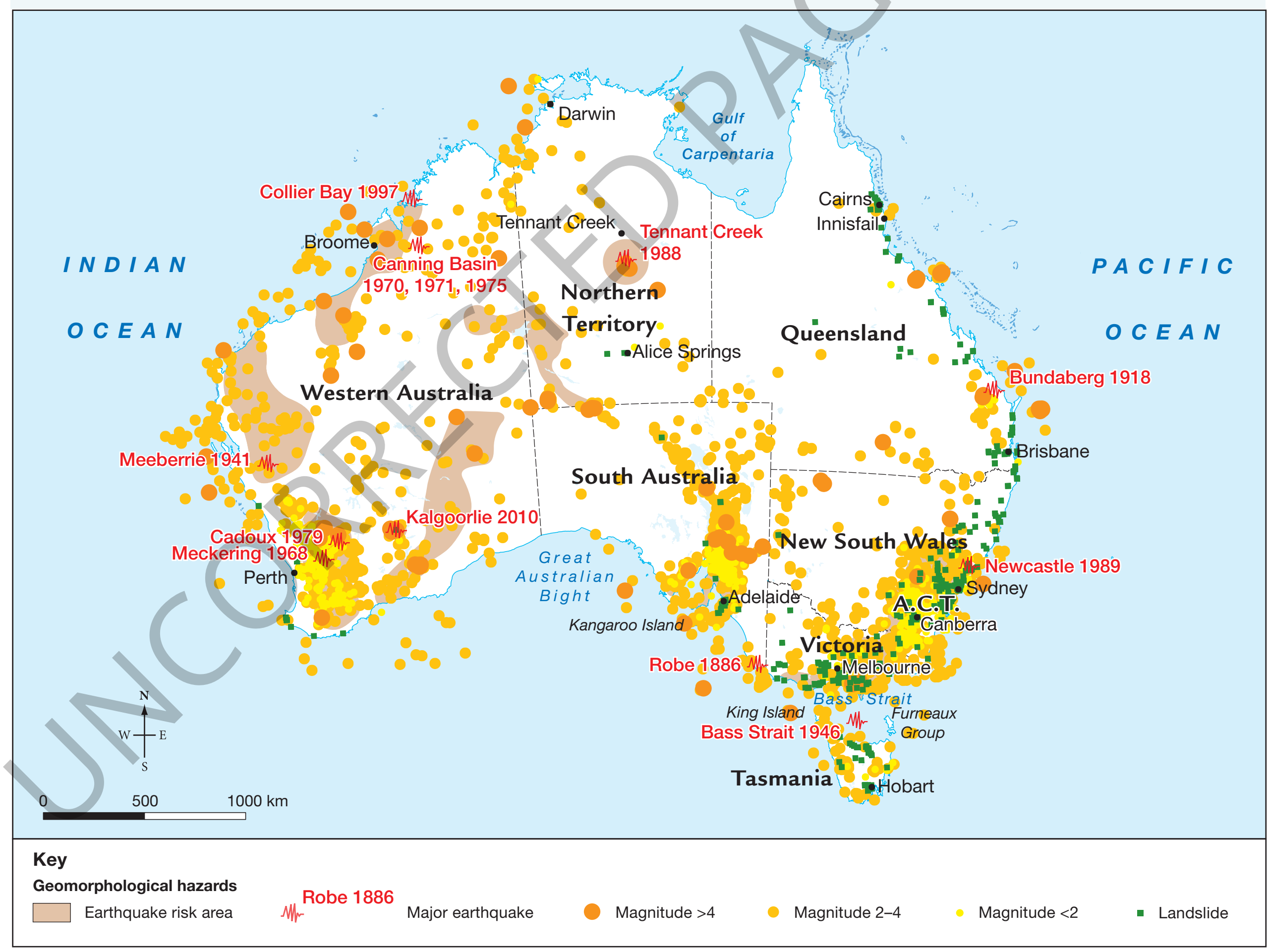
Weblink: EM-DAT: The International Disaster Database

1.4 Natural hazards in Australia

Australia is considered a naturally hazardous country because its risk level is relatively high, especially for atmospheric hazards. However, it is a very large continent with a small population. Consequently, few natural hazards in Australia become catastrophic natural disasters on the scale of the 2004 earthquake and tsunami in the Indian Ocean, which killed more than 270 000 people, or the earthquake that killed approximately 160 000 people in Haiti in 2010.

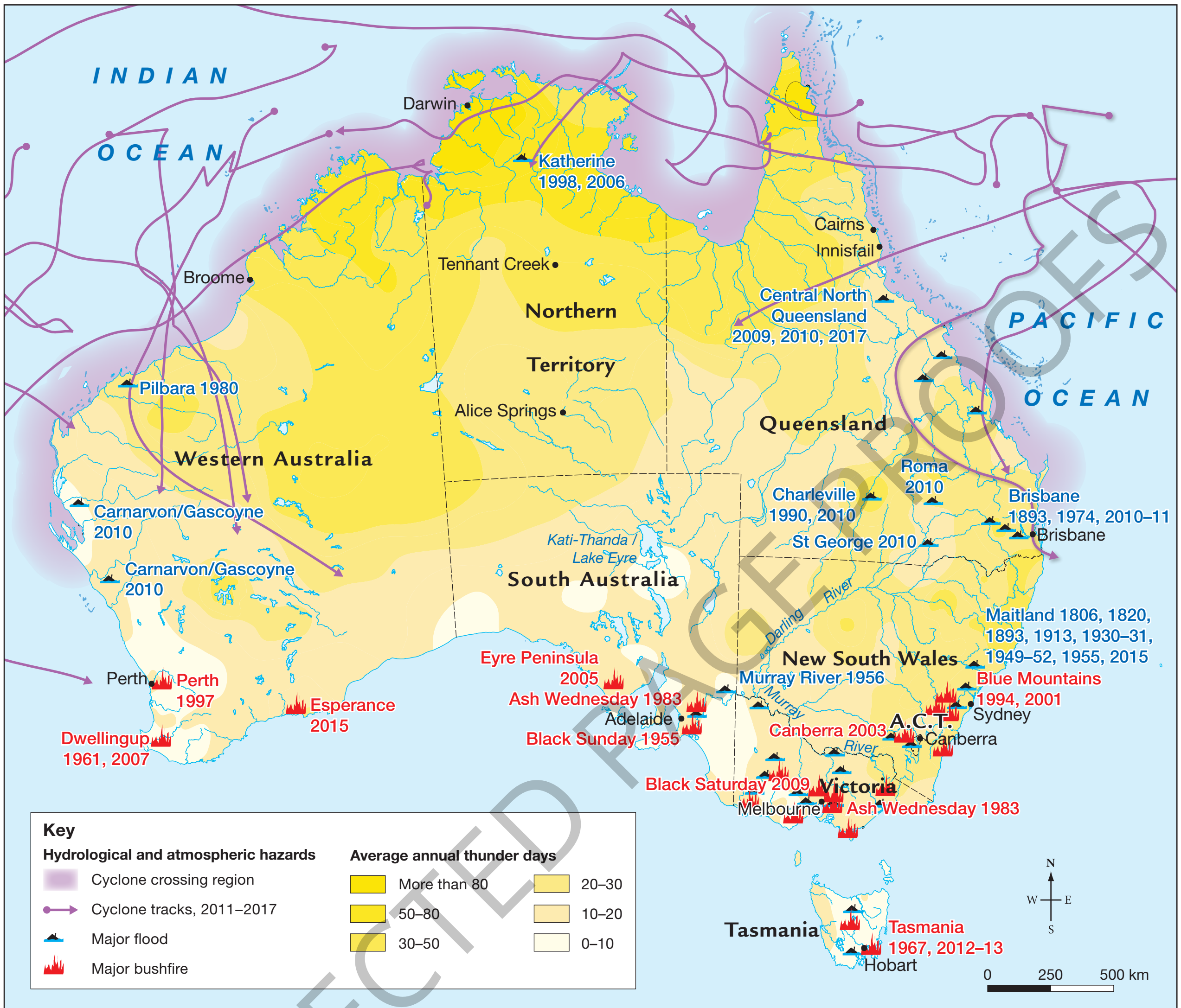
In Australia there is considerable variation in the types of natural hazards that occur between and within states (see figures 1.5 and 1.6). This influences the way people perceive natural hazards. Factors such as knowledge, experience and attitude all affect people's judgement of their level of risk and ability to cope. For example, until the Newcastle earthquake of 1989, few people in New South Wales would have considered earthquakes a risk. At the time, the Building Code of Australia, which is designed to safeguard people against major structural failure and loss of life, classified Newcastle's buildings as having a low earthquake risk. Consequently, specific building design for protection against earthquakes was not considered necessary. Given this, the impact of the earthquake was significant because of the low levels of preparedness and preparation for such an event.

FIGURE 1.5 Distribution of Australia's geomorphic and geological hazards



Source: © Commonwealth of Australia Geoscience Australia 2018. Redrawn by Spatial Vision.

FIGURE 1.6 Distribution of selected atmospheric, climatological and hydrological hazards in Australia



Source: MAPgraphics / Bureau of Meteorology

on Resources

Weblink: Geoscience Australia

Interactivity: Australia's natural hazards and disasters (int-5281)

Activity 1.4: Hazard zones in Australia

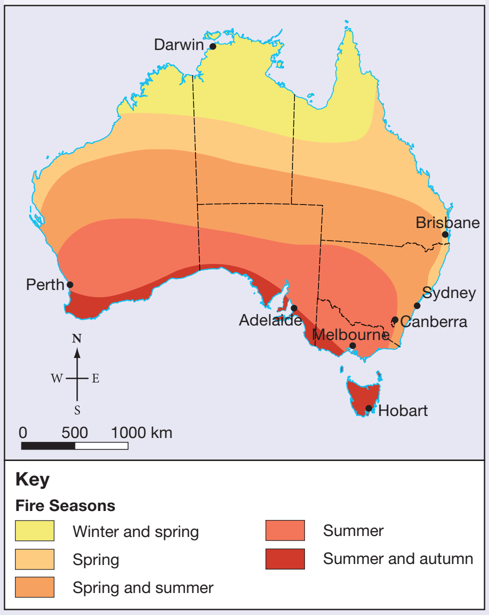
Examine figures 1.5, 1.6, 1.7 and 1.8 to answer the following questions about hazard zones in Australia.

Explain the data

1. List the natural hazards that are identified in the Australian maps.
2. Which of these hazards do you think might be the most closely linked to:
   (a) long periods of low rainfall?
   (b) movement of the lithosphere?
   (c) very high temperatures?

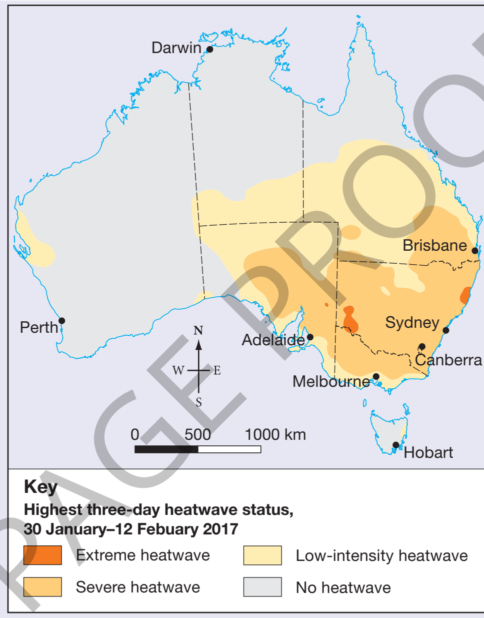
3. Which parts of Australia are most adversely affected by bushfires? During what time of the year?
4. Which states experienced a severe or extreme heatwave during January–February 2017?
5. Which states of Australia have recorded seismic tremors and earthquakes above 4 on the Richter scale?

FIGURE 1.7 Fire seasons in Australia



Source: Reproduced by permission of Bureau of Meteorology, © 2018 Commonwealth of Australia

FIGURE 1.8 Heatwaves affecting eastern Australia (Jan–Feb 2017)



Source: Commonwealth of Australia 2018, Bureau of Meteorology

6. Based on the maps above, and using an interactive mapping tool that allows annotation, create a map of Australian places that have experienced a major earthquake and are in a hazard zone for topical cyclones. Calculate the approximate distance from where you live to the closest location you have marked on your map.

Analyse the data and apply your knowledge

7. Considering both the fire seasons and the areas affected by the heatwave in 2017, which areas do you think were the most at risk from bushfires during the summer of 2017?
8. Locate the place where you live on each map. What natural hazards have been most disruptive to your area? Does this data support your experience of hazard patterns in your area? What challenges might these hazards create for people in your area?
9. Where do you consider to be the most hazardous or least hazardous places to live in in Australia? Use information from each of the maps to arrive at an answer.
10. Based on these maps, what new challenges might you face if you moved from Darwin to a bushland property in central Victoria? What steps could you take to minimise the risk to your family?

on Resources

- **Video eLesson:** Calculating distance using scale (eles-1653)
- **Interactivity:** Calculating distance using scale (int-3149)
- **Video eLesson:** Understanding thematic maps (eles-1658)
- **Interactivity:** Understanding thematic maps (int-3154)

1.5 The impact of hazards

1.5.1 Variables affecting impact

The impact of a hazard on a specific area and its people, both in the long- and short-term, depend on a range of factors.

Cause

What is the origin of the hazard? For example, a landslide might be triggered by deforestation of slopes (human causes) whereas a flood might be caused by torrential rain after a storm or tropical cyclone (natural causes). Other hazards may be triggered by a combination of causes.

Frequency

How often does it happen? Some hazards are seasonal, such as bushfires or cyclones, while others can occur at any time or without warning, such as earthquakes or a tsunami. If hazards occur with greater frequency, this leaves less time for rebuilding and risk management strategies to be put in place. If hazards occur infrequently, people may not be well-prepared for an event to occur.

Duration

How long does it last? A severe storm may only last for an hour or so, while a drought could go on for months or years. Coping with the impact of an event over a long period of time will stretch the available economic and social resources, and might mean that people affected need to leave the area permanently, or that the land may no longer be safe for human habitation. A long-running natural disaster will also affect the wellbeing of the people in the area.

Speed of onset

How quickly does it appear and was there time for any warning or response? For example, flash flooding can occur quickly without giving people time to move to safety or prepare, such as the 2011 flooding in the Lockyer Valley. A volcano may begin emitting smoke or gases in the days or weeks before an eruption, giving people time to evacuate.

Predictability

Is this kind of event foreseeable or does it occur unexpectedly? Is it a random occurrence or a regular seasonal event? A hurricane can be monitored and tracked to allow authorities to warn people in its path, but a significant earthquake might occur in an area where there has been little or no recent seismic activity.

Prevention, preparedness and adaptation

How much control do people have over the impacts and outcomes? Can they prevent a hazard from occurring or prepare and adapt to increase their chances of surviving a hazard? The threat in some bushfire hazard zones can be mitigated with controlled burns and careful land management, but this does not always lower the risk when other factors occur, such as very high temperatures, winds and arson. People might prepare for the risk of cyclones by shuttering or boarding up windows as a cyclone approaches, choosing to move away during high risk periods or building cyclone shelters. Authorities might construct sea walls to prevent storm surges flooding coastal communities.

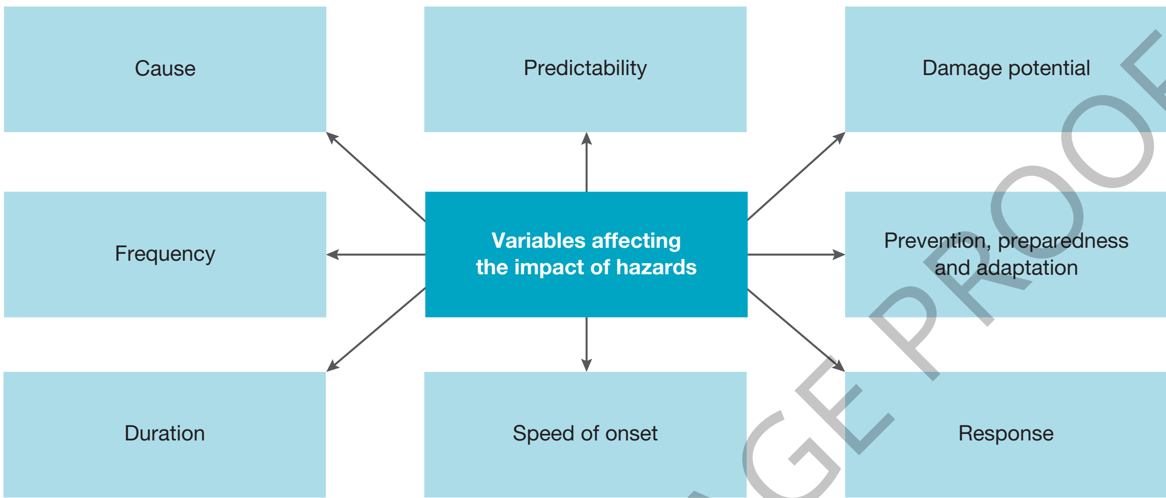
Damage potential and magnitude

How large or intense was the hazard? Is there the potential for loss of life or large-scale damage to infrastructure and the environment? The size or magnitude of a hazard may not equate to greater damage. For example, a weaker cyclone hitting a heavily populated urban area may cause more damage to buildings and infrastructure than a stronger cyclone that makes landfall in an unpopulated area.

Ability to respond

Can people respond quickly, or must they wait for assistance due to safety concerns or inaccessibility? A landslide in a remote mountain area may cut off all access for emergency crews or make existing access dangerous because of unstable ground.

FIGURE 1.9 Factors affecting the impact of hazards



Activity 1.5a: Variables affecting impact

Using the information you have learned about hazard impacts, answer the following questions.

Explain and describe how the impact of hazards can vary

1. Explain which of the factors listed in figure 1.9 will be beyond the control of a community in the path of a category 5 cyclone.
2. Which variable refers to how quickly a hazard occurs? Give an example.
3. Explain the difference between the variables *prevention, preparedness and adaptation* and *predictability.* Give examples to support your explanation.
4. Describe and give examples to explain how each of the factors listed in figure 1.9 might affect the impact of a cyclone on a major city, such as Brisbane.

1.5.2 Factors affecting vulnerability

Even though hazards can be quite different in their structures, the way they form and the way they disrupt an area, there are still some common factors that influence people's vulnerability to their impact.

Physical factors

Factors in the physical environment, such as the weather, the season (summer or winter) or terrain, can affect how people cope in the short-term when a hazard occurs. When Cyclone Debbie struck north Queensland in April 2017, relentless torrential rain made it difficult for people to put temporary covers on unroofed and damaged houses several days after the initial gales. Flooded roads also made it impossible for emergency workers such as the police to reach those in need. An example of the terrain worsening the severity of impact is when the 7.5 magnitude earthquake struck the central highlands of Papua New Guinea in February 2018 – people were still waiting for assistance over a week later because roads were blocked by landslides.

Economic factors

Preparedness, mitigation, prevention and adaptation strategies can be expensive to implement, so a community's level of economic development can affect the impact of a natural hazard. Countries with limited financial resources also have a greater chance of fatalities from hazards because they lack the money to provide the required emergency aid quickly. This emergency aid might include well-resourced emergency response teams, medical supplies and healthcare workers, shelter for survivors, and fresh food or water. When hazards such as earthquakes occur in less developed countries, affected residents must often wait for overseas aid. For example, after the Papua New Guinea earthquake in 2018, much of the rescue and recovery work was organised by an oil drilling company that was in the area because the government did not have the resources to do so.

Social and political factors

After a natural disaster, the social structures of a community and country also become an important part of the recovery. An immediate and positive response from internal government agencies (political and military), such as declaring a state of emergency, helps to ensure that the rescue and recovery process runs smoothly and efficiently. Aid efforts are also affected by the ways in which government bodies, community organisations and the media mobilise non-affected people to help sufferers, for example with generous donations of medical aid, fresh water and food, building supplies, clothing and money. Following a natural disaster, morale also needs to be high and positive for rescue and rebuilding efforts to continue, especially when victims have lost loved ones or are left homeless.

Climate change

In the past, the Earth's atmospheric and ocean systems were regarded as stable. Very little change was evident and natural hazards only occurred from time to time. Today, the potential for adjustments to the Earth's natural systems has accelerated and its impacts have become magnified. Increased levels of greenhouse gases, such as carbon dioxide (CO_2) and methane (CH_4), in the atmosphere are shown to be contributing to a higher frequency of rare (extreme) weather events and even climate change.

It is evident that the natural hazards are now having more impact on populations in terms of fatalities, injuries and property damage than in previous times. However, experts will not always agree on the underlying causes. Is the increased impact due to bigger populations and therefore more people are now exposed to risk? Is it because people are having to live in more exposed places such as hillsides, flood plains or beside volcanoes? Or is it because of changes to climates caused by global warming?

Most scientists believe that increases in CO_2 levels and subsequent general warming of the atmosphere (global warming) contribute to climate change and consequently affect natural hazards. The most obvious indicators are:

- rising global temperatures due to Earth not releasing heat
- more frequent and extreme droughts
- more frequent and damaging wildfires
- more severe and destructive tropical cyclones and hurricanes
- more frequent and destructive tornadoes
- rapid melting of glaciers, sea ice and ice-caps
- melting of permafrost in tundra regions
- gradual sea level rising that adversely affects estuaries and low-lying coastal plains
- weakening of the polar vortex causing prolonged icy periods and intrusions of warm air into parts of the northern hemisphere.

The onset of climatic changes and an expanding human–nature interface is also making communities vulnerable to bushfires (wildfires), which remain our most lethal natural hazard, particularly in southern states.

Resources

Weblink: Vulnerability to extreme weather events

1.5.3 Primary, secondary and tertiary impacts

Examining the processes and effects of natural hazards involves looking at the systems that those hazards belong to – a system is a dynamic unit with inputs, processes and outputs. Most importantly, if a change occurs in one part of the system, it will affect the whole system.

Some of these impacts will happen immediately. For example, if there is an earthquake the ground will shake, items will fall from shelves and buildings may topple. If a severe storm hits, houses may be unroofed, power could be lost and there will be local flooding. These are called **primary impacts** because they are immediate and happen first. They are also most likely to cause death or injury. It is these events emergency services (police, medical and fire) will attend to as soon as possible, depending on safety and access.

In the hours or days after a disaster, other issues will become apparent. Some people may need medical treatment or to attend to injured animals, food and water could run out, houses might not be safe to occupy, power and sewerage might not work, communication could be cut, roads could be closed, people might not be able to get to work, schools could be closed, shops and banks may not open, and transport systems can shut down and so on. These are **secondary impacts** and may continue for some time until repairs are made or help arrives.

There are also **tertiary impacts**, which are long-term. After some time, businesses or industries may be forced to close or relocate if the cost to restore them is unviable or their buildings are not able to be repaired. The tertiary impacts for individuals might include a range of physical, social or economic affects. Houses may not be allowed to be rebuilt on some sites forcing people to move, outbreaks of diseases might occur, people may become afraid and relocate, or insurance premiums become very high and unaffordable. All these factors may affect people's desire to remain in a hazard-prone area or the ways they adapt to life in the hazard zone if they are unable or unwilling to leave.

Activity 1.5b: Explain and analyse the effects of a cyclone

The severity of impacts of a hazard are often measured in terms of the environmental, economic and social effects. After a cyclone has passed over, it is a normal response for people to want to find out how friends, neighbours and others in their community survived. The following list includes some of the effects of Tropical Cyclone Yasi when it made landfall in Queensland in 2011.

- About 150 homes destroyed or uninhabitable
- Trees shredded including in National Park areas
- Wildlife killed or left without habitat and food
- Powerlines down over large area
- Schools closed
- Emergency staff (SES) unable to help people
- Roads flooded and bridges washed away
- Beaches and marinas destroyed
- Medical staff unable to get to hospitals
- Tourism sites and resorts closed for months
- 85 per cent of Queensland's banana crop destroyed
- Much of the sugar cane crop ruined
- Phone and communication towers damaged
- People unable to get to work
- Businesses closed down and workers made redundant
- Water treatment plants damaged
- Sewerage infrastructure damaged
- Supermarkets and shops unable to be resupplied

Analyse information about the effects of a cyclone

1. Create a table to categorise the impacts into groups according to whether it would be an environmental, economic or social factor. Use a table like the one below.

Environmental effects	Economic effects	Social effects

2. Using these ideas, write a paragraph about each type of effect, giving reasons for why they might have occurred and outlining some of the secondary and tertiary effects that may have occurred as a result. For example: Environmental effects. *Destructive winds over 180 km/h shredded and uprooted trees in the coastal national parks, forcing cassowaries out of the rainforests onto roadways in search of food. This also resulted in a number being struck by cars or chased by domestic dogs. Powerful storm surges inundated coastal areas with salt water resulting in …*

1.6 Assessing and responding to hazards

1.6.1 Risk assessment

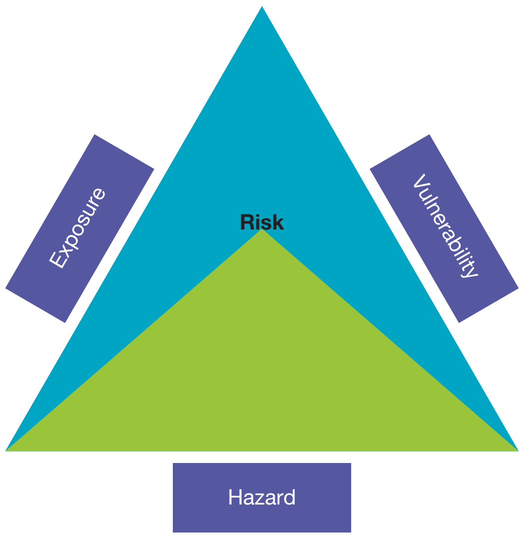
To manage a risk and reduce the possibility of harm, planners assess likely hazards and the potential worst-case scenario. A tool known as a risk assessment allows organisers to conduct a step-by-step analysis of these problems. Once the hazards have been identified, actions can be put in place to improve a community's preparedness, prevent and/or mitigate risk and help to build adaptation strategies so that people can remain safe. This process is called **risk management.**

A risk assessment for a natural hazard involves the following steps.

1. Understand the possible effects of the hazard, largely based on previous events and data.
2. Examine the physical features and topographic area where the hazard may occur.
3. Appreciate the type and distribution of human features, infrastructure and logistics in the area.
4. Consider the demographic profile of the area and ability of residents to respond to challenging situations.
5. Understand the role and availability of media, communications, emergency services and support teams that may be accessed.

Once the various threats have been identified, procedures are put in place to mitigate their impacts and keep people safe. A risk may be mitigated by a reduction in the size of any of the three main variables: (a) type of hazard, (b) elements exposed (for example, people and buildings) and (c) vulnerability. Consider figure 1.10 below, based on Crichton's Risk Triangle.

FIGURE 1.10 Reducing exposure and vulnerability to a hazard



Risk management triangle

Source: Adapted from Risk and Impact, Geoscience Australia 2018 http://www.ga.gov.au/scientific-topics/hazards/risk-and-impact

According to David Crichton, people have little or no control over a hazard's type, frequency and magnitude, but they can do something about exposure and vulnerability, particularly in places where improved technologies and communications allow residents to be better informed. **Exposure** refers to the things likely to be affected by a hazard, including people, crops, livestock, buildings and infrastructure. It also refers to intangible assets with economic value, such as work or communications. For example, if a tropical cyclone was heading towards a settlement, the residents and homes would be exposed to substantial risk. **Vulnerability** is a term used to measure the degree of risk according to its location, amount of preparedness, and counter-response resources available.

In the risk management model (right), the large blue area assumes the initial risk with each of the three variables contributing equally to the risk. However, if steps are taken to reduce both exposure (for example, by not living too close to a volcano) and vulnerability (for example, closely monitoring and recording volcanoes for signs of activity), the smaller, green triangle shows that the overall risk has been lowered.

Researching events of the past also gives people an increased probability of being able to forecast what might happen in the future. People can't prevent natural hazards from happening, but communities can reduce the risk and manage the effects and response. In most cases, it is often proactive effort and readiness that prevent a natural hazard from becoming a disaster. This is best achieved through education, technologies and funding.

Estimating a level of risk about a specific event (for example, an approaching cyclone) is difficult because precise locations and/or time of impact cannot always be known. However, risk models combining information about past events, including frequency and intensity, are now being developed to help experts predict possible hazard scenarios.

Crichton's model can be summarised as:

$$\text{RISK} = \text{HAZARD TYPE} \times \text{EXPOSURE} \times \text{VULNERABILITY}$$

These models are now used as a guide for emergency services to prepare for a range of effects, including response strategies and damage estimates. The scale and frequency of various natural disasters now form an integral part of any risk assessment and equivalent insurance considerations.

Equally important is that efforts are made to ensure critical infrastructure sites such as power stations, water treatment systems, sewage disposal plants and telecommunication networks are less vulnerable to natural hazards. When minimal disruption occurs to infrastructure, recovery is more rapid and less costly.

1.6.2 Managing impact

While scientific technology, such as satellites and weather instruments, enables us to measure changes to the Earth's surface, oceans and atmosphere, it is the accurate analysis of data and clear communication to the public that are most crucial for shaping the level of impact. Precise and current information passed on to emergency personnel, community decision makers and the media also means that people have time to prepare, respond or evacuate before the hazard occurs. Governments, councils and emergency teams need to be aware of the extent of the hazard zone, the event's potential severity and degree of impact if they're to prepare the best response in terms of safety and mitigation of damage. This process is often referred to as **disaster management**.

FIGURE 1.11 Emergency response teams help reduce vulnerability to a hazard

Resources

Weblink: Risk and impact
Weblink: Disaster management in Queensland

1.6.3 Black Saturday bushfires

Australia is a very dry continent and is often prone to bush and grass fires. Fires are extremely hazardous events that occur mainly in the southern half of the continent. Some of the worst affected areas are in Victoria, Tasmania, southern New South Wales and South Australia, and the south east of Western Australia. When bushfires are raging out of control, they are referred to as wildfires.

Bushfires, or wildfires, are a climatological hazard because of their connection to hot, dry periods of weather, but they are frequently started by humans or infrastructure failure. Common causes are careless campers or smokers, arson, vehicle accidents or power line damage. Lightning strikes also start fires in some places.

Fire experts recommend that residents in fire-prone areas have a safety evacuation plan in the event of a bushfire. People must choose to either remain in their home to be protected from radiant heat produced by the fire or decide to evacuate.

Most buildings catch fire due to wind-carried embers landing on roofs and in eaves, so it is possible that physically fit, well-prepared people can fight a slow starting fire if they have protective clothing from the ambient heat, suitable pumps and hoses, and a plentiful water supply. People who choose to leave their homes should do so before the threat of fire is close. Leaving when a fire is close presents a significant risk because of the low visibility and breathing problems caused by smoke, the danger of ambient heat and embers, the unpredictability of changing winds, and the likelihood of fallen trees and other road obstructions that make getting to safety difficult. These conditions are also very frightening and confusing, leading to people making potentially disastrous decisions from fear and lack of experience.

In southern states, some wildfires become out of control. The size and ferocity of high-intensity crown fires (fires burning in the crowns of trees or canopy of the forest) combined with thick choking smoke and powerful winds makes water bombing and back-burning impossible, and puts firefighters on the ground at risk of being killed.

This scenario unfolded in Victoria in February 2009 during what are now known as the Black Saturday fires, which devastated parts of Victoria including the Kinglake and Marysville areas, about 100 km north-east of Melbourne, and in central Gippsland to Melbourne's east. The fires burnt out over 450 000 hectares of forest, farmland and national park, killing 173 people and injuring 414 others. At least 3500 buildings were destroyed, including more than 2000 homes. More than 19 000 Country Fire Authority (CFA) personnel fought the fires.

FIGURE 1.12 Bushfire devastation in South Gippsland, Victoria, after the 2009 Black Saturday bushfires

What factors influenced the Black Saturday bushfires?

The Black Saturday bushfires and the extent of their severity were influenced by a number of factors, including:

- a series of days of 40+°C, with temperatures reaching 46°C on 7 February
- strong surface wind that gusted up to 100 km/h
- a change of wind direction late in the day that pushed the fire fronts into new areas
- crowning fires in heavily forested areas that could not be controlled by ground-based fire crews

- strong convection columns (columns of rising hot air over the fires) that took burning bark high into the air and created spot fires kilometres ahead of the fire fronts
- horizontal convective rolls that fanned flames with strong and unpredictable winds, and an 'undular bore' (the wave of cold front that increases the strength of winds on the ground)
- the heavily treed and hilly terrain, which made access difficult for fire crews.

The subsequent Royal Commission into the Black Saturday fires revealed overall costs were conservatively AU$4.4 billion (25 per cent of this was insurance claims), 13 per cent of homes were uninsured, while the RSPCA estimated that more than one million domestic animals and wildlife died.

How did the fires change response strategy?

Victoria's bushfire safety policy at the time was 'Prepare, Stay and Defend or Leave Early' – colloquially known as the 'Stay or Go' policy. The policy and the causes, response to and impacts of the fires were all scrutinised in the 2009 Victorian Bushfires Royal Commission.

Some of the questions raised about the 'Stay or Go' policy during the Royal Commission included:

- When should alerts be communicated to the public and what information should they contain?
- Did residents have sufficient understanding of the risks and their vulnerability to make an informed decision about whether they could successfully defend their property?
- Did residents have sufficient understanding of the physical and mental demands of protecting a property from a passing wildfire?
- What if conditions changed and the fire was larger than first anticipated?
- What were the risks of mass evacuations and people being cut off or trapped on roadsides?
- Did the plan adequately consider variations in bush density, access and topography?
- Did the plan adequately consider vulnerable groups, such as children or the elderly, who are not physically strong enough to help combat fires? (Almost half of those who died in the fires were younger than 12, over 70, disabled or chronically ill.)

The Royal Commission recommended 67 changes to Victoria's bushfire safety policy and the state adopted the national 'Prepare. Act. Survive' bushfire response framework. The Commission also recommended changes to policy regarding responding to bushfires, reducing the number of bushfires, reducing the damage caused by bushfires, and building on current knowledge of fire impact and activity specific to Victorian bushfire risk factors. Many of these changes take into account the need for greater shared community responsibility and local council input to ensure policies and plans suit or are tailored to suit the conditions and geography of a specific area, local area-specific education, and the need for different responses and advice based on the risk-factors present on any given day.

FIGURE 1.13 Homes destroyed in the Black Saturday fires

Some of the other recommendations included:

- building or creating more community refuges in high-risk areas to ensure people who were unable to defend their properties, but were too late to leave the area safely, had somewhere safe to shelter
- encouraging vulnerable people to leave the area earlier, particularly considering relocating on high risk days before the threat of fire is present in the area
- requiring that the CFA and Department of Sustainability have a full incident management team and accredited controller in place, and that aerial water-bombing craft and personnel are on standby by 10 am on days of extreme fire danger
- changes to the electricity infrastructure to minimise the risk if fires spark, such as using underground cabling in high-risk areas

- reviewing native bush-clearing permits, building codes and planning rules in high-risk areas to allow for greater consideration of fire risk mitigation
- reviewing prescribed burning programs to manage biodiversity and bushfire risk mitigation
- establishing a national bushfire research centre.

on Resources

- **Weblink:** 2009 Victorian Bushfires Royal Commission report
- **Weblink:** Fire danger index calculations
- **Weblink:** Unusual weather events identified during 2009 Black Saturday bushfires

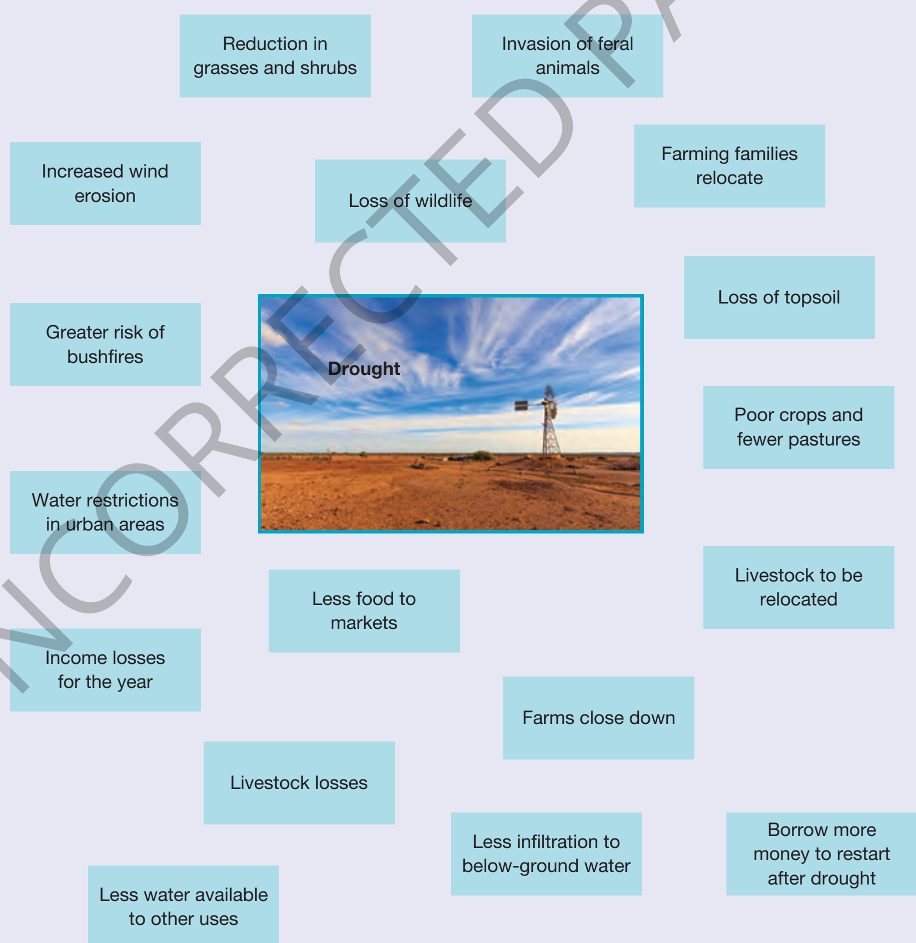
Activity 1.6: Managing hazards

Using the information you have learned about managing hazards, answer the following questions.

Explain and describe how hazards are managed

1. Explain how technology can be used to mitigate the impacts of a bushfire hazard. Give three specific examples to support your explanation.
2. Explain how risk can be mitigated by lowering *exposure* and *vulnerability* to bushfires.
3. Describe the purpose of a risk assessment and the types of information they typically include.

FIGURE 1.14 Primary, secondary and tertiary impacts of drought



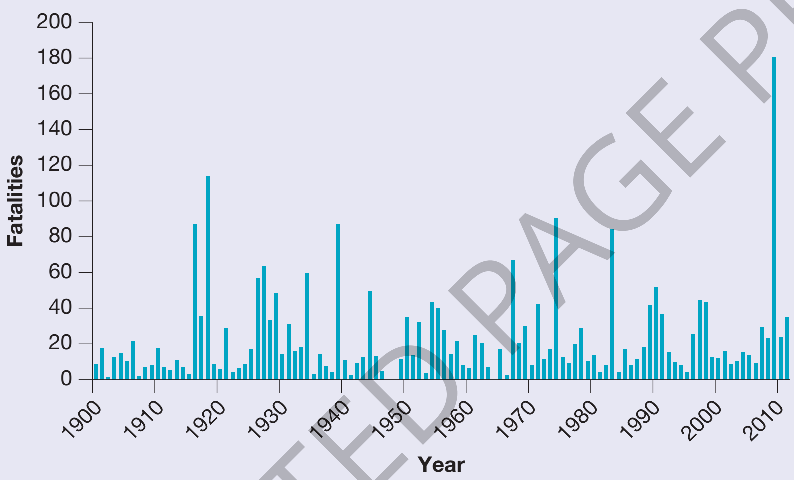
Analyse a column graph

4. Examine the impacts of drought in Australia in figure 1.14 and determine which ones are primary, secondary or tertiary. Organise them in a table like the one below.

Primary effects	Secondary effects	Tertiary effects

5. Examine figure 1.15 and locate the number of fatalities for the years in which each of these natural disasters occurred: Tasmanian bushfires (1967), Ash Wednesday fires (1983), Black Saturday fires (2009). Research each of these events and write a short paragraph about each explaining some of the variables that contributed to the impact of each of the fires, including suggestions for why these events may have had a greater impact than other fires.

FIGURE 1.15 Australian natural disaster fatalities (fire) 1900–2010



***Source**:* Used with permission from the Bushfire and Natural Hazards CRC

Propose ways to manage the risk

6. Consider the primary, secondary and tertiary impacts of drought. Write one paragraph to outline strategies that would reduce the effect of primary impacts, one to describe a strategy to reduce the secondary impacts, and one to describe a strategy to reduce the tertiary impacts.
7. What impact could climate change have on bushfires and droughts in the future? Suggest how communities in areas of high risk might act to reduce their exposure and vulnerability to these hazards?
8. Research the impacts of drought in Australia and in the Sahel region of Africa. Write a paragraph explaining each of the following:
   (a) the impact on the people of the regions affected (consider social, economic and physical impacts)
   (b) the differences in economic development of the regions affected
   (c) how governments and non-government agencies responded
   (d) the effectiveness of the responses.

1.7 Atmospheric hazards

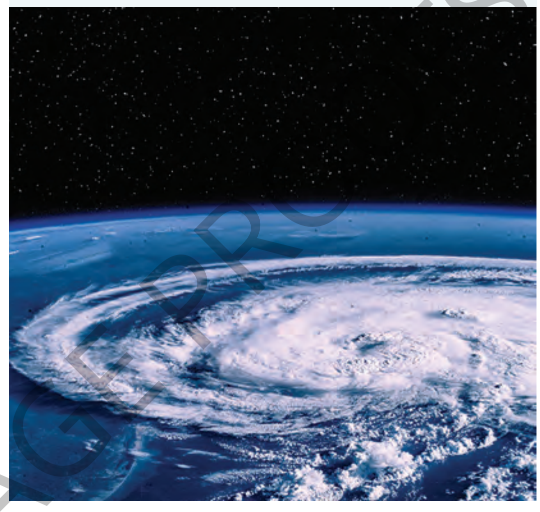
1.7.1 Introduction

Atmospheric hazards are extreme weather-related events that happen in the lower levels of the atmosphere: the troposphere. They are all part of the Earth's climate system. The most common hazards are severe storms (thunderstorms), blizzards, snowstorms, sandstorms, tropical cyclones (hurricanes and typhoons) and tornadoes. Floods can also occur as a combination of atmospheric and geomorphic processes. Many of these hazards arrive and occur quickly during a short period, for example over a few hours or a few days. Other longer-term atmospheric hazards that are linked to natural cycles or the climate are dry spells and drought. Some atmospheric hazards also occur from human causes, such as air pollution from dust, chemical vapours, industrial fumes, fogs and smog. Because these have an adverse toxicological effect on living things and can impede breathing, they are considered hazards.

1.7.2 Processes that create atmospheric hazards

The atmosphere is a clear layer of gases surrounding the planet. It keeps animals and plants alive and protects them from extreme cold. Within the atmosphere are numerous circulations of air, energy and water – a complex system powered by energy from the sun. The atmosphere around the Earth is 78 per cent nitrogen (N_2), 21 per cent oxygen (O_2) and 0.9 per cent argon (A). Carbon dioxide (CO_2) and other gases including, water vapour (H_2O), ozone (O_3), methane (CH_4), nitrous oxide (N_2O) and hydrogen (H_2) make up the remainder. Despite the relatively constant composition of the atmosphere, across the globe there are factors that create differences in the air's physical properties that generate the conditions to create atmospheric hazards.

FIGURE 1.16 A hurricane viewed from space



One of these factors is the imbalance in the amount of solar radiation that reaches the surface at different latitudes. Because the atmosphere is transparent, the sun cannot heat the atmosphere directly. Instead, it heats the Earth, which heats the air above it. The roundness of the planet means that different parts of the Earth receive different levels of solar radiation. Low-latitude areas close to the equator receive more solar energy per unit area than high-latitude areas – the equator receives more than twice the solar energy over a year than the poles.

Another factor that affects the heat variation in the atmosphere is the distribution of land and sea on the planet. Most of the world is covered by water, not land. Because water takes longer to heat than land, once it's warm, it holds heat longer and cools more slowly. The seas and oceans act like huge heat reservoirs, maintaining relatively constant temperatures, unlike land masses. Consequently, there is a net surplus of radiation between 35°S and 40°N. The reason this occurs at different latitudes in each hemisphere is partly because there is more ocean and less landmass in the southern hemisphere.

This global imbalance of heat energy in the atmosphere is largely corrected by horizontal transfers of energy. The general circulation of air accounts for 80 per cent of the horizontal energy transfer. Ocean currents complete the remaining 20 per cent. Warm ocean and air currents transport warm water to the higher latitudes, which are cooler. The Earth rotates from west to east, which causes a deflection of these flows (the **Coriolis effect**). It is also responsible for deflecting ocean currents, which are large threads of warm or cold water that circulate in the oceans. In the southern hemisphere, currents moving away from the equator are warm and circulate in an anticlockwise direction, whereas in the northern hemisphere they flow in a clockwise direction.

Because the gases that make up the atmosphere have weight, they exert pressure. At any point above the Earth's surface there is a column of air exerting pressure. When air is heated it expands, loses weight and exerts less pressure. Therefore, if temperatures vary from place to place over the Earth, it is not surprising that associated atmospheric pressure also varies.

The subtropical highs that affect Australia most of the year are made up of subsiding air that has moved from the equator; however, low-pressure systems behave very differently. Instead of air subsiding and then diverging near the Earth's surface, it converges and spirals upward. The rising air is relatively unstable and these low-pressure systems are usually associated with unsettled, cloudy, wet and windy weather. The strength of the wind depends on the **pressure gradient**. This is the difference between the pressure at the centre of the system and that of the surrounding air. If the difference is large, the pressure gradient is steep and the resultant winds are strong.

On synoptic charts, strong winds are indicated by tightly packed isobars, just as a steep gradient on a topographic map is shown by tightly packed contour lines. The winds generated by the pressure gradient usually flow parallel to the isobars. The pattern of the isobars also allows us to identify **troughs** of low pressure and ridges of high pressure. Troughs can be recognised by a distinctive V-shaped pattern of isobars similar to the contour pattern of valleys on a topographic map.

on Resources

Video eLesson: Reading a weather map (eles-1637)

Interactivity: Reading a weather map (int-3133)

1.7.3 Thunderstorms

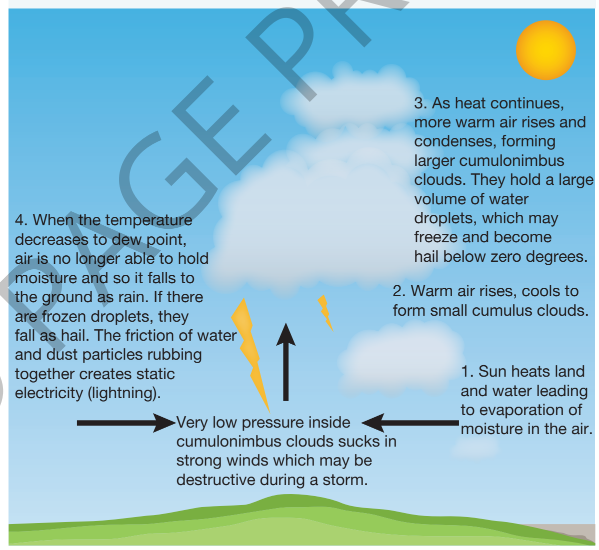
One of the most common types of atmospheric hazard is the thunderstorm. They occur all around the world, with up to 2000 happening at any one time. Thunderstorms form when warm moist air rises high into the atmosphere due to relatively hot weather and unstable air. Water vapour condenses forming huge cumulonimbus clouds.

In warmer climates, thunderstorm cells are related to low air pressure, where strong winds and updrafts carry moisture up to 20 km into the sky. This rapid thermal updraft allows huge volumes of water to remain suspended in the sky until it eventually falls as rain. Thunderstorms may only last for an hour or so but can cause havoc when they do occur due to their enormous release of energy.

Thunderstorms also develop in cooler areas. When a mass of cold air, along a cold front, forces warm air to rise, large cumulonimbus clouds form and a thunderstorm eventuates.

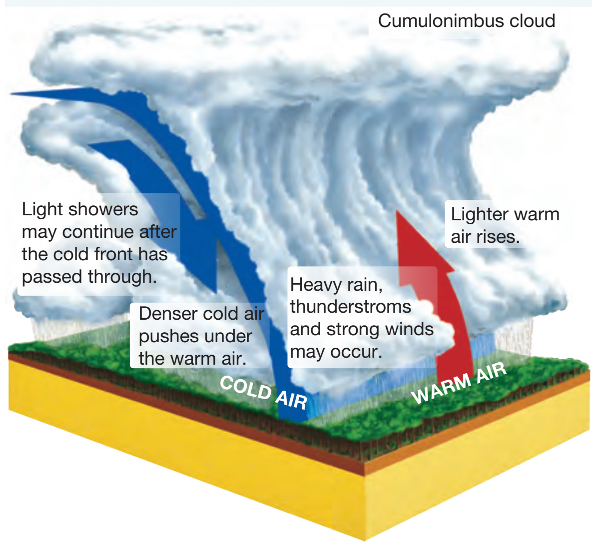
The main hazards associated with severe thunderstorms are torrential rain and associated flooding, hail, destructive winds and lightning strikes.

FIGURE 1.17 Formation of thunderstorms by warm convection currents (tropics)



Source: Bill Dodd

FIGURE 1.18 Formation of thunderstorms from a cold front (temperate regions)



Types of thunderstorms

There are three main types of thunderstorm, each with its own distinctive features. These are:

- a single-cell storm – this type is limited to a single heavy downpour, then breaks up quickly as cool downdraughts of wind smother the original warm air. A single-cell storm may only last an hour or so and seldom produces severe weather.
- the multicell thunderstorm – this type is most common and larger, often consisting of successive storms in sequence. Because it is larger and stronger, a multicell thunderstorm produces severe weather with heavy rain, hail and wind gusts.

- the supercell – this is a very large and dangerous storm with a continuous powerful updraught that seems to control the surrounding atmosphere. It has a dominant cloud shape that reaches high into the troposphere and a dark, threatening appearance. A supercell may last for many hours and is capable of very heavy rain, severe hail and destructive winds.

FIGURE 1.19 A storm cell moves across the Brisbane suburbs

Source: Bill Dodd

Activity 1.7a: Impacts of thunderstorms

Using the information you have learned about thunder storms, answer the following questions.

Explain the potential impacts of thunderstorms

1. Most parts of Australia experience severe thunderstorms. Explain how the risk to people and property from thunderstorms can be lessened by proposing three ways that vulnerability and exposure can be reduced in urban or suburban environments.
2. Compare these to three ways that vulnerability and exposure might be reduced in rural or remote environments.
3. Explain how economic factors or underlying health issues can affect an individual's vulnerability to thunderstorm events. Consider factors such as a susceptibility to thunderstorm asthma, housing security and physical mobility.
4. What strategies could authorities put in place to mitigate the risk for vulnerable members of their community in Australia?

on Resources

Interactivity: How a thunderstorm works (int-5615)

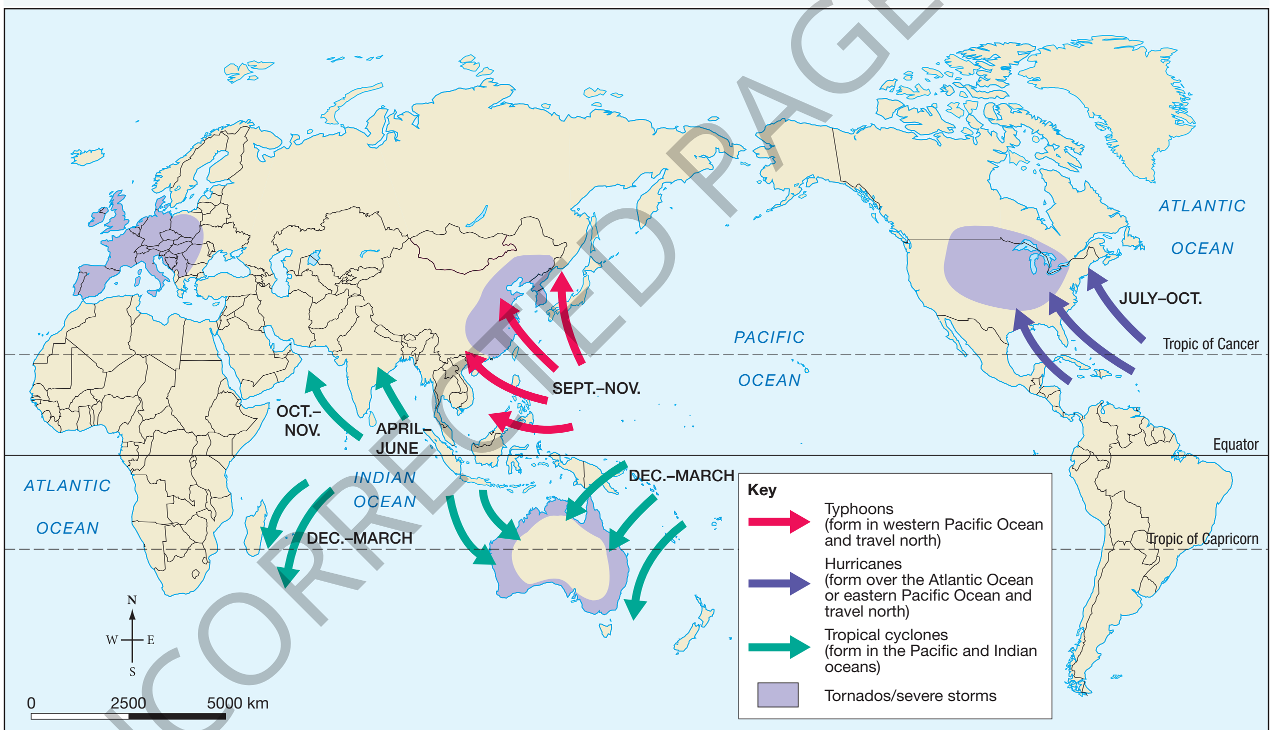
1.7.4 Tropical cyclones

Tropical cyclones are very large storms (100–2000 km in diameter) that bring heavy, driving rain and destructive winds to coastal and inland regions in tropical and sub-tropical parts of the world. Those that form over the Atlantic Ocean or eastern Pacific Ocean are called hurricanes while those that form in the western Pacific Ocean and travel north are called typhoons. Regardless of what they are called, they all form the same way.

Tropical cyclones usually form in the **inter-tropical convergence zone** (ITCZ), an area of low atmospheric pressure around the equator, because they require specific conditions to form: warmer sea temperatures, rising warm air, humidity and the right levels of **wind shear** (rapid change in the velocity or direction of the wind).

Once water temperatures exceed 26.5°C and the surrounding air pressure falls below 990 hectopascals, low-pressure cells can develop into larger tropical storms, mostly between the 5° and 30° latitudes. These newly formed cells draw in more warm moist air from the ocean surface and increase significantly in size. As the huge storm clouds extend high into the troposphere, these systems take on their characteristic circular shape with an 'eye' in the middle. Winds around the cyclone become gale force and can reach speeds in excess of 280 km/h, but the eye remains calm. Depending on the category of cyclone, the eye may be anywhere between 40 and 100 km wide.

FIGURE 1.20 World distribution of tropical cyclones by names used in different regions



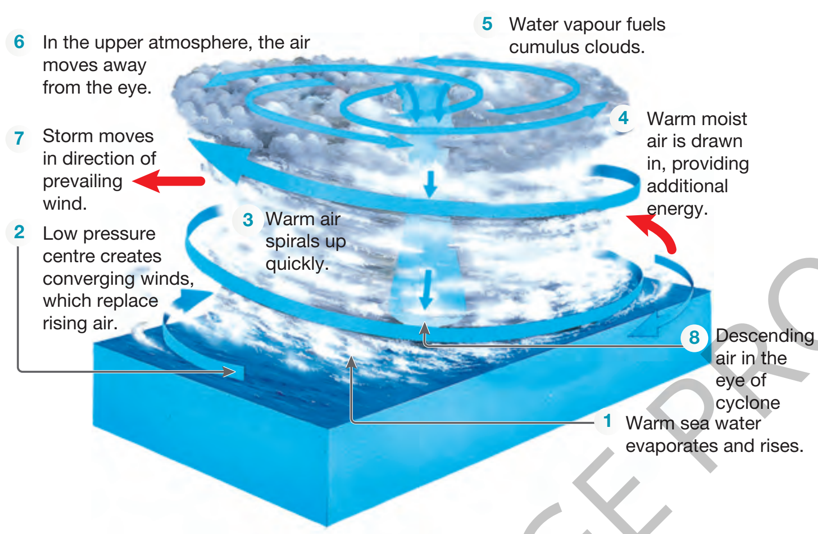
Source: MAPgraphics

The formation of cyclones is also affected by the Coriolis effect, the force that deflects winds clockwise in the southern hemisphere and anti-clockwise in the northern hemisphere. The effect of this force becomes more intense the further you move away from the equator, and is one of the key factors in shaping cyclones into their charateristic circular formation. Close to the equator, the Coriolis effect is weak. As a result, cyclones rarely form here.

Cyclones are well-known for their erratic movement, particularly as they approach land, and may persist for several days offshore, but once they cross onto land they lose their energy source (the rising warm ocean air) and become a rain depression (low pressure area).

Interestingly, it is incredibly rare – and some would argue impossible – for tropical cyclones to form in the south Atlantic Ocean between South America and Africa because the sea surface temperatures are too cold and the wind shear is too strong to allow storms to develop. However, in 2004, a strong storm made landfall in Brazil that many consider to be the first ever southern Atlantic tropical cyclone.

FIGURE 1.21 How a cyclone forms



Resources

Weblink: Tropical cyclone intensity
Weblink: Coriolis effect
Weblink: Rare south Atlantic tropical cyclone

Cyclone categories

When tropical cyclones make landfall, they can be very destructive, bringing gale force winds. Different scales are used to measure the intensity of these winds around the world.

FIGURE 1.22 Satellite imagery showing tropical cyclone, depression and storm activity in the Pacific Ocean in August 2014

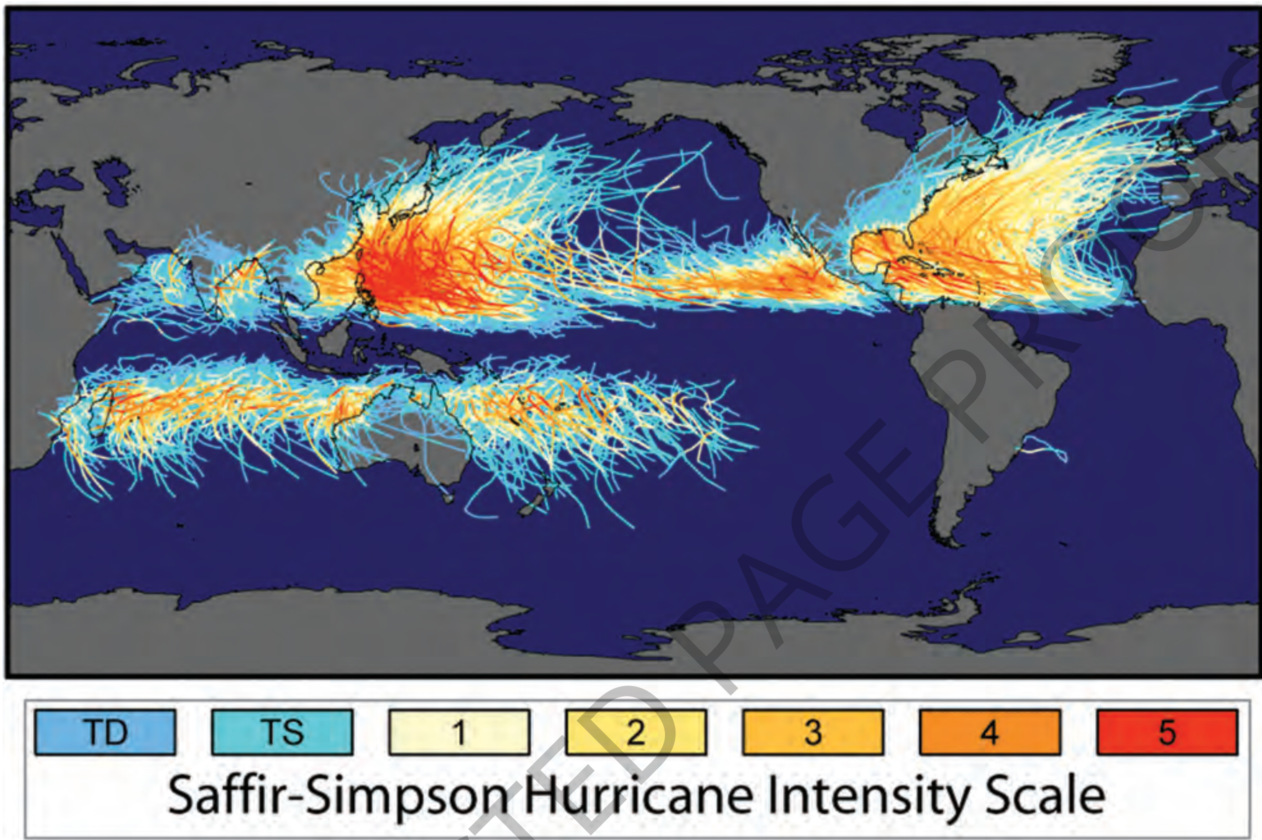
Source: NASA/NOAA GOES Project

In the USA hurricanes are measured with the **Saffir-Simpson Hurricane Wind Scale**, which rates the sustained speed of wind on a scale from 1 to 5, and provides examples of the kinds of damage expected for winds of that level. The Australian Bureau of Meterolology categorises the intensity of tropical cyclones using its own five-point scale, which also takes into account the atmospheric pressure, shown in table 1.1. Maximum sustained wind speed is determined by the peak mean wind speed, measured 10 metres above the surface of flat land or open water. In Australia this mean is measured over a ten minute period, but in the USA a one minute mean is used. Tropical cyclones are also measured in terms of their wind gust strength. In Australia, this is measured as the average speed of wind over a three-second period.

In addition to measuring their intensity, tropical cyclones are also mapped for their paths. This not only helps to determine where cyclones most commonly occur for risk assessment purposes, so communities in the likely path of a cyclone can be warned and given time to prepare, but it also helps to show whether patterns in the intensity and frequency change over time.

Figure 1.23 shows the paths and intensity of tropical cyclones for more than 150 years until September 2006, based on the records of the US National Hurricane Center and the Joint Typhoon Warning Centre. This map rates tropical cyclones using the Saffir-Simpson Scale.

FIGURE 1.23 Paths and intensity of tropical cyclones, tropical depressions and tropical storms



Source: NASA Earth Observatory

TABLE 1.1 Australian Bureau of Meteorology tropical cyclone category system

Category	Australian category name	Strongest wind gust (km/h)	Average maximum wind speed (km/h)	Central pressure (hPa)	Effects	Saffir-Simpson Scale comparison (km/h)
1	Tropical cyclone	90–124	63–90	>985	• Negligible house damage • Damage to crops and trees	119–153
2	Tropical cyclone	125–164	90–125	985–970	• Minor house damage • Risk of power failure • Heavy damage to some crops	154–177
3	Severe tropical cyclone	165–224	125–165	970–955	• Some structural and roof damage • Likely power failure	178–208
4	Severe tropical cyclone	225–279	165–225	955–930	• Significant structural damage and roofing loss • Widespread powr loss • Dangerous airborne debris	209–251
5	Severe tropical cyclone	>280	>225	<930	• Extreme danger • Widespread destruction	>252

Note: Storms with average maximum wind speeds between 52 and 54 km/h are referred to as tropical depressions, and tropical lows are storms with average maximum wind speeds between 56 and 61 km/h.

Storm surges

In addition to the immediate damage caused by the stong winds and rain of a cyclone or severe storm, strong winds can also generate very large waves.

Waves are caused by the friction of wind blowing over the sea's surface. The wind tugs at the surface of the water, causing the wave shape to move. This is like shaking a length of rope on the ground. The wave travels along the rope but the rope remains in the same place. Wind speed, duration and the distance over which it blows, commonly known as the fetch, determine the height of waves. During tropical cyclones these large waves are capable of eroding beaches and damaging coastal buildings and facilities.

This damage can be compounded by storm surges, which are increases in the height of sea level above the normal tide level. The resultant water level is known as the storm-tide level. Since atmospheric pressure is the weight of air above the Earth's surface, intense low-pressure systems, such as tropical cyclones, cause localised upward bulging of the sea surface. It is estimated that there is a rise in water level of approximately 10 cm for every 10 hectopascals of difference between the central pressure of the cyclone and the surrounding pressure (the central pressure being lower). This is known as the inverted barometric effect.

However, the height of the storm surge is not solely dependent on the intensity of the cyclone. In fact, a large component of any surge is the effect of strong onshore winds pushing water against the coast.

When wind blows over the sea's surface, it sets up a current in the water as a result of the shear stress on the surface of the water particles. When this current reaches the coast, the water tends to build up against the land. This is known as wind set-up. Consequently, the angle at which the cyclone approaches the coast and the configuration of the coastline itself are important. Shallow, sloping sea beds and the presence of bays and estuaries (which can funnel a surge into a confined area) contribute to abnormally high sea levels. Storm surges are typically between 60 and 80 km in diameter and up to 2.5 m high. Therefore, they can pose a serious threat to people living in low-lying coastal areas and estuaries.

Activity 1.7b: Tropical cyclones

Using the information you have learnt about tropical cyclones, answer the following questions.

Comprehend and explain tropical cyclones and identify their patterns

1. Categorise the type of hazards that are tracked on the world map in figure 1.23.
2. Explain the difference between a tropical depression and tropical storm.
3. Based on figure 1.23, which ocean develops the most Category 5 cyclones on the Saffir-Simpson Scale? Based on your understanding of how cyclones form, what atmospheric patterns or features would you expect to find in this area?
4. Between which lines of latitude do most tropical cyclones occur?
5. What categories on the Saffir-Simpson Scale are most common across northern Australia? What category would this type of cyclone be on the Australian Bureau of Meteorology's tropical cyclone category system?
6. Explain the geographical processes that result in the distribution of tropical cyclones shown in figure 1.23.

Analyse the data and apply your understanding

7. Which area of ocean does not seem to develop tropical cyclones, even though it is in the tropics? Suggest reasons why cyclones do not develop in this region, and predict how rising sea temperatures associated with climate change might affect this pattern.
8. If you were thinking of moving to Darwin and building a house, what category rating on the Saffir-Simpson Scale would you expect the builder to construct your home in order to withstand cyclones?
9. Family friends are arriving from Canada to visit you, and ask if early March is a good time to take a caravan holiday in northern Queensland. What advice would you give them?
10. Analyse and compare the Bureau of Meteorology's maps of the average number of tropical cyclones in El Niño years, La Niña years and neutral years using the weblinks below in the Resources tab. Suggest how these maps could help authorities to develop cyclone preparedness strategies.

11. Imagine your sister was moving to work in Taiwan for two years. Because you are studying natural hazards in geography, she emails you to ask whether you think it is likely she will experience a cyclone in that time and whether it might be dangerous. Reply to your sister explaining what she could experience.

on Resources

- **Interactivity:** How a cyclone forms (int-5299)
- **Weblink:** Cyclone intensity on the Saffir-Simpson Scale
- **Weblink:** Australian Bureau of Meteorology tropical cyclone maps

Meteorologists have determined that climate change has contributed to the way tropical cyclones develop and behave. Firstly, tropical cyclones need warm ocean water and quite cool upper atmospheric conditions to form. If the air continues to warm, the difference (gradient) between surface temperatures and upper level temperatures will be reduced, so fewer cyclones may form. Secondly, increased surface temperatures over the ocean combined with higher levels of CO_2 (more CO2 allows air to hold more moisture than it once could), provide cyclones with a much larger energy source, making them larger and more destructive.

Recent trends observed with tropical cyclones are:

- much higher volumes of rainfall near the centres when the male landfall
- an increase in high category destructive storms
- slower movement due to weakening of the circulation forces that drive movement. (In northern Australia, cyclones now move almost 20 per cent slower than they did 70 years ago, making them more destructive to settlements and causing more flooding.)

1.7.5 Responding to atmospheric hazards

Improvements in public awareness and communication have enabled communities to be better prepared for storms, cyclones and related flooding than in the past. This is evident from the decreasing number of fatalities and injuries, and despite such hazards becoming more powerful. However, an increasing population and more widespread settlements along the Australian coast have exposed community and government facilities to potentially greater economic damage.

Local authorities and emergency services play an important role in hazard response. They release information to help people prepare for and cope with the impact of atmospheric hazards in their area. In Australia, this information about cyclones comes as a Tropical Cyclone Warning Advice – either a tropical cyclone watch (24–48 hours before the onset) or tropical cyclone warning (onset within 24 hours). This advice relates important information including the area at risk (including a map), the intesity of the cyclone (using the Bureau of Meterology five-level scale), the movement of the cyclone, the range and maximum strength of wind gusts expected, and advice about what action people should take to mitigate the effects of the cyclone.

FIGURE 1.24 Tropical Cyclone Larry hits Innisfail, March 2006

1.7.6 Preparedness strategies

Housing engineering standards have improved and can now better withstand the windgusts of cyclones, but most places are not able to sustain the rapid flow of huge volumes of water from the torrential rainfall, storm surges and flooding. Strategies to prepare for cyclones and severe storms include the following.

- Installing undergound powerlines, which generally reduce the extent of outages and power failure in the event of a cyclone.
- Sea walls and shore-line sand buffers of at least 150 m in coastal developments help to reduce the impact of tidal surges during cyclones.
- Many urban areas have reclaimed or changed their natural creek, river and wetland systems through development, for example, turning their natural creeks into cement drains. Removing these and creating a wetlands network can capture and slow the water flow during a flood.
- Drinking water sources can be polluted by floodwaters after a cyclone. Very large buildings, such as shopping centres and industrial sheds, can be designed to capture water and have storage tanks for future use. This interception may seem small, but it can reduce stormwater flow in gutters and street drains.
- Cyclones and storms produce extremely high rainfall in a short period of time. Increasing available green space in urban areas allows for greater infiltration of rainfall. Large ovals and outside sports areas can be designed to have run-off flow into suburban wetlands and ponds rather than all water ending up in stormwater drains.
- The destruction caused by cyclones often forces people to seek shelter or live away from home for long periods of time until the damage can be cleared and their homes made safe again. Multi-level car parks and large sports venues can be designed as cyclone shelters and used as temporary storage facilities during emergency periods.

Individual cyclone preparedness and response

The following checklist was prepared by Emergency Management Australia and Australian state emergency services to help people prepare for and respond to a cyclone.

Before the cyclone season

- Check with your local council or your building control authority to see if your home has been built to cyclone standards.
- Check that the walls, roof and eaves of your home are secure.
- Trim treetops and branches well clear of your home (get council permission).
- Preferably fit shutters, or at least metal screens, to all glass areas.
- Clear your property of loose material that could blow about and possibly cause injury or damage during extreme winds.
- In case of a storm surge/tide warning, or other flooding, know your nearest safe high ground and the safest access route to it.
- Prepare an emergency kit containing:
  1. a portable battery radio, torch and spare batteries
  2. water containers, dried or canned food and a can opener
  3. matches, fuel lamp, portable stove, cooking gear, eating utensils
  4. a first aid kit and manual, masking tape for windows and waterproof bags.
- Keep a list of emergency phone numbers on display.
- Check neighbours, especially if recent arrivals, to make sure they are prepared.

When a cyclone watch is issued

- Re-check your property for any loose material and tie down (or fill with water) all large, relatively light items such as boats and rubbish bins.
- Fill vehicles' fuel tanks. Check your emergency kit and fill water containers.
- Ensure household members know which is the strongest part of the house and what to do in the event of a cyclone warning or an evacuation.

- Tune to your local radio/TV/mobile device for further information and warnings.
- Check that neighbours are aware of the situation and are preparing.

When a cyclone warning is issued

Depending on official advice provided by your local authorities as the event evolves, the following actions may be warranted.

- If requested by local authorities, collect children from school or childcare centre and go home.
- Park vehicles under solid shelter (handbrake on and in gear).
- Put wooden or plastic outdoor furniture in your pool or inside with other loose items.
- Close shutters or board-up or heavily tape all windows. Draw curtains and lock doors.
- Pack an evacuation kit of warm clothes, essential medications, baby formula, nappies, valuables, important papers, photos and mementos in waterproof bags to be taken with your emergency kit. Large/heavy valuables could be protected in a strong cupboard.
- Remain indoors (with your pets). Stay tuned to your local radio/TV for further information.

On warning of local evacuation

Based on predicted wind speeds and storm surge heights, evacuation may be necessary. Official advice will be given on local radio/TV/mobile regarding safe routes and when to move.

- Wear strong shoes (not thongs) and tough clothing for protection.
- Lock doors; turn off power, gas and water; take your evacuation and emergency kits.
- If evacuating inland (out of town), take pets and leave early to avoid heavy traffic, flooding and wind hazards.
- If evacuating to a public shelter or higher location, follow police and State/Territory Emergency Services directions.
- If going to a public shelter, take bedding needs and books or games for children.
- Leave pets protected and with food and water.

When the cyclone strikes

- Disconnect all electrical appliances. Listen to your battery radio for updates.
- Stay inside and shelter (well clear of windows) in the strongest part of the building, i.e. cellar, internal hallway or bathroom. Keep evacuation and emergency kits with you.
- If the building starts to break up, protect yourself with mattresses, rugs or blankets under a strong table or bench or hold onto a solid fixture, e.g. a water pipe.
- Beware the calm 'eye'. If the wind drops, don't assume the cyclone is over; violent winds will soon resume from another direction. Wait for the official 'all clear'.
- If driving, stop (handbrake on and in gear), but well away from the sea and clear of trees, power lines and streams. Stay in the vehicle.

After the cyclone

- Don't go outside until officially advised it is safe.
- Check for gas leaks. Don't use electric appliances if wet.
- Listen to local radio for official warnings and advice.
- If you have to evacuate, or did so earlier, don't return until advised. Use a recommended route and don't rush.
- Beware of damaged power lines, bridges, buildings, trees, and don't enter floodwaters.
- Heed all warnings and don't go sightseeing. Check/help neighbours instead.
- Don't make unnecessary telephone calls.

Source: Reproduced by permission of Bureau of Meteorology, © 2018 Commonwealth of Australia

Activity 1.7c: Responding to tropical cyclones

Using the information you have learnt about preparation and response strategies, answer the following questions.

Comprehend and explain ways to minimise personal risk

1. List four important things to do around your house before the cyclone season starts and explain why these actions are important in helping to mitigate the effects of the cyclone.
2. List five essential items to have in your household emergency kit and explain which effects of a cyclone they might help to mitigate.
3. Once a cyclone warning has been issued for your locality, you need to make up an 'evacuation kit'. Explain why this is important, giving examples of essential items that should be included and why.
4. If you believe your house may not be strong enough to cope with gale force winds, where should you evacuate to? What should you do with pets?
5. If you were to remain in your home when a cyclone hits, which parts of the building are most likely to be the safest? Explain why.
6. Give reasons why it is important to have a battery-powered radio in the house.
7. Why is it important not to go sightseeing after a cyclone has passed?

Analyse the data and apply your understanding

8. Imagine your home has been are cut off by rising floodwaters and emergency workers are unable to restore lost power for at least a week. You are not sure about water quality and the sewerage plant is not working due to power loss. Make a list of things you would do to keep your family and two pet dogs safe until help arrives.
9. Create a cyclone safety poster to display in hotel rooms in Queensland that instructs overseas and interstate visitors about what they should do after a cyclone passes and why these actions are important. Be specific in your advice and think carefully about the factors that might contribute to a visitor's lack of awareness of the risks present after a cyclone has passed.
10. Re-read the cyclone emergency preparation checklist. Which aspects of this list might be problematic or difficult to follow in developing countries? Which might be problematic or difficult to follow in very remote communities? Propose actions that might help overcome the difficulties of implementing these preparedness strategies in these communities.

1.7.7 Tropical cyclones in northern Australia

Typically, the cyclone season in northern Australia runs from November to April. This may vary by a few weeks if the Pacific regions are experiencing a **La Niña**.

According to the Australian Bureau of Meteorology, 10 to 13 tropical cyclones develop on average each season. It is probable that at least one tropical cyclone will cross the Australian coast each season. Most come in from the Pacific Ocean, while a smaller number form in the 'monsoon trough' above the Gulf of Carpentaria and the Northern Territory. They all tend to move in a westerly direction.

Activity 1.7d: Reading synoptic maps and weather warnings

Consider the synoptic map and read the weather warning put out by Bureau of Meteorology on Wednesday, 14 March 2018, to answer the following questions on next page.

Ex-tropical cyclone Linda is expected to produce dangerous surf and abnormally high tides along the southern Queensland coast during today and Thursday.

Weather situation:

At 4pm AEST Wednesday, ex-tropical cyclone Linda was located in the Coral Sea about 450 kilometres east to northeast of Fraser Island, moving southwest at 17 kilometres per hour. Ex-Tropical Cyclone Linda, which transitioned into a vigorous subtropical low earlier this morning, is expected to continue its southwest track for the remainder of today before shifting on a more southerly track on Thursday. The system is expected to remain offshore of the southern Queensland coast.

Strong to gale force winds over offshore waters across the southern flank of the low are expected to produce large east to south easterly swells along exposed parts of the southern Queensland coast for the remainder of today and into Thursday. This will combine with high tides to cause hazardous conditions within the warning area.

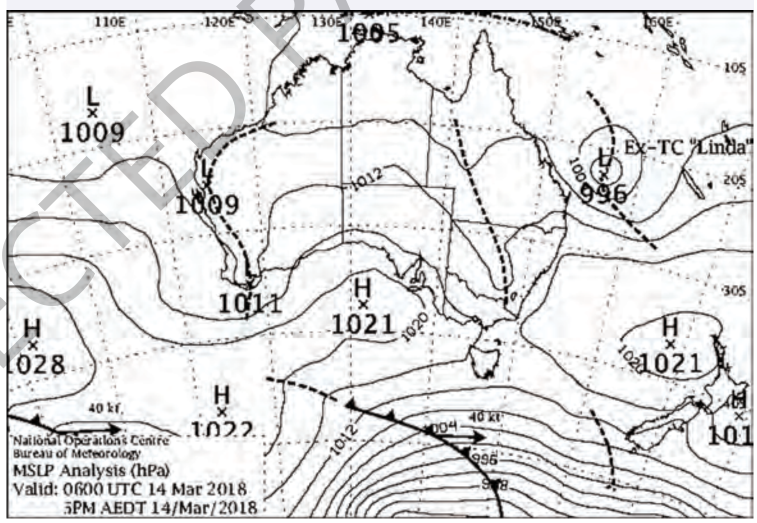
Dangerous surf conditions with possible beach erosion are expected along the east coast of Fraser Island this afternoon and evening. These hazards should extend southward towards the Sunshine Coast and Gold Coast early Thursday morning, then ease rapidly late afternoon and evening.

On Thursday morning, tides may exceed the highest tide of the year, with inundation of low-lying areas possible on the high tide. Locations which may be affected include Noosa, Maroochydore, Caloundra, Coolangatta and the eastern side of Moreton, Stradbroke, and Fraser Islands.

Queensland Fire and Emergency Services advises that people should:

- Surf Life Saving Australia recommends that you stay out of the water and stay well away from surf-exposed areas.
- Check your property regularly for erosion or inundation by sea water, and if necessary raise goods and electrical items.
- If near the coastline, stay well away from the water's edge.
- Never drive, walk or ride through flood waters. If it's flooded, forget it.
- Keep clear of creeks and storm drains.
- For emergency assistance contact the SES on 132 500.

FIGURE 1.25 Synoptic map and cyclone warning (14 March 2018)



Source: Reproduced by permission of Bureau of Meteorology, © 2018 Commonwealth of Australia

Comprehend and explain cyclone warnings

1. Where was ex-Tropical Cyclone Linda located at 4.00 pm on 14 March 2018? Based on the description and image provided, and by consulting other maps if needed, determine the longitude and latitude. What was its central pressure?
2. List three ways the system was affecting coastal communities in south-east Queensland.
3. Describe the dangerous conditions that were occurring at beaches south of Fraser Island at that time.
4. Define the terms *abnormally high tide* and *inundation of low lying areas*.

5. Explain how gale force winds (63-87 km/h) could contribute to the highest tide of the year.
6. Mark three other areas of low pressure on the map in addition to ex-Tropical Cyclone Linda. Where is air pressure highest?

Analyse the data to identify the challenges

7. If ex-Tropical Cyclone Linda continued moving and weakening as the BOM suggested, predict where it could be on a map 48 hours after this warning was issued. What challenges would this present for emergency services?

Suggest risk management strategies

8. If you were in charge of closing access to beaches along the Sunshine Coast at this time, what course of action would you take? Create a plan for when you would close access and when you would re-open beaches for swimming again. Justify your choices with evidence from the data provided in the Bureau of Meteorology map and warning.

on Resources

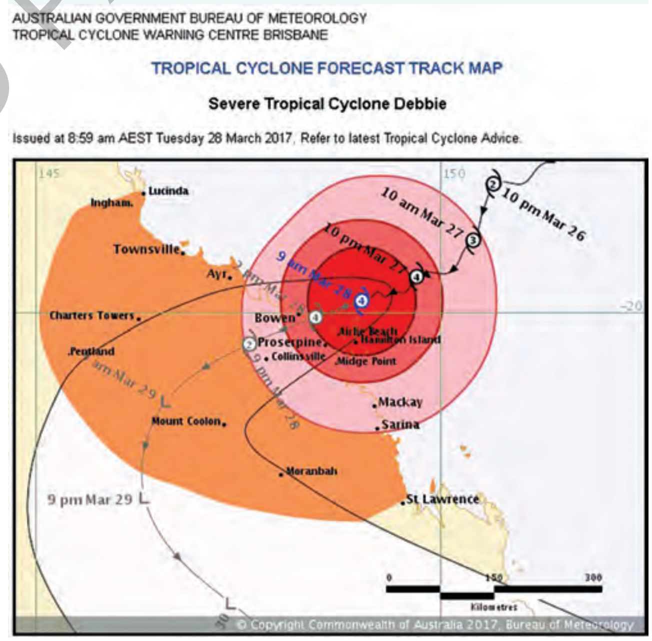
Weblink: El Niño Southern Oscillation (ENSO)

Tropical Cyclone Debbie 2017

When it hit, Tropical Cyclone Debbie was the deadliest cyclone to hit Australia since Cyclone Tracy in 1974 and the most dangerous to make landfall in Queensland since Cyclone Yasi in 2011. Starting as a tropical low in the Coral Sea, the system gradually strengthened to Category 2. As Tropical Cyclone Debbie moved closer to the coast between Townsville and Mackay, it intensified to a Category 4. After hovering off-shore for nearly 24 hours, Debbie made landfall near Airlie Beach, bringing gusts of wind in excess of 250 km/h and torrential rain. Nearby, Proserpine received 210 mm of rainfall in one hour.

Debbie continued south towards Brisbane, bringing with it torrential rain and widespread flooding of most coastal rivers and creek catchments. It then moved through to the urban areas of south-east Queensland and the Northern Rivers districts of New South Wales. Overall, Tropical Cyclone Debbie caused damage amounting to about AU$2.4 billion. Tragically, fourteen people also died, most as victims of flooding.

FIGURE 1.26 The path of Tropical Cyclone Debbie



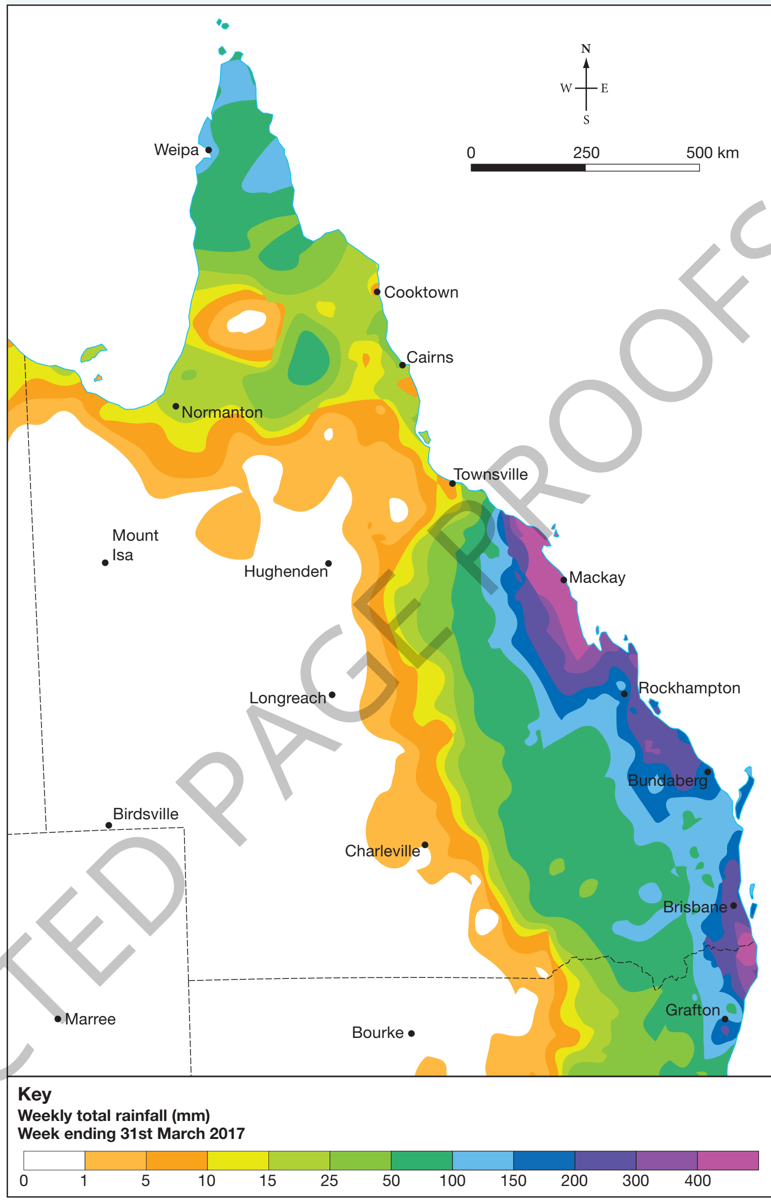
Source: Reproduced by permission of Bureau of Meteorology, © 2018 Commonwealth of Australia

Throughout Queensland, 62 weather stations received record-breaking rainfall including Plane Creek Sugar Mill, south of Mackay, which received 1300 mm of rain across the month of March 2017 – more rain than Brisbane usually receives in a year.

Other effects of Tropical Cyclone Debbie included:

- torrential rainfall along the far northern coast and in coastal river catchments
- severe flooding along coastal areas and in river valleys
- severe damage to farm crops, particularly sugar cane, vegetables and fruits
- widespread power outages and damage to the electrical grid infrastructure
- sewerage plants forced to close due to inundation
- severe damage to homes, buildings and other structures (power poles)
- roads and rail infrastructure damaged and closed
- coastal airports closed for short periods
- people forced to evacuate homes and stay in shelters for some time
- food and medical shortages in isolated townships
- people unable to work (loss of income)
- schools closed and hospitals difficult to access
- marinas, port facilities and island resorts badly damaged, including many tourist/boat operations
- damage to parks and streets from uprooted trees
- inland coal mining operations closed due to open cut pits being filled with water and machinery damage
- beaches severely eroded and coastal areas contaminated with salt water
- livestock drowned or lost.

FIGURE 1.27 Queensland total rainfall March 2017



Source: Commonwealth of Australia 2018, Bureau of Meteorology

Activity 1.7e: Tropical Cyclone Debbie

Using the information you have learned about Tropical Cyclone Debbie, answer the following questions.

Explain Tropical Cyclone Debbie's impact

1. Based on the Bureau of Meteorology scale, what category was Cyclone Debbie when it made landfall?
2. How much rain fell in the Mackay area during the week ending 31 March 2017?
3. Which three areas of Queensland experienced the heaviest rainfalls during March 2017?
4. Gold Coast – Brisbane and Mackay received much more rain than the large area between the two cities. Explain why this was the case.

Suggest risk management strategies

5. Imagine you were a tourist at the Whitsunday Islands and could not get back to the mainland as Tropical Cyclone Debbie approached. Suggest and justify strategies that might help to keep you safe.
6. To what extent would good cyclone preparedness have mitigated many of the effects of Tropical Cyclone Debbie? Examine the list of preparedness and response strategies on pages 26–27. Which three strategies do you think would have most significantly reduced risk? Justify your response by explaining how those strategies would reduce your vulnerability and/or exposure to the hazard.
7. If you were in charge of recovery operations after Tropical Cyclone Debbie had crossed the coast, where would you start? What would you do to maximise public safety with water supply, electricity, sewerage and roads? How would you communicate this information to the public if power and communications networks were down?

Resources

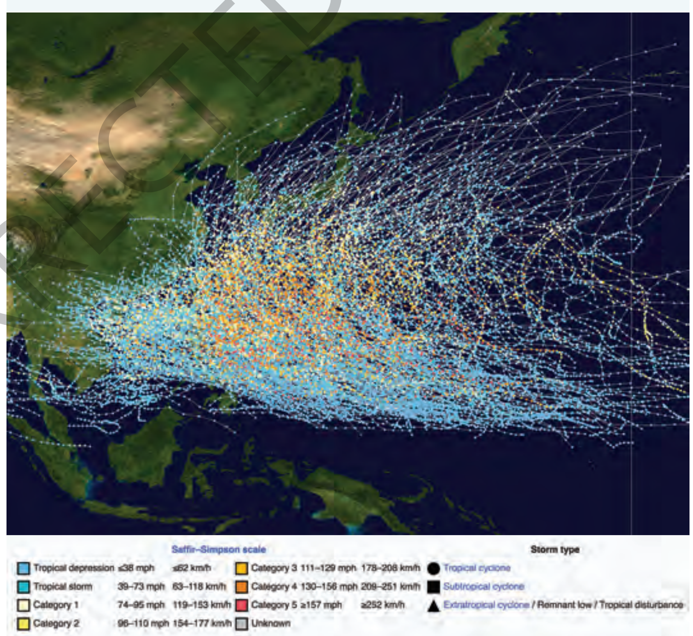
Weblink: Bureau of Meterology tropical cyclones information and warnings

Digital doc: The impact of Tropical Cyclone Debbie (doc-29158)

1.7.8 Typhoons in the western Pacific

Typhoons form the same way as tropical cyclones and have the same damaging effects. The term ‘typhoon’ is a regional name used to describe severe tropical storms that occur in the western Pacific and Asia. In central America (around the Caribbean Sea) and the eastern Pacific, these same storms are called hurricanes. Even though they have similar features, there are often significant differences in the way they affect people.

FIGURE 1.28 Maximum sustained wind speeds of typhoons in South-East Asia (1980–2005) tracked at six-hour intervals



Source: The blue tracks in figure 1.28 show tropical depressions, with increasing darkness of yellow and orange lines representing the increasing intensity of typhoons using the Saffir-Simpson Scale.
By Nilfanion [Public domain], via Wikimedia Commons

Because of the very large expanse of warm, tropical ocean in the western Pacific and the weather patterns, typhoons tend to be more frequent than tropical cyclones and hurricanes. Consider the data in table 1.2 collected between 1981 and 2016 by the Hurricane Research Division of the National Oceanic and Atmospheric Administration in the USA.

The high population and low levels of development in many areas of South-East Asia also mean that the degree of *exposure* and levels of *vulnerability* are greater than many countries where tropical cyclones and hurricanes occur.

TABLE 1.2 Annual frequency of tropical storms and cyclones by location, 1981–2016 (1981–82 to 2015–16 cyclone season for the southern hemisphere)

	Tropical Storm or stronger (greater than 17 m/s sustained winds)			Hurricane/Typhoon/Severe Tropical Cyclone (greater than 33 m/s sustained winds)		
Basin	**Most**	**Least**	**Average**	**Most**	**Least**	**Average**
Atlantic	28	4	12.1	15	2	6.4
NE/Central Pacific	28	8	16.6	16	3	8.9
NW Pacific	39	14	26	26	5	16.5
N Indian	10	2	4.8	5	0	1.5
SW Indian	14	4	9.3	8	1	5
Aus SE Indian	16	3	7.5	8	1	3.6
Aus SW Pacific	20	4	9.9	12	1	5.2
Globally	102	69	86	59	34	46.9

Source: AOML/NOAA

Over the past thirty years, typhoons from the western Pacific have become more powerful and scientists have predicted they will continue to get stronger due to ocean warming. When coastal water is warmer than usual, it tends to revitalise typhoons before they hit land. Scientists suggest the destructive power of typhoons has intensified by 50 per cent in the past 40 years due to warming seas. They also warn that global warming will continue to make giant storms even stronger in the future, posing a greater threat to heavily populated areas of the Philippines, Vietnam, China, Japan, North Korea and South Korea.

Typhoon Hato was a destructive typhoon that inflicted havoc on communities between the Philippines and Hong Kong (China) in August and September 2017. Also known as Tropical Storm Isang in the Philippines, it caused the deaths of at least 26 people and left a damage trail of approximately US$6.82 billion. With wind speeds of over 180 km/h and generating 10 m waves, Hato destroyed fish farms and boats in the South China Sea, tore down trees and unroofed buildings, flooded urban areas and rice fields, closed ferry services and airports, closed schools and businesses, and stopped power generation, which caused blackouts and forced hospitals to use backup generators. The weather bureau in Hong Kong gave it the highest typhoon intensity category seen for five years.

on Resources

Weblink: Typhoon Hato
Weblink: Typhoon Haiyan
Weblink: Typhoon intensity and ocean warming

In November 2013, one of the world's largest ever storms, Super Typhoon Haiyan, unleashed its fury on the island nation of the Philippines, then proceeded westward across the South China Sea, devastating coastal regions of northern Vietnam. Also known in the Philippines as Super Typhoon Yolanda, it originated in the western Pacific, generating highly destructive wind gusts in excess of 300 km/h. Haiyan made landfall near Tacloban City– south of the capital, Manila– destroying almost everything in its path.

Warm air and ocean temperatures ensured Typhoon Haiyan remained powerful as it moved towards Vietnam. Here, coastal and delta regions were exposed to storm surge waves higher than 5 m. Despite weakening as it crossed the coast, the typhoon still had the power to kill or injure many people.

Haiyan smashed houses and buildings, uprooted trees, knocked out water, electricity and transport infrastructure, flooded farms and fishing ports, and created havoc for residents over an area almost as large as Australia. Its devastation was extraordinary, destroying over 70 per cent of houses and infrastructure in its path and killing an estimated 6300 people. In total, about 11 million people were affected. Many people were forced to evacuate having lost family members, homes, possessions and crops. The economic damage was estimated to be more than US$4.5 billion.

FIGURE 1.29 Debris from Super Typhoon Haiyan, Tacloban, Philippines

FIGURE 1.30 (a) Before and (b) after aerial images show the damage created by Super Typhoon Haiyan in Tacloban, Philippines

While countries around the world rallied to support survivors in the Philippines and Vietnam with aid, the level of despair and suffering after these events was incredible. Widespread panic and looting from desperate, hungry survivors made the distribution of essential aid difficult.

Resources

- **Video eLesson:** Understanding satellite images (eles-1643)
- **Video eLesson:** Interpreting an aerial photo (eles-1654)
- **Interactivity:** Interpreting an aerial photo (int-3150)
- **Video eLesson:** Comparing aerial photographs to investigate spatial change over time (eles-1750)
- **Interactivity:** Comparing aerial photographs to investigate spatial change over time (int-3368)

Activity 1.7f: Typhoons in the western Pacific

Using the information you have learned about Typhoons in the western Pacific Ocean, answer the following questions.

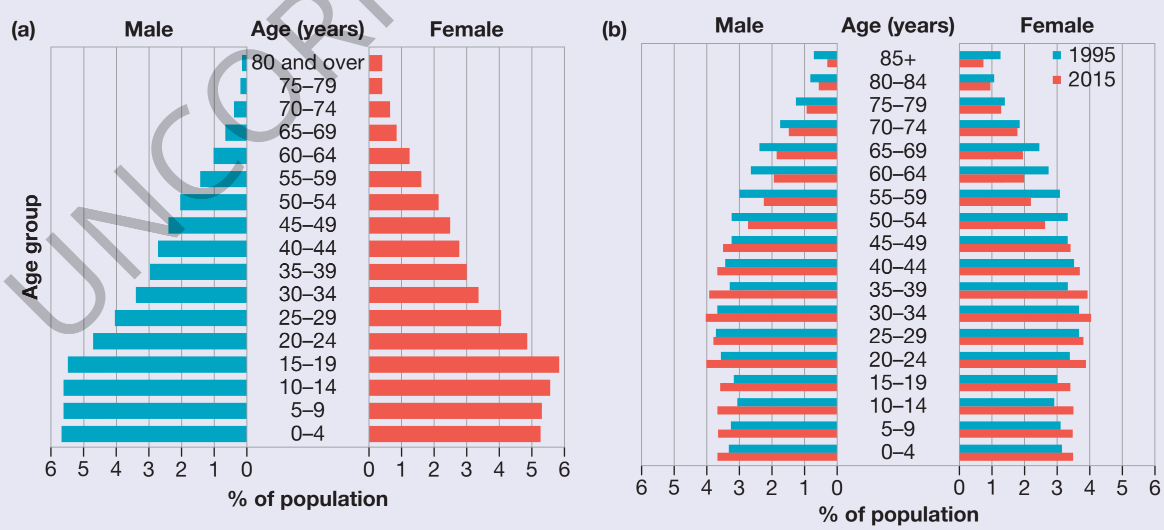
Explain typhoons and comprehend their affects

1. What names are used to describe tropical storms in
   (a) Asia?
   (b) northern Australia
   (c) central America?
2. Which is more destructive: tropical cyclones, typhoons or hurricanes? Justify your answer with evidence or examples.
3. Which type occurs more frequently? Explain the features or processes that interact to create this pattern.
4. Using the data in table 1.2, create a bar graph to display the average number of tropical cyclones that occur in each region per year.
5. Research and, as precisely as possible, mark in the paths taken by both Typhoon Hato and Super Typhoon Haiyan on a map. Insert two or three information boxes where extensive damage was done. For example, Tacloban, Philippines. You could use the map below, or complete this task digitally. (A print-friendly version of this map has been included in the Resources tab.)

Analyse the data to identify the challenges

6. Examine figures 1.29 and 1.30. What factors apart from the strong wind gusts might have contributed to the scale of the destruction caused by Super Typhoon Haiyan in Tacloban in the Philippines?
7. Using figure 1.31 below, consider the age distribution of people in Tacloban in the years prior to Super Typhoon Haiyan (a graph of Australia's age pyramid is provided for comparison; note these graphs use different parameters and are from different years, so you will need to consider them carefully). How might the age distribution of the population affect the way a city or region can recover from a natural disaster?

FIGURE 1.31 (a) Age and gender of Tacloban population (2010 census) and (b) age and gender of Australian population (1995 and 2015)



Source: (a) Philippine Statistics Authority, (b) Australian Bureau of Statistics

8. The Philippines is classified as a developing country by the United Nations. World Bank data from 2015 suggests that 21.6 per cent of Filipino people are living in poverty. What impact would the economic strength of a country have on the ability to recover from a significant natural disaster like Super Typhoon Haiyan?

Suggest recovery strategies

9. If the 2017 western Pacific typhoon season was below-average in terms of numbers and intensity than the two previous years. Predict what might happen in 2018 and 2019. Suggest and justify mitigation strategies that might need to be put in place by local authorities across the western Pacific to manage any potential hazards you predict.

FIGURE 1.32 Map the paths of Typhoon Hato and Super Typhoon Haiyan

Source: Natural Earth Data

Resources

- **Video eLesson:** Using multiple data formats (eles-1761)
- **Interactivity:** Using multiple data formats (int-3379)
- **Digital doc:** South-East Asia map (doc-29161)
- **Video eLesson:** Comparing population profiles (eles-1704)
- **Interactivity:** Comparing population profiles (int-3284)

1.8 Geological hazards

1.8.1 Introduction

A geological hazard occurs or originates within the Earth, rather than on its surface or in its atmosphere. The most common geological hazards are earthquakes and volcanic eruptions, but tsunamis (large wave surges caused by earthquakes on the ocean floor) are also geological hazards.

The Earth is divided into three parts: a dense core, a thick shell surrounding the core known as the mantle, and a thin, brittle outer crust. However, the crust is not an even or uniform surface. It is a very irregular cover of rock and soil, and is made up of large **tectonic plates**, uneven landforms and **faults** (huge cracks or weak points) that penetrate down into the upper mantle. The crust contains both hard, brittle rocks that fracture easily and elastic rocks that absorb and store energy.

FIGURE 1.33 The eruption of Klyuchevskaya Sopka in Russia (2016)

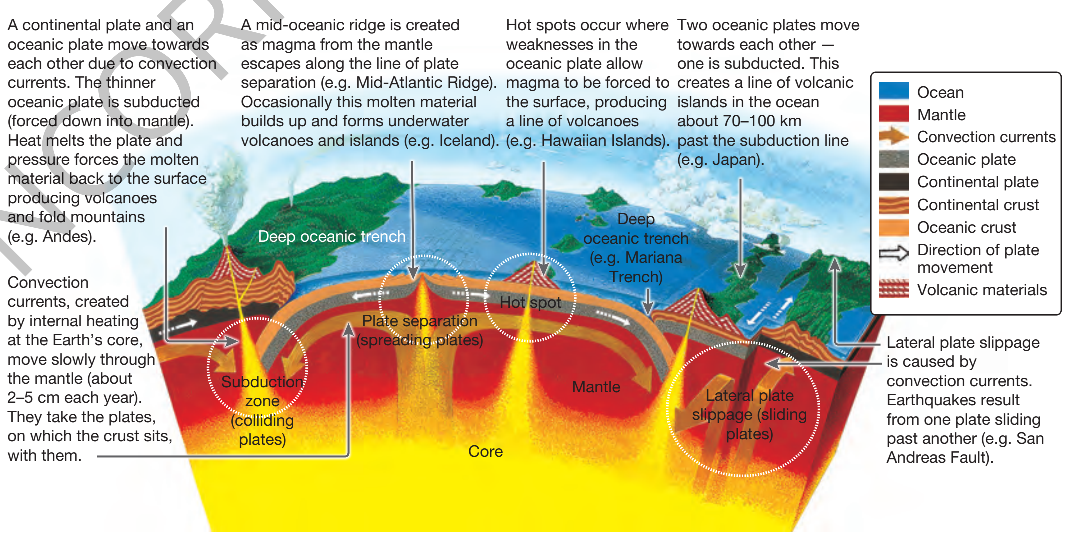
Tectonic or lithospheric plates are large sections of the Earth's crust that float on the semi-molten rocks of the upper mantle, or **asthenosphere** see figure 1.34. Over time the plates are moved around by convection currents in the mantle. These currents are created by heat from the radioactive decay of elements in the Earth's core.

Resources

Video eLesson: How to interpret a complex block diagram (eles-1746)

Interactivity: How to interpret a complex block diagram (int-3364)

FIGURE 1.34 Fault types and the movements of the tectonic plates



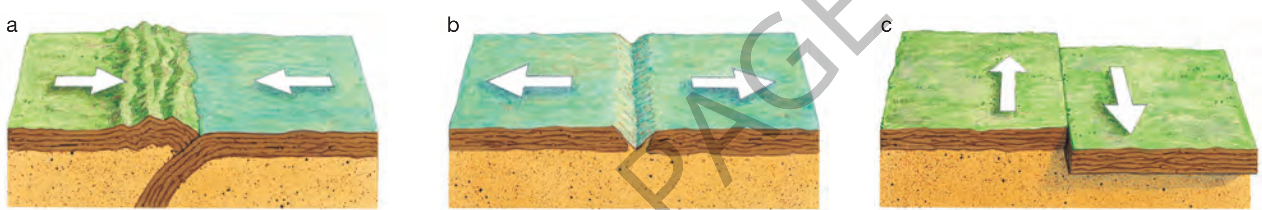
1.8.2 Processes that create geological hazards

Earthquakes occur and volcanoes are formed when forces in the Earth move sections of tectonic plates, usually at faults. The Earth's lithosphere is divided into seven major tectonic plates and about 20 smaller ones. Most crustal movement happens when these plates push together, pull apart or pass each other in different directions.

Faults are named according to the way plates or blocks of crust move along the surface. There are generally three types.

- A diverging or normal fault creates a gap when two plates pull away from each other. These occur at diverging plate boundaries and a block either goes upward or downward, or sea floor spreading occurs on the ocean floor. An example of this on land is the East African Rift Zone.
- A converging or reverse fault, sometimes also called a thrust fault, occurs where two plates collide or are forced together at converging plate boundaries. On land, these collisions build fold mountains like the Himalayas whereas on the ocean floor the process is called **subduction**. Here, one plate may override another forming deep marine trenches, such as the Mindanao Trench near the Philippines.
- A transform or strike-slip fault occurs where two plates pass each other laterally and there is very little vertical movement. The San Andreas Fault is this type.

FIGURE 1.35 (a) Converging plate boundary (b) Diverging plate boundary (c) Transform fault boundary



Converging plate boundary creates a reverse fault – two plates pushed together

Diverging plate boundaries creates a normal fault – two plates pulled part

Transform fault boundary creates a strike-slip fault – two plates slide past each other

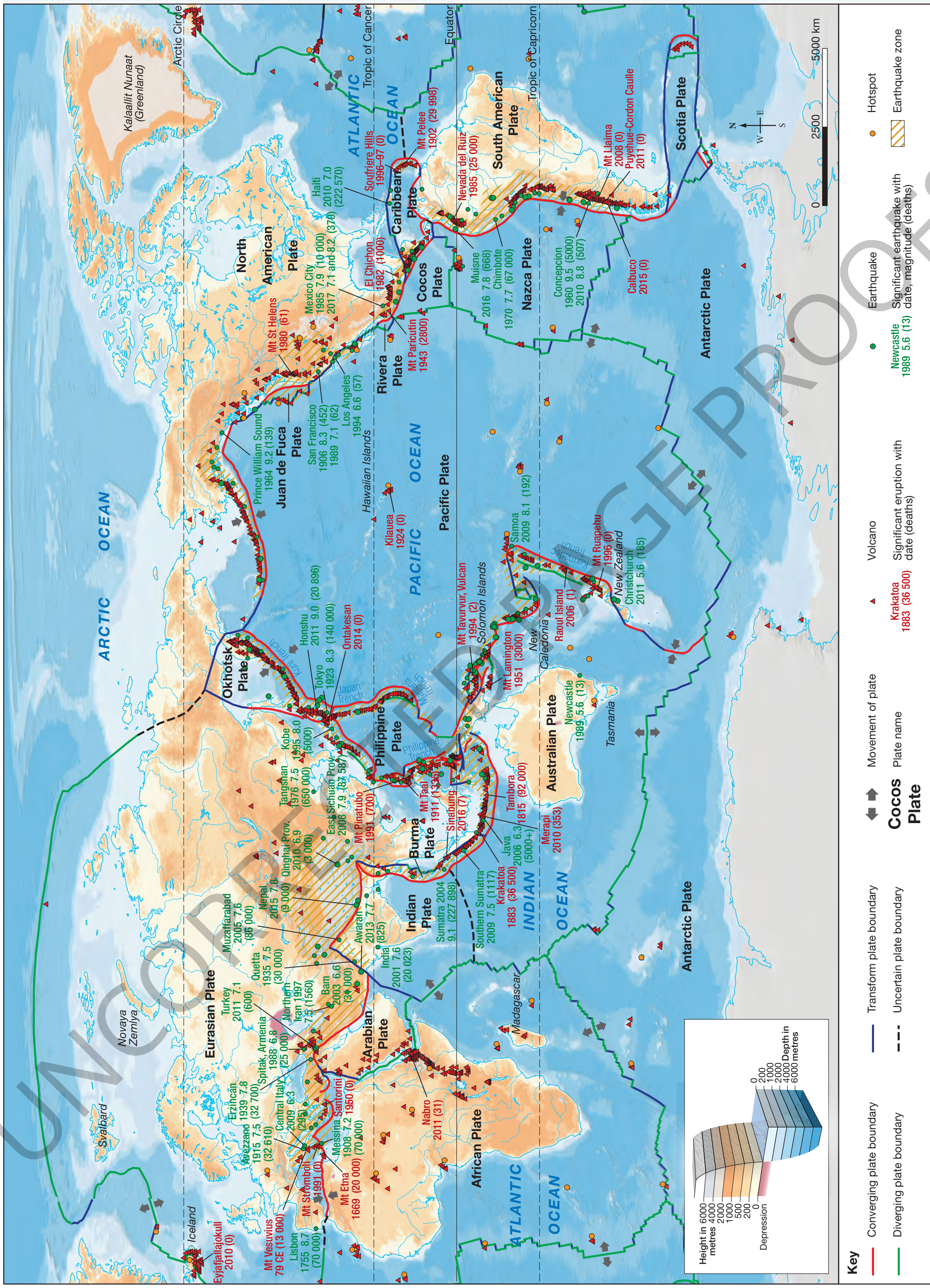
This process of plate tectonic movement involves two different types of crust: oceanic and continental. Oceanic crust is heavier, thinner and younger than continental crust. Most commonly, two diverging plates are both composed of oceanic crust. As the oceanic plates drift apart, molten rock or **magma** rises from the mantle below, cooling and forming a new oceanic crust. Such magma is basaltic in composition and creates Icelandic-type volcanoes (see section 1.8.7) and mid-ocean ridges. Earthquakes in areas near diverging plates tend to have relatively small magnitudes.

Over time, this tectonic movement puts enormous strain on crustal rocks well beyond their level of strength. Eventually, these sections of plate slip or break, releasing an enormous amount of stored energy. This sudden and powerful slipping of sections of crust is called an earthquake. Because of the sheer size and force of the Earth's tectonic plates, surface movement is extremely powerful and there is nothing people can do other than take preventative action to survive. Even though most earthquakes happen in the crust, they can also occur in the upper mantle, mostly near **subduction zones** where plates collide. The site where rock begins to break is called the **focus**. Most earthquake tremors occur directly on the surface at the **epicentre** (the location on the ground immediately above the focus).

The strength of the earthquake depends on how much rock 'breaks' and how far it is moved. Following a major quake, several 'adjustments' called aftershocks or tremors occur, adding to the fear and uncertainty of people affected. Earthquakes below the ocean can displace large areas of sea bed and water, sometimes causing a tsunami — for example, the tsunami that hit the coast of Sulawesi, Indonesia, after a magnitude 7.5 earthquake in September 2018.

At the surface, seismic vibrations cause damage to infrastructure, particularly in populated areas. People can be killed or injured when buildings collapse or fires break out from the rupturing of fuel tanks and gas lines. They can also cause other types of hazards such as landslides and **liquefaction** (when the ground acts as though it is liquid, rather than solid).

FIGURE 1.36 World map of tectonic plates



Source: Redrawn by Spatial Vision based on information from the Smithsonian National Museum of Natural History.

Many active volcanoes are also associated with pressures at convergent and divergent plate boundaries. Subduction occurs at convergent boundaries, when one plate is pushed below another. When this occurs, surface material is forced down into the mantle where it softens. At some other weak point in the crust, this molten material can be carried upwards to the surface through a fissure (crack) as a volcano. Earthquake clusters can also occur in association with magma movements. At divergent boundaries, where crustal plates pull apart, large underwater ridges (mid-ocean ridges) form as hot molten lava oozes out across the ocean floor and cools.

Activity 1.8a: Tectonic plate movement

Refer to the world map in figure 1.36.

Comprehend and explain tectonic plate movement and its impacts

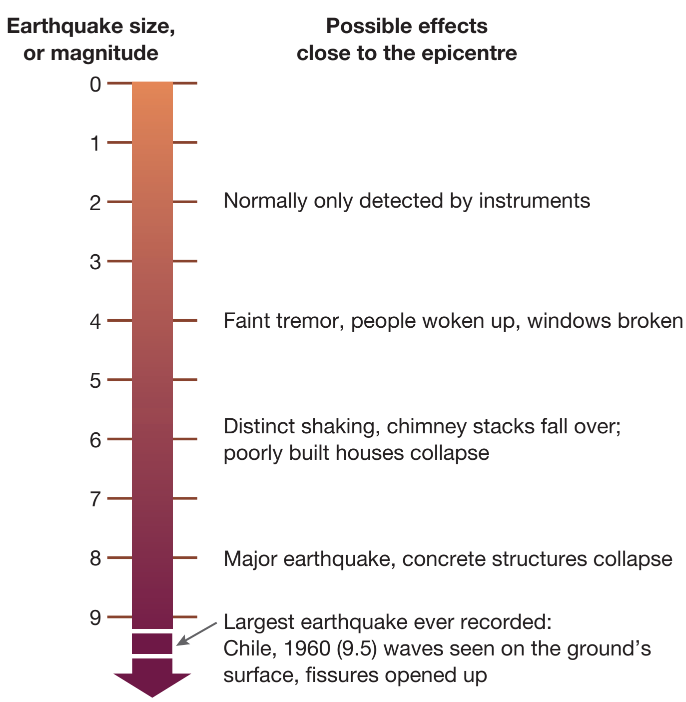
1. Do the world's continents mainly sit on their own separate plates?
2. According to the map, which continents are largely unaffected by convergent faults and divergent faults?
3. On which plate is Australia located?
4. Which of the seven large plates covers the largest area?
5. Identify two continents that are severely affected by faults. From their position and the plate movement arrows on the map, suggest what type of faults affect these continents.
6. Identify which continent has a major subduction zone off-shore and is located close to the deepest ocean trenches.
7. If Australia continues to move north-east at about 6 cm per year, describe the approximate location of where Cape York be in 50 million years' time?
8. Scientists have established the Pacific Ocean is getting smaller, the Atlantic Ocean is getting larger and the Himalayas are getting taller. What could be causing these to happen?
9. With close reference to figure 1.36, explain the geological processes that result in earthquakes and volcanic activity in New Zealand.

1.8.3 Earthquakes

When an earthquake occurs, **seismic waves** (energy vibrating through the Earth) travel outwards from the focus (also called the hypocentre). The fastest waves (known as **P-waves,** or primary waves) travel at about 6 km/sec through the Earth. These P-waves pass seismic recording stations, a network of sensors located in over 150 different places around the globe – the Global Seismographic Network (GSN). The arrival time of the P-wave is detected and noted in real-time by the network's computers, which collate the information about the speed and direction of the P-waves' travel to calculate the location of the earthquake. The epicentre location is often available less than one minute after an earthquake occurs.

The magnitude of an earthquake is determined from the strength of the seismic waves detected at each station. There are several different formulas to calculate the magnitude. Most formulas depend on a measure of the

FIGURE 1.37 The Richter Scale



shear waves (S-waves, or secondary waves), which have the largest amplitude and carry the most energy. S-waves travel more slowly than P-waves so it may take a few minutes to calculate its magnitude. S-waves travel at between about 1 and 8 km/second, and P-waves between about 1 and 14 km/second. The speed of any seismic wave depends on variables such as the density and composition of the ground it is travelling through.

One common method of measuring the strength of an earthquake is the Richter Scale. Invented by Charles Richter in 1935, it compares the amount of energy released from an earthquake using numbers on a logarithmic scale – a magnitude 8.0 is ten times more powerful than a 7.0. The largest earthquake ever recorded was in May 1960, when a magnitude 9.5 was measured near Valdivia, in southern Chile.

Another method of measuring earthquake intensity is the Mercalli Scale. This is also a numerical scale shown in Roman numerals with I at the low-intensity end and XII at the high-intensity end. On the Mercalli Scale, a value is assigned to a specific location based on how people were affected or how much structural damage occurred. Lower numbers match how or what people felt, while higher numbers are based on observed structural damage to infrastructure such as buildings or roads. This means that an earthquake might be low on the Richter Scale, but if there is significant damage it may rate high on the Mercalli Scale. This might occur, for example, in a developing country where communities do not have the resources to construct larger buidings that are strong enough to withstand weaker earthquakes, or in mountainous areas prone to landslips.

TABLE 1.3 Modified Mercalli Scale, used to determine levels of earthquake damage (USGS)

Mercalli scale	Shaking	Effects
I	Not felt	Not felt except by a very few persons under especially favorable conditions.
II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognise it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened during the night. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures. Some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

Source: Abridged from The Severity of an Earthquake, USGS General Interest Publication 1989-288-913

Resources

Weblink: Global Seismographic Network

1.8.4 Responding to earthquakes

Earthquakes can happen at any time. There is very little warning; many people are caught in the middle of the shaking. Most deaths and injuries occur from falling objects or buildings. People who live in earthquake zones practice safety drills, such as 'Drop (Duck), Cover, and Hold on!' Authorities suggest that when an earthquake strikes people should:

- keep calm
- if possible, turn off electricity, gas, and tap water
- protect yourself from falling objects such as signs, light fixtures and potted plants
- do not rush out of a building or use elevators.

In many communities at high risk of earthquakes, response and recovery efforts begin before an earthquake occurs, for example, by ensuring buildings are able to withstand predicted intensities of earthquakes in the area, ensuring people know what to do when an earthquake strikes and that they have the appropriate equipment ready.

After the earthquake, immediate concerns include finding and providing medical assistance to injured people, recovering the bodies of people who have been killed, ensuring collapsed or damaged buildings and infrastructure are made safe or cordoned off from the public, and managing safety issues such as fallen powerlines or broken gas, chemical spills and water mains. Displaced people then need to be given shelter and access to food, water and other necessities. As time passes, the recovery moves into a rebuilding phase where the debris is cleared and buildings and infrastructure can be repaired or replaced.

Part of the recovery process after any natural hazard is also repairing the social and economic impact of the event. Government agencies and community organisations might offer counselling and financial support, building assessment services or longer-term accommodation options. Systems and supports may also be put in place to help the community adapt in the longer term. For example, in New Zealand after the Christchurch earthquake, some people had to relocate permanently because their homes were no longer habitable.

The ability of a community to respond to an earthquake – at each stage: preparedness, mitigation, prevention and adaptation – often depends on their level of economic development and existing infrastructure. Countries with more money to spend on sturdier infrastructure, preparedness, education, communication and emergency response systems have fewer casualties and costs than countries that are unable to fund comprehensive programs to mitigate or prevent significant impact.

Recovery efforts and reconstruction of areas devastated by earthquakes, including supporting people who have been left homeless by a quake, are also expensive. Developing countries often do not have the financial means to do this as quickly and efficiently as developed countries, especially in remote or inaccessible areas. For example, a major city in a developed nation, like Christchurch, has highly-trained emergency response teams and sophisticated equipment accessible in the city that can be mobilised when an earthquake strikes.

FIGURE 1.38 Earthquake damage to the road near Kaikoura, New Zealand (2016)

Communications infrastructure also provided people in Christchurch with the means of seeking help; media reports and social media both featured footage and images of the 2011 earthquake within minutes.

In contrast, in the remote southern highlands of New Guinea in 2018 aid workers could not access many affected communities for weeks after the earthquake because roads were cut by landslides or dams bursting. The only way that aid agencies and the PNG government could assess the affect on some communities was through photographs taken from aircraft or satellite imagery. This did not just mean the the affected communities could not access much-needed aid, it also meant that the event was not reported on as widely by the media, meaning that public support and the resulting aid donations were slow to eventuate. Strong, shallow aftershocks measuring up to 6.5 on the Richter Scale also made it difficult for aid agencies to access affected areas. In some areas, the UN also suspended their operations for fears that localised violence made the region unsafe for their staff.

Access to information and levels of literacy and education can also be an important factor in recovery, as can restoring access to electricity and communications, such as internet access and phone towers. In the short-term, mobile communications allow people to access emergency help, but communications and access to information are important for long-term recovery too. For example, after the Christchurch earthquake in 2011, the Christchurch City Libraries posted pages of earthquake recovery information that collated links to all of the agencies and organisations that could provide people with information and assistance.

on Resources

Weblink: Recovery from the Great East Japan Earthquake

Weblink: Papua New Guinea recovers from a remote major earthquake

Activity 1.8b: Earthquake impacts and responses

Using the information you have learnt about earthquakes, answer the following questions.

Comprehend and explain the impacts

1. As with other natural hazards, the impact of an earthquake can be sorted into primary (immediate consequences), secondary (medium-term) and tertiary (long-term) impacts. Construct a table to divide the following effects into primary, secondary and tertiary impacts.

farms close
airports close
power lines fall
buildings collapse
sewage lines rupture
dams at risk of breaching
telecommunications out
schools close
outbreak of disease due to hygiene issues
water supply is closed
tourist industry downturn
towns not rebuilt due to cost
roads and rail lines are destroyed
looting and theft
liquefaction
people sleep outside for weeks
landslides block roads
tsunami
gas lines break causing fires

Suggest risk management strategies

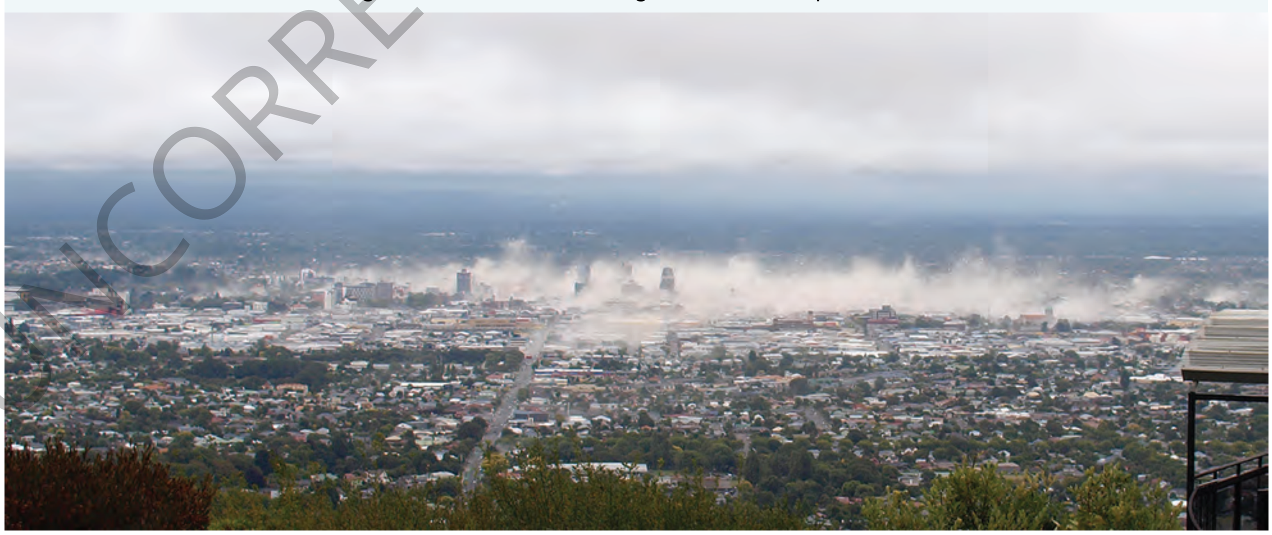
2. If you were travelling in a car when an earthquake occurred, what action could you take to keep safe? Justify your answer with reference to the three variables that would affect your level of risk: the hazard, your vulnerability and level of exposure.
3. How might the geographical location and the level of development in an area affect earthquake responses? Write two paragraphs describing how the impacts of an earthquake might be managed differently in a remote location in a developing nation, compared with a remote location in a developed nation.
4. The San Andreas Fault is a continental transform fault running through California, the USA's most populous state with over 37 million residents. The fault is about 1200 km long and forms part of the boundary between the Pacific Plate and the North American Plate. Both plates are moving to the north, but the Pacific plate is moving slightly faster than the North American Plate. An enormous level of stress energy has been building up for over a hundred years, and seismic experts fear it has reached a critical state. With so many cities in the region, a large earthquake could be catastrophic. How might such a large population affect earthquake response? Propose two well-justified strategies to mitigate risk and to manage response if such an earthquake occurs.

FIGURE 1.39 The San Andreas fault in California, USA, is a continental transform fault.

1.8.5 Earthquakes in Christchurch, New Zealand

New Zealand has a high risk of earthquakes because of its position in relation to the Australia Plate and the Pacific Plate (see figure 1.41). New Zealand has had up to 15 000 tremors recorded each year, with more than 100 large enough to be felt. Many are low magnitude or happen in remote areas; however, when they happen close to populated and urban centres, the results can be disastrous.

FIGURE 1.40 Dust clouds rising from Christchurch during the 2011 earthquake

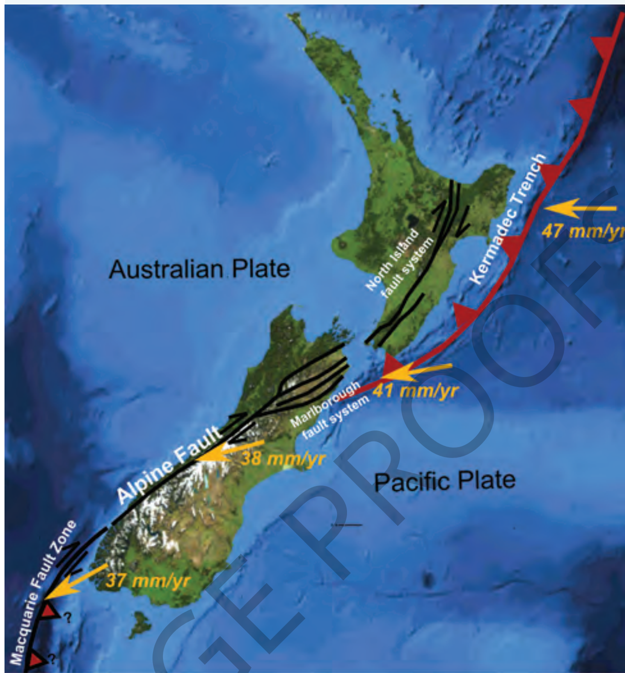


Source: © Gillian Needham

On 22 February 2011, much of inner city Christchurch was severely damaged and 185 people died when a magnitude 6.3 earthquake, with an epicentre at a depth of 5 km, struck 10 km from the city during the busy lunch period; many people were killed or injured by collapsing buildings and falling objects. More than 10 000 commercial buildings and 10 000 homes were destroyed, with an estimated 25 per cent of buildings in the centre of the city 'red tagged' (deemed unsafe to enter). This earthquake followed a 7.1 magnitude quake that had struck the previous September in the same Canterbury region – 40 km west of Christchurch at a depth of 11 km. The combined cost of these two earthquakes is estimated by the New Zealand Treasury to be NZ$15 billion.

As well as suffering extensive damage to road, rail and air infrastructure, utilities such as water supplies, electricity, gas and sewerage were made inoperable. Huge quantities of liquefaction created more than 400 000 tonnes of silt in the city's eastern suburbs, blocking roads and burying properties and vehicles. Many of the historic buildings which were the city's tourist attractions were destroyed and rendered unsafe to enter.

FIGURE 1.41 The boundary between the Australian and Pacific plates



Source: By Mikenorton [CC BY-SA 3.0 https://creativecommons.org/licenses/by-sa/3.0 from Wikimedia Commons

FIGURE 1.42 Cars in liquefied soil on the road in Christchurch (2011)

Tremors continued for weeks, with many people afraid to enter buildings or travel. Residents relied on delivery of water by tanker and used chemical toilets for months until services were restored. As Christchurch is the main gateway for tourists visiting the South Island, the tourism industry and ski fields were shut down for the remainder of the year. For some, rebuilding was impossible and about 9000 people left the city to live elsewhere. Reports and research on the aftermath of the earthquake by the New Zealand government suggest that it can take five to ten years for people to socially and psychologically recover after a natural disaster of this size and significance.

A research paper commissioned by the New Zealand Parliament in October 2014 identified social impacts of the earthquakes that struck the Canterbury region in 2010 and 2011. Some of the findings are outlined below.

Social effects of Canterbury earthquakes

FIGURE 1.43 Earthquake damage to Christchurch Cathedral (2011)

Health

- 4 September 2010 earthquake: 377 people injured during and more than 1000 injured in the aftermath
- 22 February 2011 earthquake: 185 fatalities, 3129 injured and 1293 injured in the aftermath.
- The shock and effects of the disaster itself are followed by secondary, recovery-related issues: damaged homes, insurance claims and damaged roads and community facilities.
- Research in 2013 found that 80 per cent of respondents in the Canterbury area felt their lives had changed significantly, a third that it had caused financial problems, and 64 per cent felt guilty that others in their community had been affected more severely. By 2014, 66 per cent felt like their lives had been 'normal' over the last year compared to 60 per cent two years prior.
- Otago University research found that people from the area were 40 per cent more likely (than people from other areas) to experience major depression, post-traumatic stress disorder or an anxiety disorder.

Population

- In the two years ending June 2012, more children and their parents left the city than arrived and fewer young adults moved to Christchurch to study.
- In the year ending June 2013, the population aged 25 to 34 grew, partly due to the arrival of construction workers and engineers from overseas.

Crime

- Total recorded crime in the Canterbury District fell from 52 981 in 2009 to 40 393 in 2013.
- Reports of family violence offences increased (262 during February 2011 to 291 the following month before falling to 253 in May). Figures reported in 2013 suggest family violence reports continued to rise.
- There were changes in patterns of crime, including more crime being reported around shopping malls.

Source: Parliamentary Library of New Zealand, 'Social effects of the Canterbury earthquakes', 8 October 2014. Used under CC BY 3.0 licence

Some geologists predict that New Zealanders should be prepared for a very large earthquake (magnitude 9.0) to strike and warn of the possibility of a disaster like the 2011 earthquake in Japan, when 16 000 people died from the earthquake and the tsunami that followed.

Resources

- **Weblink:** Earthquake recovery information
- **Weblink:** Economic impacts of the Christchurch earthquake
- **Weblink:** Impacts on tourism in New Zealand
- **Weblink:** Earthquake building safety regulations in New Zealand

1.8.6 Earthquakes in Mexico

Mexico City, one of the world's most populated cities, is another at high risk for earthquake hazards. On 19 September 1985, a powerful earthquake, with a Mercalli Sale rating of IX and measuring 8.1 on the Richter Scale, struck close to the city causing many buildings to collapse and killing more than 10 000 people. Another 30 000 were injured and hundreds of thousands were left homeless. Because of this calamitous event, Mexico City improved its building and construction standards and established an emergency response team, *Brigada Internacional de Rescate Tlatelolco*, known as *Los Topos* ('the moles').

In 2017 on the same date, 19 September, a 7.1 tremor struck Puebla near Mexico City killing 370 people. This occured only twelve days after an 8.2 magnitude earthquake struck off the coast of Mexico near Chiapas, generating a tsunami alert. As buildings shook and collapsed, thousands fled onto the streets in fear. Because this quake struck during office and school hours, many casualties were workers and children. Rescue teams of *Los Topos* and volunteers sifted through the debris and damaged buildings looking for survivors feared buried.

The following article, published in *The Conversation*, outlines some of the social and economic impacts of earthquakes for regions in Mexico.

Mexico's road to recovery after quakes is far longer than it looks

In the span of just 11 days, Mexico was devastated by two major earthquakes that destroyed buildings and claimed lives across southern and central Mexico. The official death count was higher than 400 as of Sept. 24, but it will continue to climb as relief efforts turn from rescue work to the recovery of bodies buried in the rubble.

In the days ahead, other measures of the disaster's extent will emerge, including the number of people who were physically injured and the estimated costs to the Mexican economy. No matter the measure, the disaster has clearly devastated many parts of Mexico. But, even then, those measures still obscure the true human cost of the disaster.

Long after the dust settles and new buildings are erected in the place of those that crumbled, tens of thousands of Mexicans will continue to feel the impact of the disaster. Many families, especially those living in poverty, will see their health, well-being and ability to escape poverty worsen for decades. Some will be affected for life.

I study how earthquakes and other natural disasters affect individuals, households and communities – and how to prevent natural hazards from becoming natural disasters in the first place. My research on past earthquakes and other natural disasters shows that these events exacerbate social disparities that are much more difficult to repair than the physical destruction.

The hidden consequences of disaster

Despite being the 15th-largest economy in the world Mexico's GDP per capita is only US$18,900, compared to $57,400 in the United States. To make matters worse, more than half of Mexico's population – 67 million people – live in outright poverty.

In southern Mexico, the region most affected by the twin earthquakes, the consequences are likely to be particularly severe: More than 70 percent of people in Guerrero, Oaxaca and Chiapas states live in poverty. Many of those families live in extreme poverty, on less than $2 per person per day.

FIGURE 1.44 Damage in the streets of Juchitan, Oaxaca, Mexico, a month after the September 2017 earthquake

Losses caused by a natural disaster almost always affect the poor disproportionately and can even cause poverty. Beyond the devastating loss of a loved one, the loss of life is catastrophic for a household that struggles to put food on the table every day. For a poor family, the loss of a breadwinner threatens the future of everyone. For many families, even a modest loss of access to food can lead to malnutrition or affect the long-term health of family members.

And a minor loss in the ability to work or farm profoundly threatens the welfare in households that live close to the subsistence level.

What little savings poor households have are typically tied up in the value of their house, their livestock or some other physical asset. These life savings are often meant to support children through school or to invest agricultural equipment that could substantially increase yields. In developing communities where access to credit is limited, a household's ability to escape poverty depends almost exclusively on savings. In the blink of an eye, the life savings of thousands of Mexican families disappeared this month.

While shaking near the epicenters of the two earthquakes was 8.1 and 7.1 on the Richter scale, both of which can cause even modern buildings to crumble, shaking as low as 5.5 can cause noteworthy property damage. While fully collapsed buildings, fatalities and even injuries were fairly concentrated, at least nine states outside of Mexico City experienced widespread shaking high enough to ruin a poor household's assets.

The loss of property deteriorates a family's ability to sustain the agricultural output upon which their food security and other needs depend. The 2017 earthquakes came during the middle of a growing season for many households. It is too soon to know just how badly the agricultural capacity in southern Mexico has been affected. In other disasters, like the earthquakes in Nepal in 2015, there was a significant loss of crops.

Lower agricultural output will have widespread consequences across the region, inevitably affecting food prices. As the yield drops, or the price of sustaining the yield increases, food prices must rise. Poor families will in turn have a harder time sustaining a sufficient diet, or they will have to reallocate funds intended for long-term improvements to satisfy immediate needs. Many households that sustained no direct damage will be affected.

Beyond the misleading measurements

While the fatality count was higher for the second earthquake, which caused major structural collapses such as the collapse of a primary school with young children trapped inside, the first earthquake will probably have greater long-term consequences. It struck three southern states hardest, each near a 50 per cent poverty rate.

The United States Geological Survey predicts losses of between $100 million and $1 billion for the second of the earthquakes alone. However, these numbers almost certainly underestimate the long-run consequences that accrue, especially in the case of poor families.

As Mexico moves forward and the world responds, it will be important to remember that the total number of assets lost is not a meaningful indicator of how deeply lives are affected by the disaster. Losses of expensive luxury or vacation homes will quickly increase the total asset losses, while not affecting the food security of their owners. A $100 loss, while adding little to the total, can mean ruin for a subsistence-level household. Such a loss can cause not only short-term food insecurity but also an inability to escape poverty in the long run.

The emergency response will soon end and the world will turn its attention to the next disaster, but Mexican families will still feel the effects of the twin earthquakes for years to come.

Source: Morten Wendelbo, Lecturer, Bush School of Government and Public Service; Research Fellow, Scowcroft Institute of International Affairs; and, Policy Sciences Lecturer, Texas A&M University Libraries, Texas A&M University, published in *The Conversation*.

Activity 1.8c: Comparing the effects of earthquakes

Using the information you have learned about earthquakes in Mexico and New Zealand, answer the following questions.

Explain the impact of earthquakes in different communities

1. Use reports and available data in the text to list some of the main effects and responses to the earthquakes in Christchurch in 2011 and Puebla in 2017. Use a table like the example below to collate your findings.

	Christchurch, New Zealand 22 February 2011	**Puebla, Mexico 19 September 2017**
Population of country	4.6 million	112 million
Approx. GDP per capita	US$39 400	US$8201
Other data	NZ population 4.6 million GDP per capita US$39 400	Mexico population 112 million GDP per capita US$8201
Primary impacts (e.g. fatalities, injuries, impact on buildings and infrastructure)		
Secondary impacts (e.g. effects on water, food supply, sewerage, power supply, health)		
Tertiary impacts (e.g. effects on infrastructure, insurance, businesses, employment, residency)		

2. Write an extended paragraph describing the similarities between the earthquakes' impacts by providing examples from your table. Use the terms primary, secondary and tertiary in your response.
3. Were the primary, secondary or tertiary impacts of the earthquakes different for each place? Using data from your table, write a paragraph describing the different impacts and suggest what might have contributed to this difference.

Apply your understanding of earthquake responses

4. Suggest how communities in these places could manage the effects of future earthquakes. Complete a table like the one below to compare primary, secondary and tertiary effects of two geological hazards that have occurred recently. (Refer to the Smithsonian Institution Global Volcanism Program and the USGS Earthquake Hazards Program weblinks in the Resources tab to find recent events.)

Effect	Earthquake	Volcano
Primary		
Secondary		
Tertiary		

on Resources

- **Weblink:** 7 September 2017 earthquake
- **Weblink:** Mexico's vulnerability to earthquakes

1.8.7 Volcanic eruptions

Volcanoes exist on every continent. At present, several thousand are extinct or dormant and pose no threat to life. However, there are about 600 volcanoes above sea level that are highly active. When they erupt, they may cause death and injury to people as well as destroy property and crops; however, volcanoes also produce mineral-rich soils, and so people settle around the base to make the most of the fertile farmland. In doing so, they put their lives and communities at risk.

Most volcanoes occur when magma can escape or be released at weak points of the Earth's crust. Over 60 per cent of all volcanoes occur along tectonic plate boundaries where either subduction or sea floor spreading is occurring. The most active volcanoes occur over subduction zones, many in the Pacific Ring of Fire (see figure 1.36). Volcanoes also form at isolated weak points in the crust known as 'hot spots', such as the Hawaiian Islands.

Volcanoes differ according to the type of lava that is discharged from them. There are two main types.

- Basic lava cones are low with gentle slope like those in Hawaii and Iceland. This lava is low in silica and runs out quickly, and may travel a considerable distance from the volcano. These cones are commonly called shield volcanoes.
- Acidic lava volcanoes have tall, steep cones. This lava is high in silica, and is viscous (thick); it moves slowly and may even clog some of the volcano's vents resulting in violent, explosive eruptions that can blast tonnes of rock and ash, and hot, poisonous gases into the air. Acidic volcanoes are an extremely dangerous hazard because of this explosive force. They are also referred to as **pyroclastic** cones.

Impacts of volcanic eruptions

The most obvious effect of volcanic eruptions is the threat to life, but eruptions can also destroy forests and wildlife, houses, farmlands and rivers, as well as contaminate the atmosphere. They create lava flows that travel long distances and burn, bury or harm anything in their path, and are often associated with earthquakes, mudflows lahars and avalanches. The gases they emit, such as carbon dioxide (CO_2) and sulfur dioxide (SO_2), are not only toxic and smelly, but also cause acid rain in regions some distance away. Large quantities of rock, ash and dust can bury things, cause roofs to collapse and make it difficult for living things to breathe. Volcanic ash also affects aircraft engines, sometimes even leading to the failure of key navigation equipment. If ash is sucked into aircraft engines and accumulates, it can potentially lead to engine failure. Because it is unsafe to fly through airborne volcanic ash, flight paths are often closed down near ash plumes, causing significant disruptions to travel and tourism. These hazards can cover significant distances, so volcanic exclusion zones (areas from which people are encouraged to evacuate in order to stay safe) can be quite large.

FIGURE 1.45 Pyroclastic cloud, Mount Sinabung, Indonesia

FIGURE 1.46 Features of an active volcano

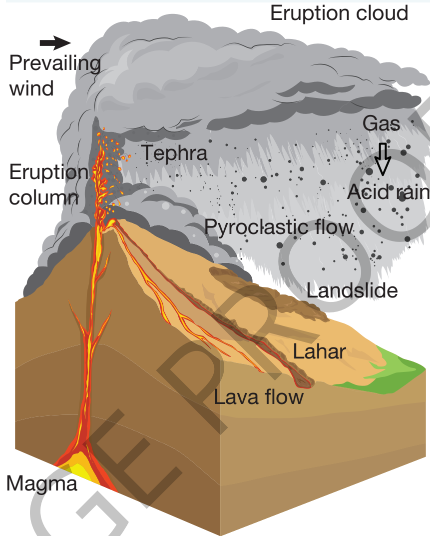


TABLE 1.4 Impacts of ash falls

Ash depth	Impacts
<1 mm	Lung and eye irritation Airport closures due to potential damage to aircraft Vehicles, houses and equipment potentially damaged by fine abrasive ash Water supplies potentially contaminated, particularly roof-fed tank supplies Poor road visibility and traction due to dust or mud
1–5 mm	Amplification of impacts of less than 1 mm of ash Crops potentially damaged Feed for livestock reduced and possible contamination of water supplies Houses may sustain some damage from fine ash soiling interiors or blocking air-conditioning filters Electricity substations may short-out from wet ash (low-voltage systems more vulnerable than high-voltage) Water supplies may be cut or limited because of power cuts to pumps Water supplies may be contaminated by chemical leachates Water supplies may become restricted because of the increased water usage required for clean-up Roads may need to be cleared to reduce the dust nuisance and to prevent stormwater systems from becoming blocked Sewerage systems may be blocked by ash, or disrupted by failing or damaged electricity infrastructure Electrical equipment and machinery may suffer damage
5–100 mm	Amplification of impacts from less than 5 mm of ash Pasture and low plants may be buried, foliage may be stripped from some trees (most trees survive) Most pastures will be destroyed with falls of more than 50 mm of ash Urban areas will require major ash removal Weak roof structures could potentially collapse with 100 mm ash coverage, particularly if the ash is wet Road transport will cease due to the build-up of ash on roads, cars may stop working from clogged air filters Rail transport may cease due to signal failure brought on by short-circuiting if ash becomes wet

(*continued*)

TABLE 1.4 Impacts of ash falls (*continued*)

Ash depth	Impacts
100–300 mm	Amplification of impacts from less than 100 mm of ash Roofs may collapse if buildings are not cleared of ash, especially from large flat-roofed structures and if ash becomes wet Trees suffer severe damage, including being stripped of foliage and broken branches Electrical reticulation fails due to falling tree branches and shorting of power lines
>300 mm	Amplification of impacts from less than 300 mm Widespread death of vegetation Soil horizon is completely buried Significant numbers of livestock and other animals die or experience serious distress Aquatic life in lakes and rivers dies Many roofs collapse from ash loading Power and telephone lines break Roads are inaccessible

Source: GNS Science

Activity 1.8d: Interpreting isopach maps

An **isopach** map is one that shows lines connecting points of equal formation thickness. It could be used to show fallout from a volcano or thickness of mining seams.

Refer to data in table 1.4 and the isopach map in figure 1.47 to answer these questions. (Note that the map and table show measurements in different units – mm and cm – so you may need to convert some data to make accurate comparisons.)

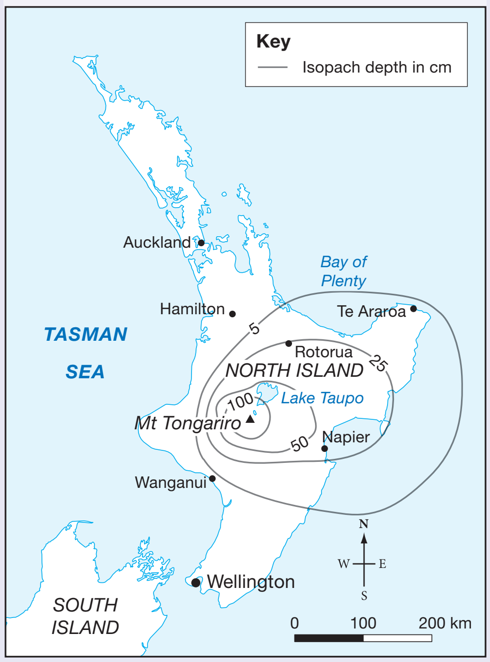
Comprehend and explain the information

1. Name the volcanic peak in the centre of the isopach lines.
2. What is the interval used (in cm) to distinguish between the isopach lines?
3. Name two cities where ash could reach a depth of at least 25 cm.
4. What depth of ash could fall on Lake Taupo?
5. Why might more ash could fall to the east of the volcano?
6. Which city could have the most ash fall: Wellington or Auckland?
7. Estimate the depths of ash that might have fallen at both Auckland and Hamilton.
8. What effects would ash fall have on the aquatic life in Lake Taupo?
9. How would road and rail transport in and out of Te Araroa be affected?
10. What affects might Napier have suffered that Wanganui did not?

Apply your understanding and suggest risk management strategies

11. How might residents of Auckland, Wellington and Napier better prepare themselves for future eruptions of Mt Tongariro? Construct a risk mitigation plan that might be distributed in each community to help people prepare.

FIGURE 1.47 A hypothetical isopach map of the North Island of New Zealand showing potential depths of ash fallout



Source: Bill Dodd / Natural Earth Data

Resources

- **Video eLesson:** Constructing and describing isoline maps (eles-1737)
- **Interactivity:** Constructing and describing isoline maps (int-3355)
- **Weblink:** Unzen pyroclastic cloud
- **Weblink:** Smithsonian Institution Global Volcanism Program

1.8.8 Earthquakes and volcanoes in South America

One of the lithosphere's most active areas over the last century is The South American west coast has been one of the lithosphere's most active areas over the last century, particularly around Ecuador's mainland and the Galapagos Islands. The Galapagos Islands and Hawaii are well-known hot spots in the Pacific where magma has protruded through the crust to eventually form island chains. The ocean floor of the Nazca Plate between the Galapagos Islands and the coast (about 1000 km away) is being subducted below the South American Plate. However, a section of this sea floor about 450 km wide is an **aseismic ridge** (known as the Carnegie Ridge). An aseismic ridge is one that forms when a tectonic plate moves over a hot spot and undersea mountains and guyots (flat-topped undersea mountains) may form.

The Carnegie Ridge consists of rock that is less dense than the surrounding sea floor, and so is not subducted to the same depths as it passes into the Colombia–Ecuador trench and below South America. However, this uneven shallow subduction does cause several geological issues, such as:

- generating additional tectonic stress as old seamounts and guyots on the sea floor get dislodged into the plate
- tearing of the lithosphere, which increases the potential for earthquakes near the subduction zone (Ecuador has had six major earthquakes in the past 100 years)
- generating 'shallow' (close to the surface) earthquakes, which are more intense and dangerous
- developing **adakitic** volcanoes (where magma consists of partially melted sea floor and basalt, which can be highly explosive). There are 11 active volcanoes south of the Ecuadorian capital, Quito, and all are within 200 km of each other.

The tectonic threat to Ecuador is very high. Currently, Ecuador has more than 20 volcanoes that are either currently active or have been active recently. The best-known are Sangay, Cotopaxi, Reventador and Pichincha. Of most concern is the proximity of these dangerous volcanoes to highly populated, built-up areas such as Quito, which has more than 2.6 million inhabitants. At least 9 per cent of the total population lives around the base of volcanoes and about 66 per cent of the road network is in seismically active country. These volcanoes are not only close to major centres, they are also very active. Sangay has erupted almost daily since 1934 and there are frequent earth tremors because of the off-shore subduction.

Because they are part of the Andes Mountain chain, Ecuadorian volcanoes also have very high summits. Cotapaxi, for example, has an elevation of 5897 m above sea level and is covered with thick snow year-round. Cotopaxi also contains many glaciers, so the surrounding lowlands are at significant risk of lahars and flooding. In fact, lahars from Cotapaxi have been known to reach the headwaters of the Amazon in past eruptions. Water supply in Ecuador is dependent on alpine rivers and springs, so it is also quite vulnerable to pollution from the heavy metals found in volcanic ash. Because of the high levels of risk associated with Cotopaxi, the volcano is monitored for activity with seismographs, which monitor tremors, and

FIGURE 1.48 Cotopaxi, Ecuador (2014)

Source: Sandra Duncanson

for the increased pressure associated with the chamber filling with magma. The slopes are also continuously monitored, measuring any changes in nanometres (thousand-millionths of a metre).

Ecuador has a GDP per capita of less than US$6000, which affects the capital and resources available to reinforce and protect infrastructure, and to evacuate and protect citizens. The United Nations and humanitarian organisations such as the Red Cross and Oxfam play key roles in the planning for and response to volcanic eruptions in Ecuador. Emergency situations are coordinated through relevant government ministries that operate under a National Decentralized System, bringing together all government and non-government organisations (NGOs) for assistance and advice during times of heightened risk.

The 2015 eruption of Tungurahua created ash deposits of up to 6 mm in nearby towns and villages. The eruption affected an estimated 130 000 people, including 5000 who required direct assistance. Government agencies issued an orange alert, indicating residents should remain alert and prepare for the possible need to evacuate. Even though the threat from the volcano eased within a few days, the ash coverage still had a significant impact on the affected communities.

As soon as the government alert was issued, Ecuadorian Red Cross units were mobilised to coordinate efforts with community leaders, to set up emergency operations, assess and gather information about damage, and to ensure local communication channels were maintained and remained open in the event that the disaster worsened. This included the number of people who needed to be made aware of evacuation and emergency procedures, potential numbers of people who might have needed humanitarian assistance and thorough risk assessments based on data taken from previous eruptions and their impacts. Key objectives then took into account the vulnerability of groups in the area and potential scenarios from explosive pyroclastic flows and ongoing gas and ash emission to activity ceasing entirely.

NGOs such as the World Food Programme and UNICEF also operate in Ecuador outside times of emergency, developing contingency plans for significant volcanic eruptions or earthquakes.

Activity 1.8e: Volcano alert codes

In Ecuador, there are four levels of alert: white, yellow, orange, and red.

- White – almost no possibility of an eruption, although the volcano is not extinct
- Yellow – there has been minor seismic activity with release of some gases and ash. This is an early warning where the government may declare a state of emergency and warn people to prepare for possible evacuation.
- Orange – seismic activity has increased and eruption is imminent; residents near foothills are evacuated due to lahars or pyroclastic flows
- Red – a volcanic eruption has occurred.

Explain and analyse volcano alerts in Ecuador

1. Find out if any of these well-known volcanoes are currently on alert: Sangay, Cotopaxi, Reventador and Pichincha. Describe the features and extent of the volcanic activity that is occurring.
2. Why would it be important to be give a hazard zone map to tourists that shows where lahars may be possible?
3. Considering the history of seismic activity in Ecuador, what information should walkers climbing Cotopaxi be told before they begin their climb?
4. What challenges might communities in hazards zones around active volcanoes in Ecuador face that tourists would not need to consider? Make lists of primary, secondary and tertiary impacts for local people that would not affect visitors to the region.

1.8.9 Responding to volcanic eruptions

When there is a volcanic eruption, and if residents or tourists have time, it is safest to move beyond the exclusion zone. However, if this is not possible or people fail to leave, there are certain steps to take. People should protect themselves against ash and dust by wearing a mask or placing a wet cloth over their mouth and nose, wearing long-sleeved clothes and removing contact lenses. This helps to prevent acid-coated ash irritating their lungs and eyes. Keeping at least three days' supply of clean drinking water, a supply of food, a battery-operated radio, cash and a first aid kit is also important. People should also protect electronic equipment with plastic.

Responses to volcanic eruptions vary according to the severity and impact of the eruption, and the community's ability to respond. Consider the plan of action for the Tungurahua Volcano in Ecuador and the preparedness guide developed by the US Geological Survey found in the Resources tab.

on Resources

- **Weblink:** Volcano Discovery: live updates and webcam footage from Ecuador's volcanoes
- **Weblink:** Tungurahua Volcano emergency plan of action
- **Weblink:** US Geological Survey: Volcano preparedness

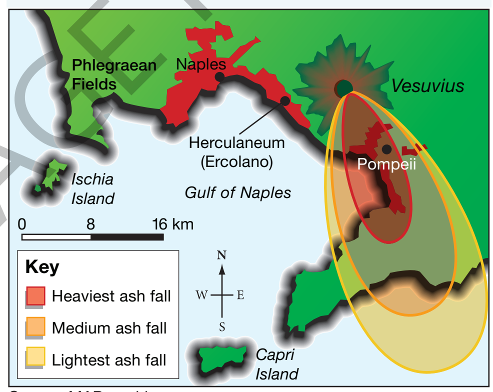
1.8.10 Mt Vesuvius, Italy

Italy is home to some of the world's most famous volcanoes, including Vulcano, the island which gives us the name used for all eruptive mountains, as well as for a type of volcanic eruption. Better known volcanoes, such as Vesuvius and Stromboli, have also provided names used to describe types of volcanic eruptions. Italy has about 30 volcanoes, seven of which are still considered active. Two Italian volcanoes, Etna and Stromboli, are almost continuously active, and Etna, at a height of 3323 m, is also Europe's largest continental volcano. Italy's volcanic activity is due to a collision between the African and Eurasian tectonic plates. As the African plate moves towards the Eurasian plate, subduction of the African plate occurs and magma rises to the surface through the weakened and fractured crust.

Even though Italy's volcanoes have provided its farmers with rich, fertile volcanic soils, especially around Mt Vesuvius and Mt Etna, they are also a grim reminder of Earth's awesome authority. In 79 CE, Vesuvius, a massive stratovolcano overlooking the Bay of Naples, erupted with overwhelming fury, destroying the Roman cities of Pompeii and Herculaneum, killing many of their occupants.

Vesuvius has erupted many times since 79 CE, most recently in 1944. It is still regarded as active and is monitored daily for gas and temperature changes. Today, Naples and the area adjacent to the base of Vesuvius is a heavily populated urban and tourist centre. More than 3 million people live within 12 km of its cone and are exposed to the wrath of Vesuvius, which continues to rumble and discharge smoke. Vesuvius's history of violent eruptions make it one of the world's most dangerous volcanoes.

FIGURE 1.49 Mt Vesuvius and surrounding areas, 79 CE



Source: MAPgraphics

FIGURE 1.50 Plate boundary, southern Italy

Source: MAPgraphics

Vesuvius evacuation plans

Authorities in the areas surrounding Vesuvius have formulated plans to evacuate over 700 000 people if the volcano erupts. The Department of Civil Protection, which is charged with risk management and emergency response in Italy, has identified a 'red zone' for risk that includes 25 towns, all of which can be evacuated within 72 hours of a significant erution. Another 63 towns, with a combined population of more than 1 000 000 people, lie in a 'yellow zone' that would be likely to suffer from falling ash and rock from the volcano.

The plan also includes four alert levels: basic, attention, pre-alert and alert. When the pre-alert level is activated, patients in care facilities and hospitals are relocated and heritage monuments are protected. Activation of the alert level means the plans to evacuate come into effect.

Risk management plans contain key strategies that need to be developed while the mountain is dormant. These include:

- delineating the three emergency zones based on proximity and potential fallout. The red zone is the area around the base of Vesuvius, where the risk of pyroclastic flow, heat and toxic gases is greatest. The yellow zone is further away and is the area most likely to be affected by fallout of ash and lapilli (rock fragments being launched from the volcano). Homes would be at risk of collapsing and residents would suffer from respiratory problems. The blue zone falls inside the yellow zone, but is considered at higher risk because of its topography. Here there is more chance of flooding or mudflows.
- educating and informing people for an orderly evacuation and removing complacency, without becoming alarmist. Money has been set aside for school education programs.
- having operational strategies to evacuate the entire red zone in 72 hours (12 hours for organisation, 48 hours for movement and a buffer of 12-hours if needed) using a fleet of 375 000 registered cars, 500 buses and 220 trains each day of the evacuation period.
- arranging evacuation centres. Each of the 25 local regions has been 'twinned' with another area of Italy where evacuated residents would be accommodated. Each township has been allocated a specific mode of transport depending on the destination of evacuees. For example, Pompeii residents would leave by boat to Sardinia, while Neapolitans would board trains that would take them to Lazio, the administrative region around Rome.

FIGURE 1.51 Looking across Naples towards Mt Vesuvius

FIGURE 1.52 Satellite image of the area around Mt Vesuvius

Emergency planning

Despite these emergency plans, and extra funding being assigned to improve infrastructure and help spread awareness of the emergency protocol, there are many unresolved issues and complexities when an active volcano is located so close to a major city and tourist area.

- Public officials and emergency services personnel might not be familiar enough with the plan to implement it immediately.
- Thousands of tourists visit the area daily and most would not be familiar with local conditions.
- Language barriers between locals and visitors might prevent people from understanding instructions.
- Much of the area in the hazard zone is still farmland accessed by smaller, rural roads.

A program has been set up offering money for families living near Vesuvius to relocate out of the danger zone, but this has not proved popular.

Activity 1.8f: Mt Vesuvius, Italy

Using the information you have learned about Mt Vesuvius, answer the following questions.

Analyse the data

1. Using the information available, complete a SWOT analysis of the National Emergency Plan for Naples. (A printer-friendly version of this analysis grid can be found in the Resources tab.)

FIGURE 1.53 SWOT analysis grid

Strengths (+)	Weaknesses (–)
• • •	• • •
Opportunities (+)	**Threats (–)**
• • •	• • •

Comprehend primary sources

Read through the description of Vesuvius erupting in 79 CE, as written by Pliny the Younger, and answer the questions that follow.

Extract from Pliny the Younger's account of the eruption of Vesuvius (24 August 79 CE)

> 'One night the earth shocks became so violent that it seemed the world was turned upside down . . . We decided to escape, and a panic-stricken crowd followed us . . . When we were clear of the houses we stood still . . . The sea seemed to roll back on itself . . . the shore had widened, and many sea creatures were beached on the sand. In the other direction appeared a horrible black cloud ripped by bursts of fire . . .

Soon the cloud began to descend upon the earth and cover the sea . . . We were enveloped in night like the darkness of a sealed room without lights. We could hear the cries of women, the screams of children and the shouting of men. Some were calling to their parents, to their children, to their wives. Some lifted their hands to the gods, but a great number believed there were no gods now, and that this night was to be the world's last eternal one . . .

We were immersed in darkness and ashes fell thickly upon us. From time to time we had to get up and shake them off for fear of being buried and crushed under the weight . . . Finally, a real daylight came. Before our terror-stricken sight everything was covered by a thick layer of ashes like a heavy snowfall. We returned to Misenum and had no thought of leaving until we received news about my uncle.'

1. What was Pliny describing in his account?
2. Make a list of things that came out of the volcano.
3. What hazardous events could Pliny have been describing when he said, *'The sea seemed to roll back on itself … the shore had widened, and many sea creatures were beached on the sand.'*
4. What was Pliny recalling when he said, '… *horrible black cloud ripped by bursts of fire … Soon the cloud began to descend upon the earth and cover the sea.'*
5. What evidence is there to suggest the ash fall was both substantial and light?
6. Using figure 1.52, identify where Pliny might have been standing to witness the events of the eruption as he describes them.
7. Use figure 1.49 to explain why Pompeii was completely buried by ash and its occupants incinerated by hot gas.

on Resources

- **Weblink:** Mt Vesuvius Emergency Plan
- **Weblink:** What if Vesuvius erupted today?
- **Weblink:** Smithsonian Institution Global Volcanism Program
- **Digital doc:** Volcano warnings (doc-29160)
- **Digital doc:** SWOT analysis grid (doc-29162)

1.8.11 Mt Agung, Indonesia

Every year, more than 1 million Australians visit Bali for holidays or business. Visitors fly in to the main airport at Denpasar, the largest city, and stay at local resorts or at Kuta, a popular beach area. However, the tourist experience is sometimes overshadowed by the presence of a large stratovolcano called Mt Agung, which is situated about 50 km north-east of Denpasar. Rising more than 3000 m above sea level, Agung has provided Bali with rich lava soil, in which farmers cultivate rice, vegetables and tropical fruits.

The mountain holds special spiritual and cultural significance for locals, and several temples are built on its slopes. For the many Balinese people who hold Hindu beliefs, Mt Agung is the most sacred mountains on the island.

In late 2017, Agung erupted again, pouring ash and smoke from its crater and threatening people in the surrounding area. A safety exclusion zone of 12 km was declared and thousands of people were forced to evacuate the area, leaving their farms and homes.

FIGURE 1.54 Mt Agung in Bali, Indonesia, erupts (2017)

The eruption also had a significant impact on tourism. Air travel in and out of Denpasar was severely disrupted by volcanic gas and ash clouds and many flights were cancelled for safety reasons. The airport became a temporary holding centre for hundreds of stranded passengers, many with little money. Hundreds of international holiday bookings were cancelled, so many resorts were left without customers, and local businesses were temporarily closed, leaving workers without income.

on Resources

Weblink: The cultural significance of Mt Agung

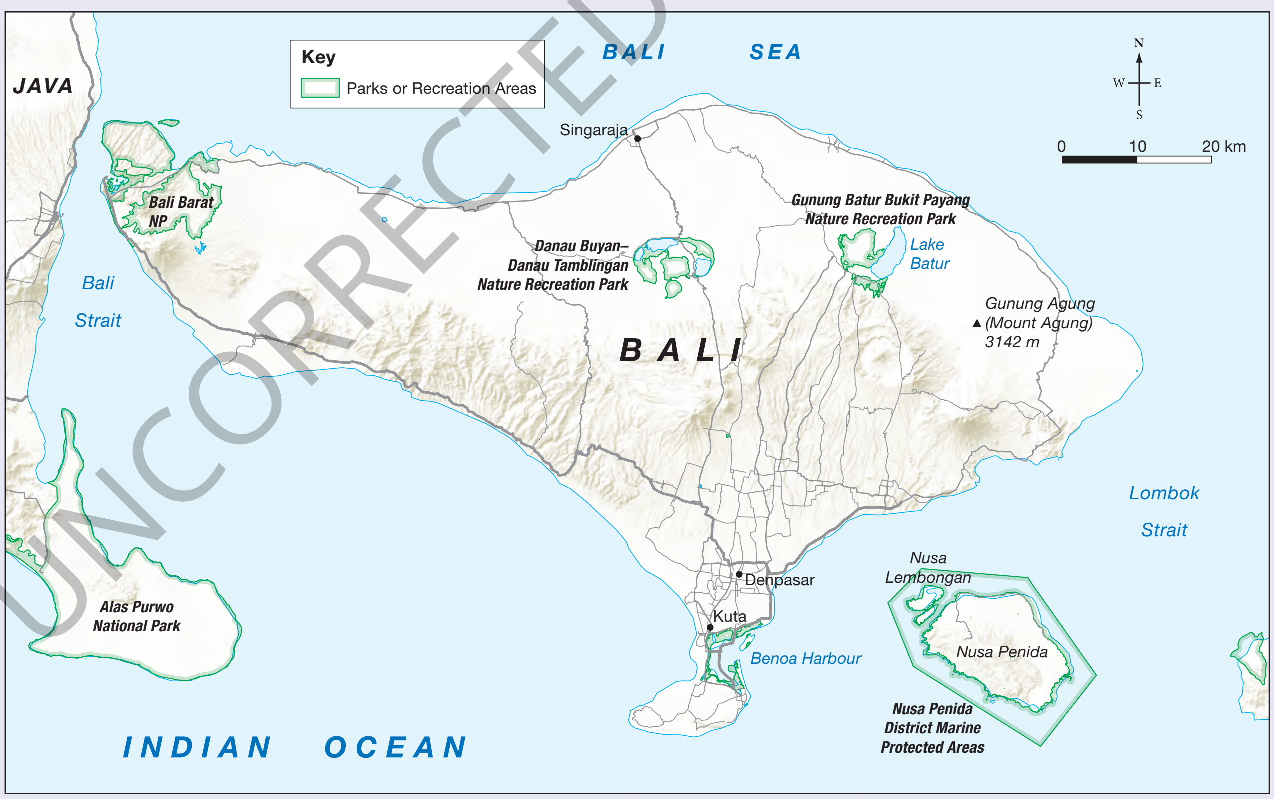
Activity 1.8g: Risk assessment

Using the information you have learned about volcanic eruption risk assessment and the map of Bali on the following page, answer the following questions. (You will also need to complete some online research.)

Comprehend and explain the risks

1. Mark in the exclusion zone of 12 km around Mt Agung.
2. Bali is divided into eight administrative areas. Research these divisions and their population densities, and mark them on the map.
3. Research and mark in key infrastructure and facilities that might be affected or are vital to response efforts during or after a volcanic eruption, such as hospitals and airports.

FIGURE 1.55 Bali is a popular tourist destination for many Australians but resorts' and flight paths' proximity to Mt Agung can pose a potential risk for tourists and locals



Source: © OpenStreetMap contributors

Suggest and justify risk management strategies

You have been asked by the Bali Tourist Bureau to undertake a risk assessment to determine if the National Parks and walk trails around the base of Mt Agung are safe for residents and tourists in the short- to medium-term. Create a proposal using the questions that follow to guide your assessment of the risks.

4. Complete a table like the one below to compare primary, secondary and tertiary effects of two geological hazards that have occurred recently. (Refer to the Smithsonian Institution Global Volcanism Program and the USGS Earthquake Hazards Program weblinks in the Resources tab to find recent events.)

Effect	Earthquake	Volcano
Primary		
Secondary		
Tertiary		

5. List the key criteria that you will need to consider to assess the risk. Specifically consider the vulnerability of different groups using the area, how risk might be mitigated, preparedness and the ability of tourists, locals and local authorities to respond quickly in the event of an eruption. Design a decision-making matrix to consider the various criteria upon which you will make your decision. Your criteria might include social, economic, geographical or other factors that affect people's level of risk, vulnerability or willingness to follow your proposed strategy.
6. Identify and prioritise which criteria are most important. Use an ordinal system.
7. Write your response to each of the criteria , listing as many positive and negative factors that might contribute to your decision and giving examples or evidence where possible. For example, considering the needs of tourism operators might be important because tourism now makes up 80 per cent of Bali's economy.
8. Once you have outlined your key points on the matrix, rank the key points listed under each criteron.
9. Write a paragraph about each criterion and its key points, providing evidence and elaborating on the positives and negatives of each of your points.
10. Using this evidence, propose a course of action for the management of the trails.

1.9 Geomorphic hazards

1.9.1 Introduction

Geomorphic hazards are the result of processes that occur on the crustal surface or lithosphere. Often called 'mass wasting', they refer to **slope failure** (which occurs when the pull of gravity causes a hill or mountain slope to collapse), **subsidence** (when part of the land sinks or collapses), or **flow movement** (when rock, soil or sand mix with water and air and move downhill in a flow). The most common geomorphic hazards are landslides, mudslides and avalanches (snow). These usually happen when the force of gravity cannot be withstood any longer because of one of two changes:

- geological movement, particularly in an already unstable area
- human activity that has caused changes to the topography, such as vegetation clearing, changes to drainage patterns and below-ground seepage or wild fires.

Even though mass wasting of rock, soil, mud or snow is less common than earthquakes and volcanic eruptions, it happens without warning and, in many cases, people are completely unprepared. The consequences can be catastrophic, causing widespread death and injury as well as burying towns and villages, destroying buildings and infrastructure (roads, tunnels, bridges and property), and even reshaping the surface topography. Across the world, landslides, mudflows and avalanches are some of the biggest killers of people in mountain regions, particularly where people live on or below hillsides.

The speed at which material travels downslope ranges from very slow (creep) to very fast (rockfall). Momentum and force of a flow is usually determined by the mass of material (size and weight), the mix of material (clay, rocks, soil, debris), the amount of water/fluid to lubricate and reduce friction, and the slope angle.

TABLE 1.5 Classification of flow movement

Average speed	Saturated flows	Non-saturated flows
Very slow (e.g. 1 cm/yr)	Solifluction	Soil creep
Slow (e.g. 1 m/day)		Earth flow
Moderate (e.g. 1–2 m/hr)	Debris flow	
Rapid (e.g. 50 km/hr)	Mudflow	
Very rapid (over 100 km/hr)		Debris avalanche

1.9.2 Types of mass wasting

A **landslide** is a geomorphic event where rock, soil, mud or artificial fill move down a slope under the force of gravity (slope failure). They may be caused by any number of natural processes, including long-term weathering of rocks and scree (producing regolith: loose weathered rock fragments), soil erosion, vegetation removal, earthquakes or volcanic eruptions. Human activities can also trigger landslides. The most common human causes are road building, construction on very steep slopes, poorly planned changes to drainage and disturbing old landslide sites.

The most lethal landslide in Australia occurred in July 1997, when a large section of steep mountainside collapsed in Thredbo, New South Wales, carrying the Carinya ski lodge at high speed onto the Bimbadeen ski lodge below. Both buildings were destroyed and 18 people died beneath the rubble. One injured man survived for three days within the landslide debris before being rescued. In comparison, a huge debris avalanche in Peru in 1970, which moved at speeds of up to 400 km/h, killed more than 20 000 people and destroyed the towns of Yungay and Ranrahirca.

A **mudflow** is a type of mass wasting where soil and debris become saturated (liquefied) and move rapidly down a slope (flow movement). Often, there is insufficient vegetation to hold the soil together due to land clearing or fires. In recent times, mudflows have happened due to very heavy rain falling in areas where slopes have been cleared for farming (the Philippines, Nepal) or razed by wildfires (California, USA). A mudflow is not the same as a mudslide.

Another common trigger for mass movements is heavy rainfall, such as that associated with tropical cyclones and severe thunderstorms. Large volumes of water add weight to soil and weathered rock particles, making slopes more unstable and susceptible to the influence of gravity. Water may also lubricate rock surfaces, thus reducing friction and allowing easier movement of overlying soil and rock. In countries that have cleared slopes from either farming or bushfire, heavy rain can trigger mudslides, often with tragic consequences.

Mass wasting is most common on uneven or hilly ground, particularly if there is heavy rainfall. In wet tropical areas such as South-East Asia and central Africa, heavy rainfall associated with thunderstorms or tropical cyclones adds weight to soil and rock particles, making slopes unstable and vulnerable to gravity. Water may also lubricate rock surfaces, thus reducing friction and allowing soil and rock to move easily.

FIGURE 1.56a Types of slope failure

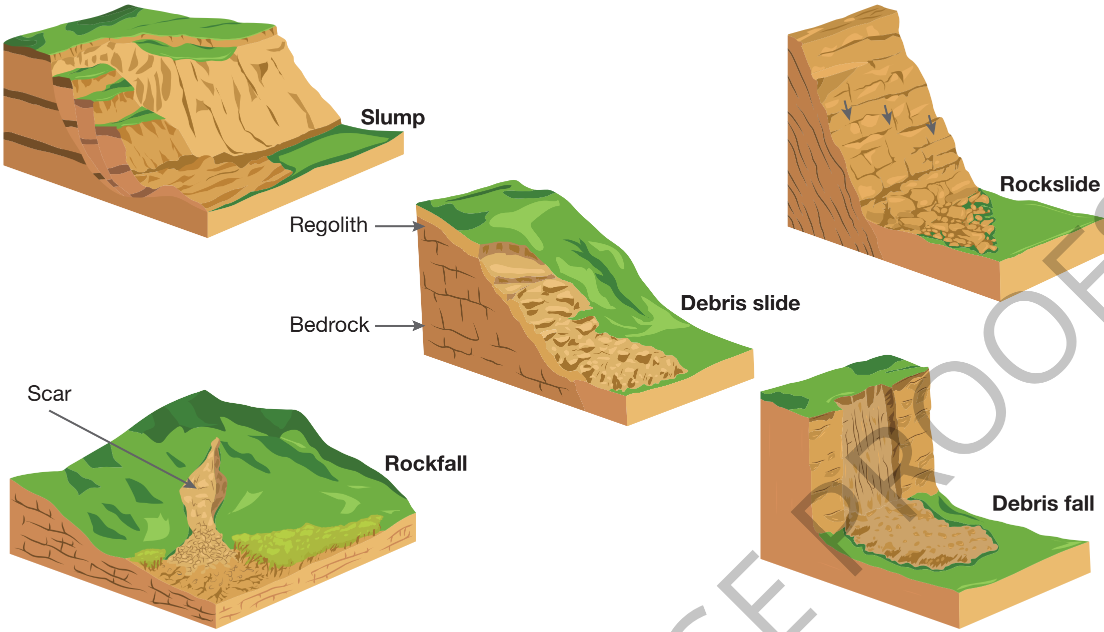
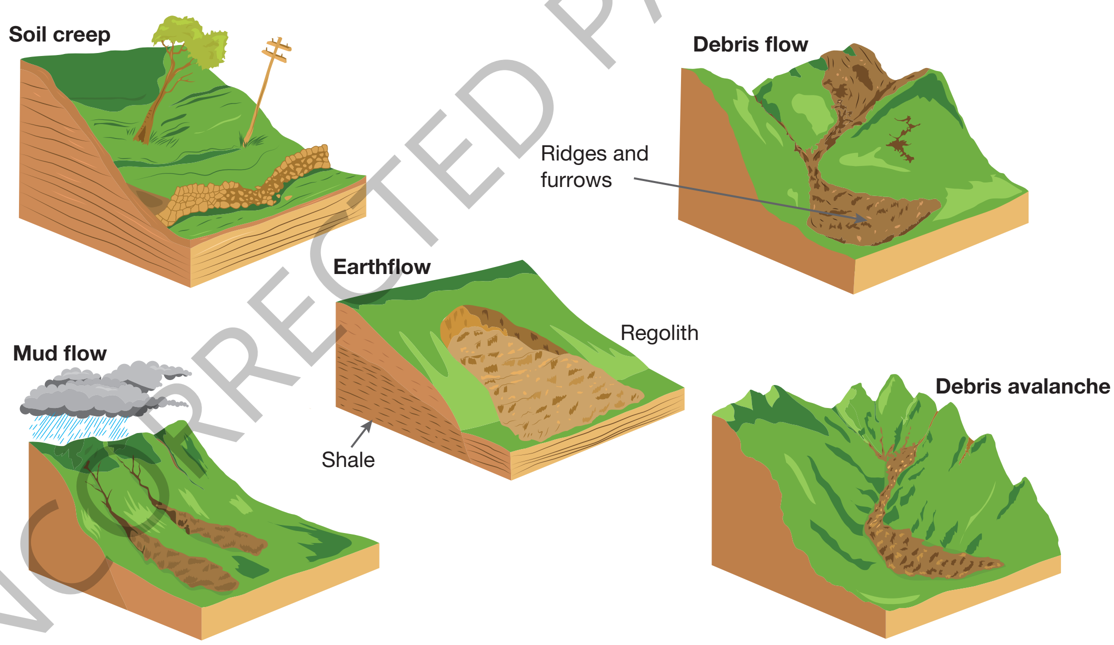


FIGURE 1.56b Types of flow movement



1.9.3 Responding to geomorphic hazards

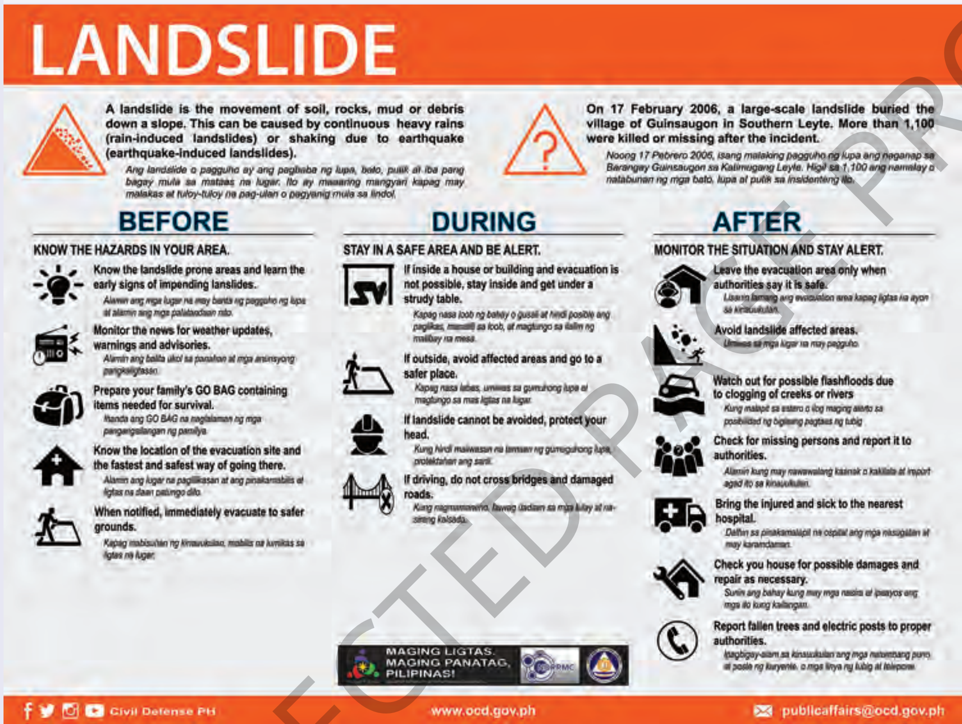
As with all other hazards, the best response to geomorphic hazards is understanding how to reduce harm and preparedness for and after the event. Most people have limited choices about where they live, and humans have little or no control over natural events, so strong mitigation, prevention and adaptation strategies are required to minimise risk.

While the type, scale and scope of geomorphic hazards vary according to the location and proximity of people to the threat, they all have a common thread – they are potentially dangerous for everything in their path. The most significant variable in humans' ability to survive such a hazard is a country's level of development and the amount of money available for relief efforts when an event occurs.

Activity 1.9a: Landslides

Using the information you have learned about responding to geomorphic hazards, answer the following questions.

FIGURE 1.57 Information and advice on landslides for the Philippines

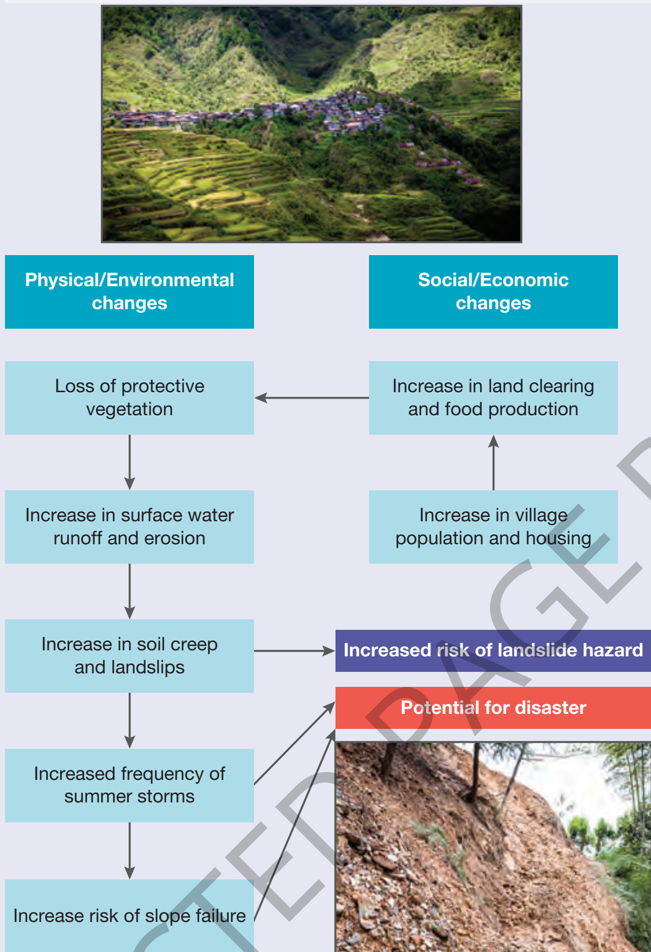


Source: NDRRMC Office of Civil Defense, Phillippines

Comprehend and explain landslide response strategies

1. Read through the Landslide Information Sheet and make a summary of key points using a flow diagram.
2. Put the points in order of importance based on safety in each section.
3. What adjustments might be made to the plan if:
   (a) the landslide occurred to night instead of during the day?
   (b) visitors arrived the day before?
4. Consider this flow chart showing a series of events that could contribute towards a landslide in a hot, wet region, such as South-East Asia.
   (a) What does the phrase 'potential for disaster' mean?
   (b) Identify a place in the flow chart where the first early warning signs might appear.
   (c) What interventions could be made to reduce the risk of a landslide?
   (d) Which of the physical variables might be magnified due to climate change?
   (e) Describe a situation where the two 'Social/Economic' changes might be interchanged with each other.

FIGURE 1.58 Flowchart showing events leading up to landslide



Assess and suggest risk management strategies

5. Which do you think has the greatest impact on the potential for landslides, social/economic changes or physical/environmental changes? Give reasons to support your answer.
6. What actions could you propose to mitigate the risks of landslide hazards in poor, mountainous regions like rural Nepal? Explain each mitigation strategy and justify your decision with clear reasons.

1.9.4 Landslides in Nepal

Nepal is a small country of around 141 000 km2. It is roughly rectangular-shaped and lies north of India. The topography is dominated by the tallest mountains in the world, the Himalayas. These fold mountains formed because of a collision between two tectonic plates: the Indo-Australian to the south and the Eurasian to the north. They continue to grow today at a rate of two to ten millimetres a year. Because Nepal lies in such an active tectonic zone, where mountain building processes continue, the country is highly susceptible to hazards such as earthquakes, landslides, avalanches and glacial lake outburst floods. Avalanches and floods can be caused

FIGURE 1.59 Nepal lies to the north of India in the Himalayas

Source: NDRRMC Office of Civil Defense, Phillippines when unstable glacial lakes fracture and collapse, sending a torrent of water down into valleys. These floods have become more frequent due to increased melting of glaciers caused by climate change.

Nepal is a very mountainous country wedged between India and China. It comprises three regions: the Terai Lowlands (17 per cent), the Mid Hills/Mountains (68 per cent) and the High Himalayas (15 per cent). The population of Nepal was approximately 30 million in 2018 and was increasing at a rate of about 1.09 per cent per year. Nepal ranks among the poorest and least developed countries in the world with a GDP per capita of approximately US$835 reported by the World Bank in 2017.

Farming provides a livelihood for 70 per cent of the Nepalese people, but population growth is causing farmers to seek more land on higher and steeper slopes to terrace for farming. Forests are also being stripped to feed livestock, and for fuel for cooking and warmth. This land clearing, the naturally steep slopes and Nepal's heavy monsoonal rains make it vulnerable to landslides and flooding. Occasionally there are earthquakes, which also trigger landslides. It is estimated that every five years, between 10 and 25 per cent of Nepal's mountain roads are completely lost due to landslides or floods.

Low levels of education and generally poor construction standards make many Nepalese people more vulnerable to mass wasting hazards. Most homes are mud and timber and are built without the benefit of the modern engineering techniques that can help a structure withstand hazards.

In August 2017, Nepal received heavy monsoonal rains that created flooding and landslide hazards in half of the country's districts, most significantly in the Terai Lowlands region. The disaster affected around 1.7 million people. Despite widespread damage, only 70 lives were lost; a result largely attributed to the quick response of government search and rescue teams.

The cost of recovery from the disaster was estimated to be around US$705 million, but specific challenges hampered reconstruction efforts. According to the United Nations Office for Coordination of Humanitarian Affairs, by May 2018, most of the eligible families whose homes were completely destroyed (about 41 000 homes) or damaged (about 150 000 homes) were yet to receive their allocated rebuilding grant from the government. Food shortages were being experienced in the hardest hit areas of the Terai Lowlands and some education, health and sanitation facilities were still inoperable.

FIGURE 1.60 Landscape profile of Nepal

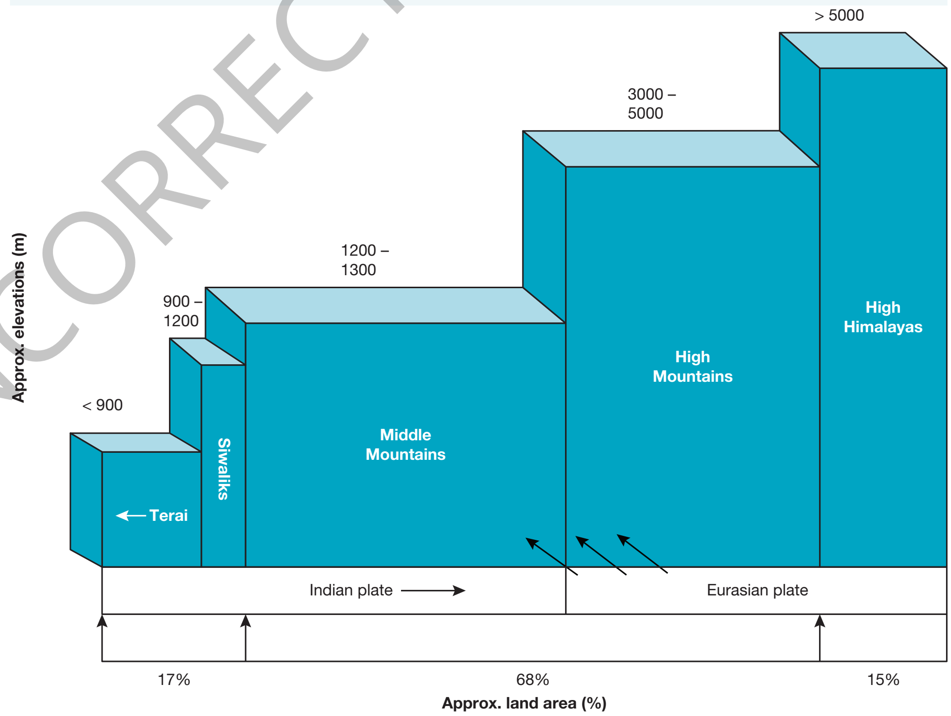


TABLE 1.6 Recent natural hazards in Nepal

Year	Landslides	Floods	Earthquakes
June 2013		39 killed 18 missing More than 1000 homeless	
August 2014		53 killed More than 29 000 displaced	
April 2015			9000 killed 22 000 injured
July 2016	73 killed	64 killed	
August 2017	70 killed		

on Resources

Weblink: Nepal floods and landslides

Digital doc: Landslides in Nepal (doc-29159)

Reducing the risk of hazards in Nepal

Given Nepal's location, it is not possible to eliminate the risk of earthquakes, landslides, floods and other natural hazards. However, it may be possible to influence or change some people's actions, which have increased the risk of these hazards. Some examples include:

- better road construction would reduce exposure to landslides
- not using heavy machinery and blasting to cut through slopes
- using netting and grasses to stabilise slopes
- containing material from hillside cuts behind stone walls.

At present, the Annapurna Conservation Area Project is designed to seek broader goals in land rehabilitation and tree planting, but could assist with the reduction in landslides too.

Activity 1.9b: Landslides in Nepal

Analyse the information and apply your understanding

1. Streams flowing from the Mid Hills and High Himalayas into the Terai are fed in part by glacial melt as well as rainfall and runoff. If warmer air temperatures and more intense monsoon rains are now occurring, how might this combination of factors effect denuded slopes and lowland rivers of the Terai?
2. What specific challenges might Nepalese authorities and non-government organisations working in region face in mitigating the risks of landslides? Consider physical, economic and social factors.

1.10 Review

After reviewing the causes and effects of several natural disasters, it is apparent that many of the worst events occur in developing countries. Data supports the view that people living in countries with the least wealth are less able to prepare for or respond to hazards.

Some economists argue that natural disasters trigger economic growth and improve economic development. Evidence suggests that in a developed country, natural disasters may stimulate production and increase employment to meet construction activity and produce resources needed for rebuilding infrastructure. Retail sales also increase to replace goods lost in the misfortune. However, these arguments may not include lost opportunity costs. For example, could this money have been used for further improvement of infrastructure rather than rebuilding?

However, evidence shows that natural disasters in developing countries weaken already struggling economies. If people or property are lost, the natural disaster becomes a human disaster. As people are the driving force of production and growth, a human disaster is an economic disaster. No matter whether a country is rich or poor, a natural disaster does not deliver favourable economic outcomes for many.

Analysing spatial and statistical data

Data reveals that about 1.35 million people have died from natural hazards over the past 20 years. During the 7056 disasters recorded in that period, more than 50 per cent of fatalities occurred due to earthquakes (and tsunamis). By far, the greatest number of deaths were from low and middle-income nations (see table 1.7) According to the United Nations, the least developed countries had the most fatalities in terms of numbers killed per disaster and per 100 000 of population. However, several trends have emerged from figures gathered over the past two decades.

- The frequency of geological events such as earthquakes, tsunamis and volcanic eruptions remained constant and similar to previous patterns.
- There was a significant increase in climate/weather-related events such as storms, cyclones, blizzards and heatwaves. The number of these hazards was more than twice that of the previous twenty years.
- There was more extreme weather, and new temperature and rainfall records set, in many parts of the world.
- The number of fatalities doubled against the previous twenty years. It is uncertain whether this is due to more people living in disaster-prone areas or a spike from mega-disasters such as the tsunami in the Indian Ocean (2004) or the Haiti earthquake (2010).

Activity 1.10: Analysing data and constructing a scattergraph

A scattergraph is a diagram used to plot and compare two sets of data and investigate if there is a genuine link between them. The idea is to plot two sets of data – one using the x-axis and the other using the y-axis, and then determine if the distribution of points shows a pattern. You can draw in a 'line of best fit' in the most preferred position of the trend. The link between the two sets of data is referred to as a correlation. It may be positive or negative depending upon the slope of the pattern. Important things about scattergraphs are:

- if data on the y-axis increases as data on the x-axis increases, the correlation is positive
- if data on the y-axis decreases as data on the x-axis increases, the correlation is negative
- if points are scattered randomly with no clear trend, there is no correlation
- if a point is plotted and well away from the line of best fit, it is called an anomaly.

TABLE 1.7 Deaths caused by major natural disasters
(Australia GDP per capita US$49 600 for comparison purposes)

Country	Deaths 1996–2015	Major natural disasters	GDP per capita ($US)
Haiti	229 699	earthquake, hurricane	740
Indonesia	182 136	tsunami, tropical storms	3570
Myanmar	139 515	tropical storms	1275
China	123 937	earthquake, floods	8123
India	97 691	earthquake, tsunami, floods	1709
Pakistan	85 400	earthquake, floods	1468
Russian Federation	58 545	extreme weather, earthquake	8748
Sri Lanka	36 433	floods, landslides	3835
Iran	32 181	earthquake	4957
Venezuela	30 319	floods	14 300

Source: EM-DAT: The Emergency Events Database – Université catholique de Louvain UCL – CRED, – www.emdat.be, Brussels, Belgium

Create a scattergraph

1. Use ordinal numbers to rank the ten countries in table 1.6 by
   (a) number of fatalities between 1996 and 2015
   (b) wealth of country as determined by GDP per person.
2. Rank the hazards in order of highest fatality first, followed by the others. You may decide that some terms are synonymous or go together.
3. What patterns or trends can you identify just by looking at the data?
4. What hazard stands out as being most lethal?
5. What atmospheric hazard is the biggest killer?
6. Is there an irregularity in the list of hazards you may not have expected? Explain.
7. Construct a scattergraph by plotting GDP per capita on the x-axis and fatalities on the y-axis.
8. Draw in a line of best fit and determine the correlation (positive or negative). Are there any anomalies? Suggest reasons to explain the correlation or anomalies.

Resources

Video eLesson: Constructing and interpreting a scattergraph (eles-1756)
Interactivity: Constructing and interpreting a scattergraph (int-3364)