Summary: Reason's Swiss Cheese Model of disaster causation

The Swiss Cheese Model of disaster causation is also known as the *cumulative act effect model* (Figure 2.19) and is widely used in risk management and analysis, especially by the aviation industry. This industry in particular is very conscious of safety so there are many barriers put in place to minimise accidents – the idea of layered security or duplicate back-up systems. In the model the layers of cheese represent these safety systems and the holes the weaknesses in each line of defence. J. Reason, the developer of the model, argued that an accident occurs when all the holes line up in a single trajectory.

So, in natural hazards science, a disaster is thought to occur as a result of a series of coincidental events and processes. It highlights the fact that a particular disaster can be linked to a single hazard event, but then there is a cascade of other events (possibly through the 'holes') that provide a context for the hazard. Generally the hazard becomes a disaster when several holes line up (a trajectory of accident opportunity), which creates the conditions for loss of life, property and livelihood.

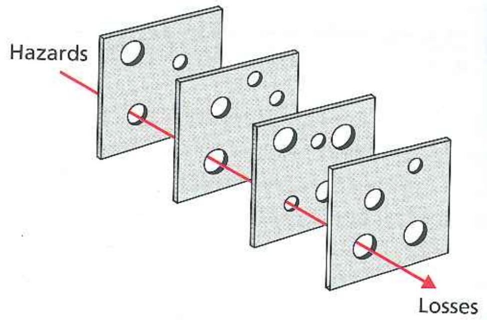

Figure 2.19 Reason's Swiss Cheese Model applied to hazards and disasters

Review questions

1 Explain how a natural hazard can become a disaster.

2 What is the difference between high- and low-resilience communities? Support your answer with examples.

3 How does the PAR Model help us to understand more about vulnerability hazard impact?

4 Explain how the social and economic impacts of tectonic hazards might affect people, the economy and the environment in different parts of the world.

5 Explain how unsustainable development rebalances the risk equation. Give examples of places and regions where you think this is happening.

6 Examine the most important root causes in the PAR Model.

7 Summarise the places globally where there are the highest degrees of vulnerability and state why, grouping into social, economic and political.

Further research

Research data from the International Disaster Database to investigate patterns and trends, and to look for links between magnitude of events, deaths and economic damage: www.emdat.be

Use International Red Cross World Disasters Reports to compare hazard impacts (loss of life, numbers affected and so on) between hazard types and regions: www.ifrc.org/en/publications-and-reports/world-disasters-report/world-disasters-report

Find out more about the role of UNISDR and what it does: www.unisdr.org

Research the most significant earthquakes in the last 30 days using the USGS website. If possible use GIS to show their distribution and then add a layer to show vulnerability in terms of wealth: http://earthquake.usgs.gov

Munich Re is a Swiss re-insurer. Research its connection to natural hazards online.

Research different tectonic hazard events in areas of varying development and explain the ways in which the context of each disaster is different.

3 Management of tectonic hazards and disasters

How successful is the management of tectonic hazards and disasters?

By the end of this chapter you should:

- understand the complex trends in disasters over time and how some disasters can become mega-events and have impacts over a very wide geographical area
- recognise the hazard models and frameworks that can be used to understand the prediction, impact and management of hazards
- know how tectonic hazard impacts can be managed through a range of mitigation and adaptation strategies which have varying successes.

It is worth remembering that seismic tectonic and volcanic processes cannot be prevented, and it's unlikely that they ever will be. Yet we have found out that the risks seem to be increasing for many people, especially those in the middle income and poorest groups. This increase in hazard vulnerability is mostly due to human factors rather than physical factors, as the trends in tectonic hazards reveal a pattern that does not indicate a significant increase in the last 50 years. This idea is true but complex and needs additional explanation.

3.1 Understanding tectonic and other disaster trends since 1960

In comparison with other natural hazards, few tectonic hazards manifest themselves into disasters. Figure 3.1, for example, shows that in the period 2004–2014 tectonic hazards had a low occurrence compared to hydrological and meteorological hazards, and also *much lower* numbers of victims compared to the other three hazards (climatological, hydrological and meteorological).

A look at the overall patterns

The overall longer-term natural hazard trends, since about 1960, show a number of key points:

- The total (aggregate) number of recorded hazards has increased over the last 50 years.
- The number of reported disasters seems to be falling, having peaked in the early 2000s (but that appears to be an anomaly to the longer-term trend).
- Number of deaths is also lower than in the recent past, but there are spikes with mega-events.

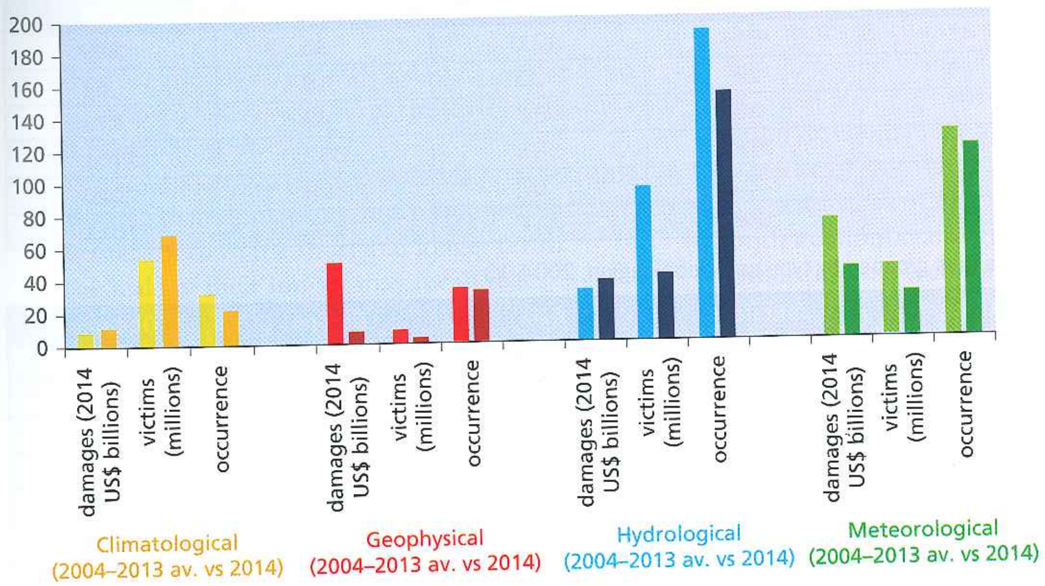

Figure 3.1 Natural hazards, 2004–14 (Source: CRED Annual Disaster Statistical Review 2014: The numbers and trends. http://cred.be/sites/default/files/ADSR_2014.pdf)

- The total number of people affected is increasing for some hazard and disaster types, especially meteorological and hydrological (Figure 3.2).
- The economic costs associated with both hazards and disasters of all types have increased significantly since 1960.

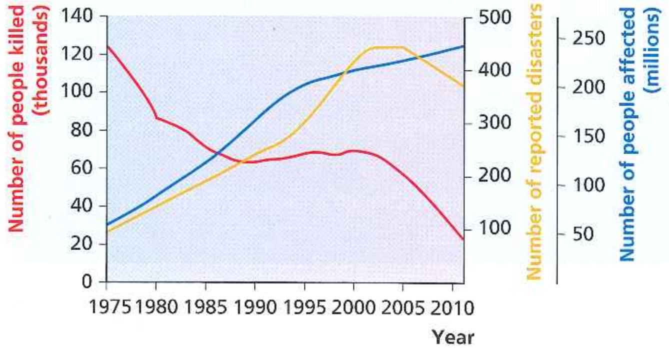

Figure 3.2 Natural disaster trends (all types), 1975–2011

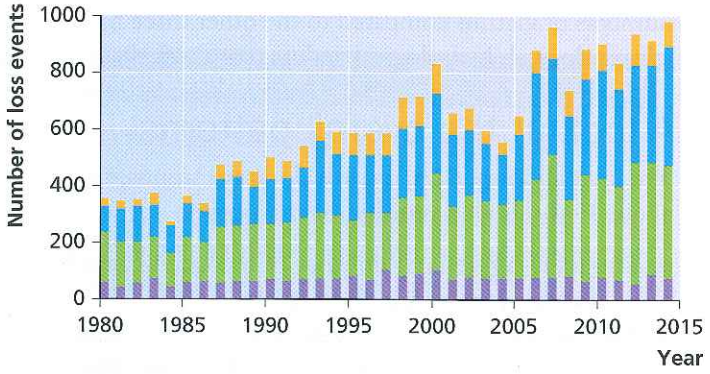

Figure 3.3 Number of hazard loss events (all types), 1980–2014

Note that tectonics (purple) remains stable compared to the other types, especially meteorological and hydrological, which appear to be increasing

But trends relating to tectonic (geophysical) hazards only show a *different* overall trend, one which is much more stable in terms of the number of events (Figure 3.3). However, somewhat hidden within that overall pattern is one that shows that the number of people affected and number of deaths does vary considerably year on year.

Spatial variation of tectonic disasters

Another important aspect of disaster geography is the spatial variation of tectonic impacts. It is wrong to assume that the locations of hazard impacts always translate into simple distributions. Data from the Centre for Research on the Epidemiology of Disasters (CRED) and the International Red Cross shows that the number of disasters reveals a complex pattern when either viewed by world region or by level of development.

Table 3.1 Total number of reported disasters grouped by type and level of economic development, 2004–13

	Very high human development	High human development	Medium human development	Low human development	Total
Earthquakes/tsunami	41	71	121	36	269
Volcanoes	5	12	30	10	57
Mass movements	7	33	84	49	173
Floods	237	378	585	552	1751
Droughts	14	25	57	129	225
Windstorms	384	146	347	134	1011

Table 3.2 Total number of reported disasters grouped by type and global region, 2004–13

	Africa	Americas	Asia	Europe	Oceania
Earthquakes/tsunami	18	39	174	27	11
Volcanoes	5	20	22	1	9
Mass movements	12	34	115	8	4
Floods	443	343	702	215	49
Droughts	124	51	37	9	4
Windstorms	82	336	400	139	54
Total	684	823	1450	399	131

How good are disaster statistics?

There is neither a universally agreed definition of a disaster nor a universally agreed numerical threshold for disaster designation. Reporting disaster impacts, especially deaths, is therefore controversial for a number of reasons:

1. It depends on whether direct (primary) deaths or indirect (secondary) deaths from subsequent hazards or associated diseases are counted.
2. Location is significant because local or regional events in remote places are often under-recorded.
3. Declaration of disaster deaths and casualties may be subject to political bias. The 2004 Asian tsunami was almost completely ignored in Myanmar but perhaps initially overstated in parts of Thailand, where foreign tourists were killed, and then played down to protect the Thai tourist industry.
4. Statistics on major disasters are difficult to collect, particularly in remote rural areas of low human development countries (LHDs), for example the earthquake in Kashmir in 2005, or in densely populated squatter settlements, for example the Caracas landslides in 2003–2004.
5. Time-trend analysis (interpreting historical data to produce trends) is difficult. Much depends on the intervals selected and whether the means of data collection have remained constant. Trends (deaths, numbers affected, economic impacts) can be upset by a cluster of mega-disasters, as happened in the 2004 Asian tsunami or the 2011 Haiti earthquake, or even in the 2015 Kathmandu earthquake.

Tectonic mega-disasters

Tectonic mega-disasters have several key characteristics:

- They are usually large-scale disasters on either an aerial/spatial scale or in terms of their economic and/or human impact.
- Because of their scale, they pose serious problems for effective management to minimise the impact of the disaster (both in the short and longer term).
- The scale of their impact may mean that communities, but usually government as well, often require international support in the immediate aftermath as well as during longer-term recovery. This may be at a regional level (for example the Asian tsunami of 2004) or globally (for example Japan 2011). These events can affect more than one country either directly or indirectly.

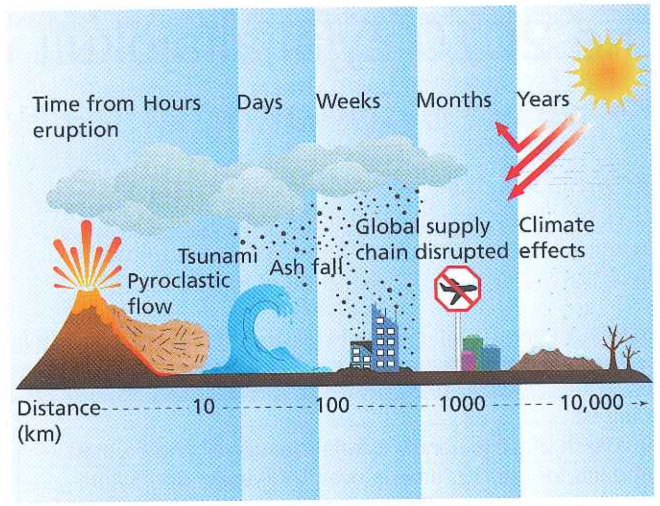

Figure 3.4 Diagrammatic representation of the likely range of impacts following a large VEI 6 (or above) eruption

Figure 3.4 illustrates how a large volcano, for example, can have significant impacts in both time and space.

Tectonic mega-events and disasters are often classified as high-impact, low-probability (HILP) events. So, one-off high-profile crises such as the 2010 Haiti earthquake and the 2011 Japanese earthquake and tsunami were all mega-disasters requiring rapid responses at a global level. But known hazards such as earthquakes and volcanoes (as well as floods and hurricanes), which, owing to the low likelihood of occurrence or the high cost of mitigating action, often remain ill- or under-prepared for in many parts of the world. These events are impossible to predict but very likely to occur over long time scales.

The globalisation of production and supply chains has increased manufacturing efficiencies, but it has also reduced resilience in the case of some events. High-value manufacturing is often most at risk because of its just-in-time (JIT) business model. The consequences of HILP events spread rapidly across both economic and geographic boundaries, creating other impacts (economists might call these negative externalities) that are difficult to plan for. The Japanese earthquake in 2011, for example, led to a five per cent reduction in the country's GDP. There were much wider knock-on impacts for global transnational corporations (TNCs) however, such as Toyota and Sony, which were forced to halt production.

The 2010 Eyjafjallajökull volcano and 2011 Japanese Tohoku tsunami

Two examples of significant tectonic events in recent years are the Iceland Eyjafjallajökull eruption in 2010 and the Japanese tsunami mega-disaster of 2011. They both had significant, but different, impacts at a global scale. Table 3.3 considers the effects on the global supply chain (Eyjafjallajökull) as well as the wider concerns about nuclear power (Tohoku).

Table 3.3 Context and impacts of two recent high-profile tectonic events

Eyjafjallajökull, Iceland	Tohoku tsunami, Japan
Context In March 2010 Iceland's Eyjafjallajökull volcano erupted into life for the first time in over 190 years. By 15 April 2010 the ash plume generated from the eruption had begun to affect much of Europe, spreading as far as northern Italy. The ash cloud grounded flights in most of Europe for several days. More than 100,000 air-journeys were cancelled, leading to the worst disruptions in air travel since the 9/11 terrorist attack in 2001. However, this was a relatively small eruption 'in the wrong place', with no direct deaths. It was high profile due to the impact on the air movements (passenger and freight).	**Context** A magnitude 9.0 earthquake in March 2011 produced a great tsunami that wreaked destruction along the Tohoku (eastern) coast of Japan, including to the Fukushima nuclear power station. It was the largest earthquake recorded in Japan and the combined impacts of the earthquake and tsunami left 15,749 dead and 3962 missing; 63 per cent of the dead were aged 60 and over. The event eroded public trust in the Japanese government and its nuclear energy policies. This was a very large magnitude event causing widespread deaths and large-scale destruction along the coast to properties, infrastructure and communities. It was particularly high profile because of the nuclear impact.
Evaluating the 2010 volcano's effect on the global supply chain Imports and exports in and out of Europe were greatly affected by the air travel shutdown in 2010. Although airfreight accounts for a tiny amount of world trade by weight, it accounts for a much higher proportion of trade by value. For example, airfreight accounts for approximately 0.5 per cent of UK trade by weight but a much bigger 25 per cent of trade by value. **Example 1: Car manufacturing disruption** The disruption to airfreight by the eruption highlighted how important airfreight is in supplying high-value key components to many manufacturers. The Nissan plant in Japan, for example, had to stop production of the Cube, Murano SUV and Rogue crossover models because they ran out of a critical sensor produced in Ireland. Airfreight is only used for a small quantity of high-value but vital electronic components where there are few alternative suppliers. **Example 2: Impacts on the transport of perishable goods** There were impacts on the producers of flowers, fruit and vegetables in African countries such as Kenya, Zambia and Ghana, with delays in transportation meaning large quantities of fast-perishing produce rotted, leading to losses for producers. The World Bank estimated that, in total, African countries may have lost US$65 million due to the effect of the airspace shutdown on perishable exports.	**Evaluating the earthquake and tsunami's impact on costs and attitudes to nuclear energy** The tsunami hit the Fukushima Daiichi nuclear power plant on the east coast of the island of Honshu, about 200 km northeast of Tokyo, and disabled the power supply. This affected the cooling of three reactors, causing high radioactive releases. Contaminated water leaked from the plant into the Pacific Ocean and into fishing grounds. The effects of the accident on energy security were not restricted to Japan. **Example 1: LNG price rises** The worldwide availability and affordability of liquefied natural gas (LNG) were affected by Japan's increased demand. This had the biggest impact in the Asian market, where they had the quickest rate of increasing energy consumption. **Example 2: Public acceptability of nuclear power and rising costs** The accident itself resulted in the loss of public acceptability of nuclear power and led countries, such as Germany and Italy to immediately shutdown some of their nuclear reactors or abandon plans to build new ones. The accident has also contributed to the escalating capital costs associated with the construction of new nuclear reactors because of the additional safety measures required.

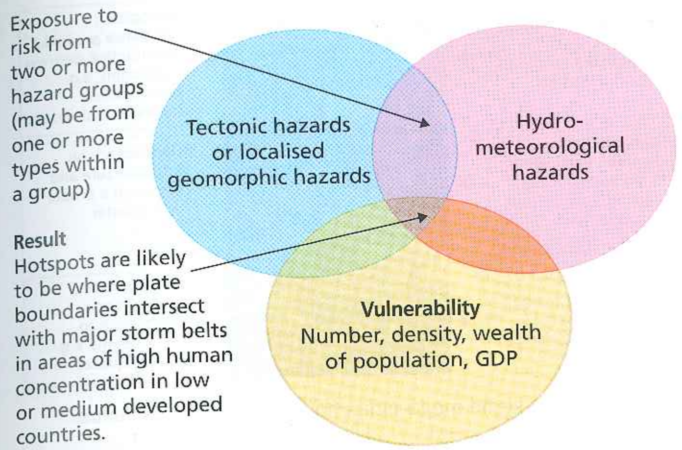

Figure 3.5 The characteristics of a hazard hotspot

Multiple-hazard zones

Multiple-hazard zones are places where a number of physical hazards combine to create an increased level of risk for the country and its population. This is often made worse if the country's population is vulnerable (wealth/GDP, population density, and so on) or suffers repeated events, often on an annual basis, so that there is never any time for an extended period of recovery. Such places are often seen as **disaster hotspots**.

Hazards in multiple-hazard zones are, in fact, part of a wider picture of more complex geography linked to vulnerability over both space and time. This often makes their impact greater and more challenging to manage. The magnitude of the hazard event together with the human geography of the area in which it occurs are important factors, but hazards generally form part of a much more complex web of socio-economic-environmental issues that makes the impact greater and harder to manage. Table 3.4 lists the countries that are most exposed to multiple hazards globally. Figure 3.6 is a global summary of the multiple-hazard pattern.

Table 3.4 The countries most exposed to multiple hazards (Source: International Red Cross World Disasters Report www.ifrc.org/Global/Documents/Secretariat/201410/WDR%202014.pdf)

Country	Total area exposed (%)	Population exposed (%)	Number of different hazards the country is exposed to
Taiwan	73.1	73.1	4
Costa Rica	36.8	41.1	4
Vanuatu	28.8	20.5	3
Philippines	22.3	36.4	5
Guatemala	21.3	40.8	5
Ecuador	13.9	23.9	5
Chile	12.9	54.0	4
Japan	10.5	15.3	4

Key term

Disaster hotspot: A country or area that is extremely disaster prone for a number of reasons, as shown in Figure 3.5.

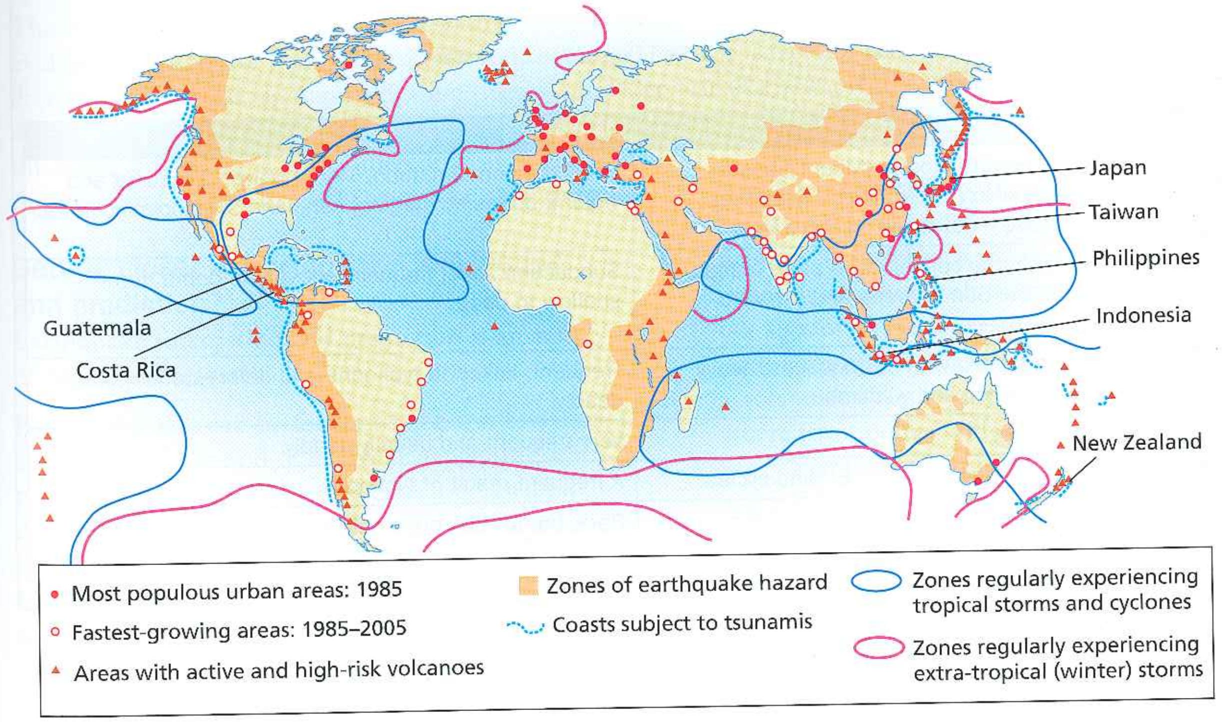

Figure 3.6 Global summary of the multiple-hazard pattern

There may also be variation in disaster risk within smaller geographical areas. Large urban areas are often zones of multiple-hazard risk (Figure 3.7). Cities are centres of economic development (economic cores) as they represent a natural focus for investment and development. They are also frequently centres of growing population as a result of the rapid urbanisation occurring in most developing countries. Many cities have huge areas of unplanned, poor-quality housing where growing numbers of the urban poor live, often located on marginal, potentially dangerous sites such as river banks and steep slopes.

Analysis of the global distribution of these rapidly growing mega-cities shows that many of them are located in hazard-prone areas. With such high densities of people, up to 25,000 per km^2, hazard management in large urban areas is both expensive and complex, making disasters inevitable, both socially (high concentration of vulnerable people) and economically (for example, loss of infrastructure).

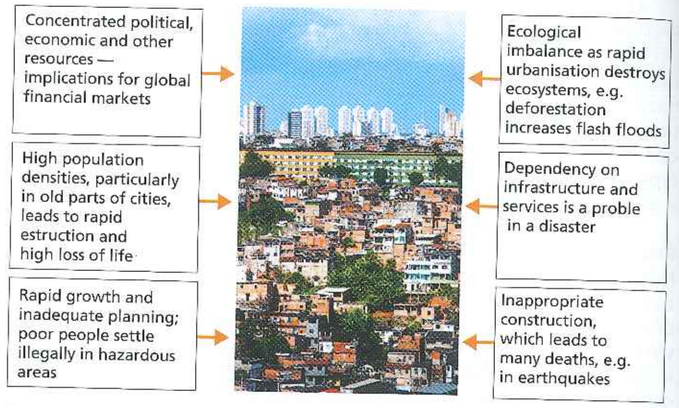

Figure 3.7 Why some mega-cities have low hazard resilience

Comparing the Philippines and California – classic multiple-hazard geography

There is a tendency to assume that all hazards occur in both places, and that the hazards may have the same root causes. In the Philippines, the main risk is typhoons with typically five or six storms a year as it lies on a major storm track. Annual deaths far exceed the long-term average for California (the last time more than 100 people died in a Californian natural disaster was the 1933 Long Beach earthquake). The Philippines has to spend around two per cent of its annual GDP cleaning up after typhoons. Table 3.5 summarises the hazard similarities and differences.

Table 3.5 Hazard similarities and differences (Source: International Red Cross World Disasters Report www.ifrc.org/Global/Documents/Secretariat/201410/WDR%202014.pdf)

	Californian coast	Philippines
Volcanoes	Rarely in northern California (Mount Shasta, Lassen Peak), which is part of the Cascades subduction zone – not really on the coast.	Very common; Pinatubo, Mount Mayon. Frequent and violent; andesitic magma, ash, lahars, pyroclastic flows.
Earthquakes	Frequent, within the conservative plate margin that includes the San Andreas and Hayward faults; usually shallow.	Subduction zone; frequent but vary in depth from shallow to deep.
Landslides	Frequent; associated with earthquakes, heavy rain, coastal erosion and wildfires.	Frequent; linked to typhoons and deforestation; often deadly.
Cyclones	Never occur here.	Very frequent and usually deadly.
Flood	Rarely; can be associated with El Niño cycles.	A frequent result of typhoons.
Drought	Very common, e.g. 2008–11 and 2012–15.	Rare, but El Niño does cause these, e.g. 1999 and 2010.

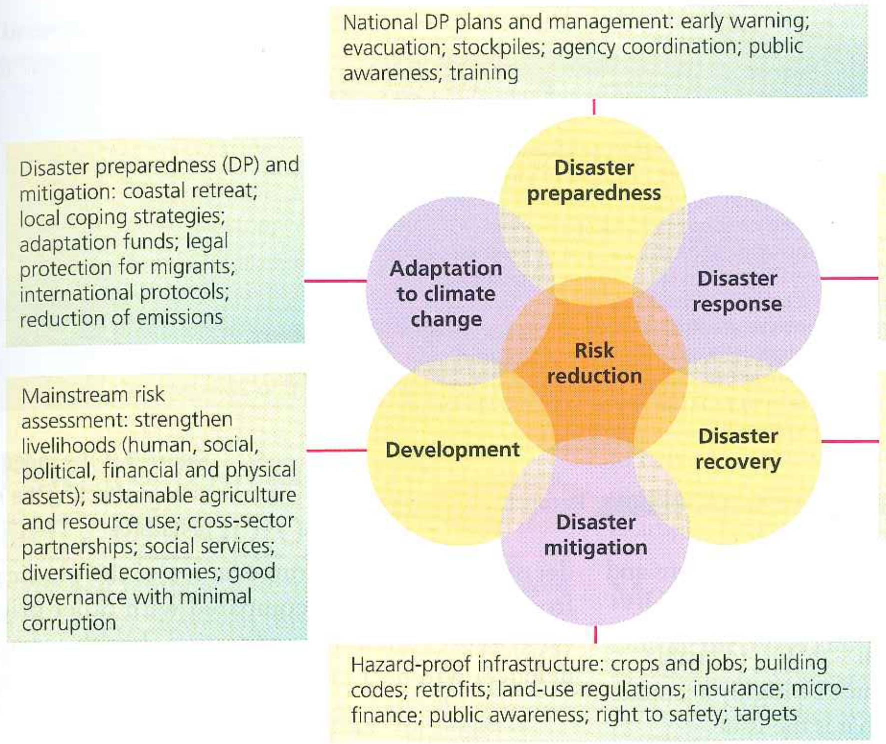

Figure 3.8 The risk disk – a model to help better understand disaster management

3.2 Managing tectonic hazards

Prediction and forecasting frameworks

The 'risk disc' (Figure 3.8) is one model that attempts to explain the reasons for the decline in deaths in terms of disaster preparedness, disaster mitigation (hazard proofing), disaster response and disaster recovery. The next section of this book will examine these different areas, together with the associated models that help to explain their purpose.

Getting closer to earthquake forecasting and prediction?

Earthquake forecasting and prediction is an active topic of geological research.

Earthquake risk can be forecast since it is based on a statistical likelihood of an event happening at a particular location. These forecasts are based on data and evidence gathered through global seismic monitoring networks, as well as from historical records. Long-term forecasts (years to decades) are currently much more reliable than short- to medium-term forecasts (days to months). Forecasting is very important as it can encourage governments to enforce better building regulations in areas of high stress, or create improved evacuation procedures in areas of highest risk.

Currently it is not possible to make accurate predictions of when and where earthquakes will happen. For this to be possible, it would be necessary to identify a 'diagnostic precursor' – a characteristic pattern of seismic activity or some other physical, chemical or biological change – which would indicate a high probability of an earthquake happening in a small window of space and time. So far, the search for diagnostic precursors has been unsuccessful.

Some geophysicists are trying to improve prediction based on calculating the underground movement of magma. Their models try to predict where the plates are running together with the most stresses, often a tell-tale sign of where an earthquake might hit. They map underground patterns of activity in the Earth's mantle across underground grid points. The models then predict where stress points will occur by simulating different rocky mantle flows. The calculations can ascertain where, as a result of these flows, the plates are likely to run together, and automatically detect these stressed zones.

Such models are still in their infancy and need considerable refinement as the link between earthquakes and underground mantle flows is complex and hard to model. Other scientists are working on predicting earthquakes

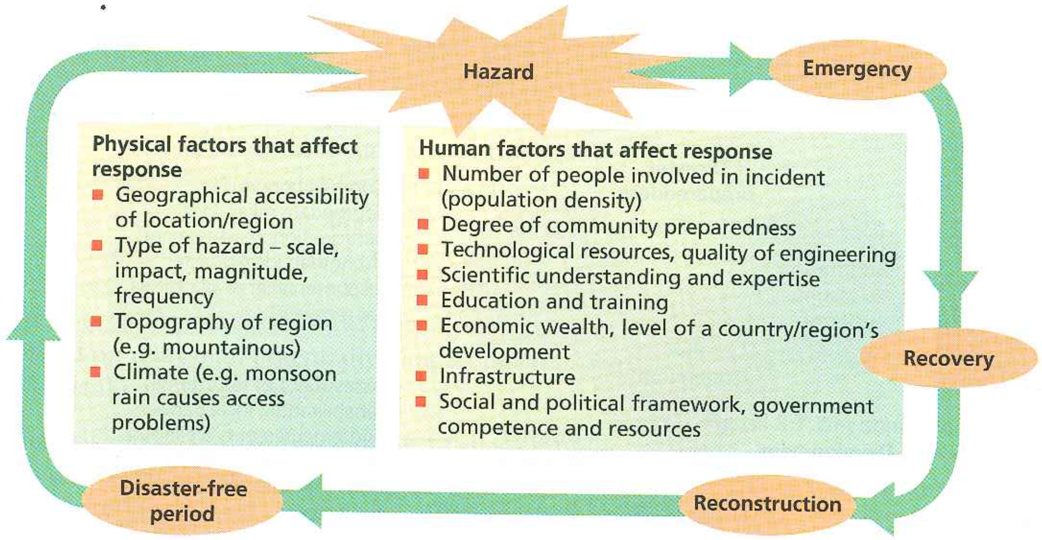

Figure 3.9 The range of factors affecting the response to hazards

based on animal behaviours, changes in radon emissions and electromagnetic variation, but with very limited success.

However, for predictions to be useful – that is, to enable evacuation of affected areas – they must be highly accurate, both spatially and temporally. And that is the issue. At present the science makes this impossible and most geoscientists do not believe that there is a realistic prospect of accurate prediction in the foreseeable future. They suggest that the main focus of research instead should be based on improving the forecasting of earthquakes.

Understanding the hazard management cycle

Figure 3.9 shows how the choice of response depends on a complex and interlinked range of physical and human factors. As people, communities and organisations have limited resources and time to make decisions, the relative importance of the physical risk from natural hazards, compared with other priorities (such as providing jobs, education, health services and defence) will be a major factor in influencing how resources are devoted to reducing hazard impacts.

Park's Model and levels of development

Park's Disaster Response Curve (1991) (Figure 3.10) can be used as a framework to help better understand the time dimensions of resilience: from a hazard striking to when a place, community or country returns to normal operation.

Each stage on the *x*-axis shows the different stages of time during which either relief, rehabilitation or reconstruction is started. The words on the *y*-axis describe quality of life, stability and infrastructure.

The model can be used to help plan and understand risk and resilience, as well as to better prepare for future events, for example through modification of the responses to the event.

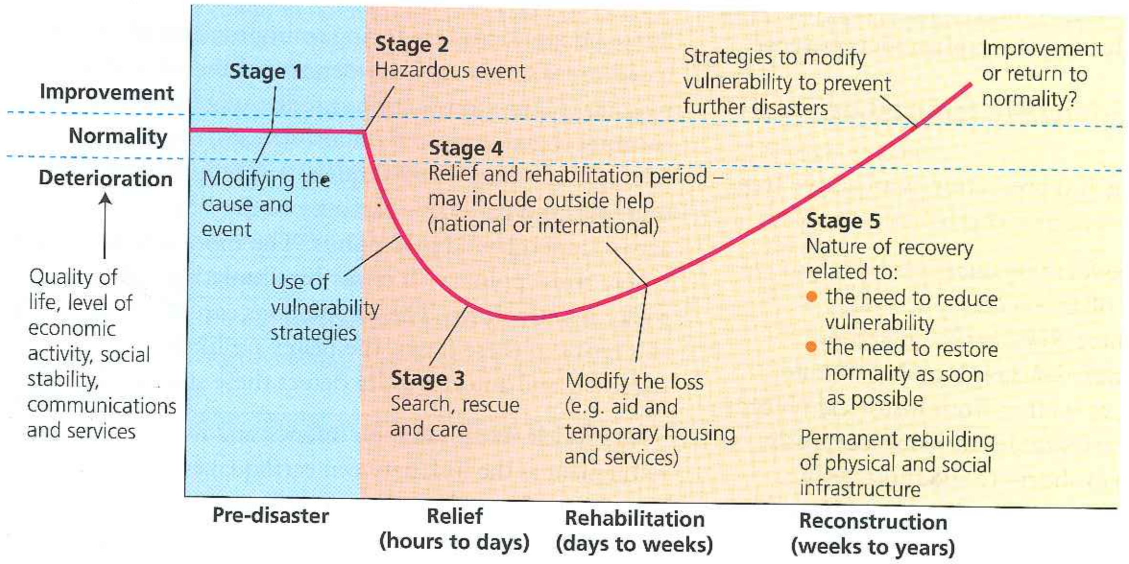

Figure 3.10 Park's Model – the Disaster Response Curve

Table 3.6 Understanding the stages in the Disaster Response Curve

Pre-disaster	Quality of life is normal before a disaster strikes; people do their best to prevent and prepare for such events happening, for example by educating the public on how to act when disaster strikes, preparing supplies, putting medical teams on standby, and so on.
Relief	The hazard event has occurred – immediate relief is the priority with medical attention, rescue services and emergency care provided. This period of time can last from hours to a number of days. The quality of life has seemingly stopped decreasing and is beginning to move up slowly.
Rehabilitation	Groups (for example, the government) try to return the state of things back to normal, by providing food, water and shelter to those who are without these basic needs.
Reconstruction	In the longer term rehabilitation moves into the reconstruction period during which infrastructure, crops and property are invested in. During this time organisations may use preparation and prevention to improve from the mistakes of this disaster to respond better to the next one.

3.3 Hazard management: a variety of approaches

In theory, the best response to tectonic hazards is to avoid all danger. In reality, however, this is impossible because of the conflicting development pressures on land. Hazard management is, therefore, always a series of imperfect solutions. The Swiss Cheese Model (page 28) suggests that hazard and disaster risk can be reduced by:

1 reducing the number of holes in each layer (that is, the number of systemic weaknesses), or,
2 reducing the size of the holes in each layer (that is, the 'gaps' in the system, or the scale of the system weaknesses).

A better understanding of the complexity of tectonic risk through systematic analysis is important. The Swiss Cheese Model, for example, provides a framework for tectonic hazard management which links a number of areas. These include where possible:

- modifying the hazard event
- modifying vulnerability and resilience (at an individual, community and country scale)
- modifying the loss (a component of resilience).

It is important to develop a number of frameworks when taking an overview of hazard events and their ability to develop into disasters so that descriptive accounts of suffering and damage are avoided. Figure 3.11, for example, provides a framework for response analysis.

Modifying the hazard event

During the 1970s and 1980s there was a general feeling that the technological capability and engineering skills to control earthquakes would soon be developed, for example by lubricating the fault plates. But it is now realised that seismic activity cannot be controlled, so efforts instead focus on science and civil engineering solutions to reduce the hazard by either *micro* or *macro* protection techniques:

- Micro: strengthening individual buildings and structures against hazardous stress.
- Macro: large-scale protective measures designed to protect whole communities.

Earthquakes

Micro approaches are generally used in the case of tectonic hazards. For earthquakes, most energy has been focused on public buildings and facilities, especially those expected to remain operational during a disaster: hospitals, police stations and pipelines. Schools and factories were also strengthened so that people could shelter in them. More recently there has been a shift towards improving the planning

Figure 3.11 A framework for response analysis

Figure 3.12 Mangroves may provide an important coastal buffer both against rising sea levels and tsunamis

frameworks for private houses. Some authorities insist on the strengthening (or demolition) of existing hazardous buildings through a retrofit programme.

Tsunamis

No technologies can prevent tectonic disturbance but some regions and communities have put engineering solutions in place, for example tsunami walls that work for a given amplitude or threshold of wave. Research shows that replanting of coasts (Figure 3.12) may be a way of affording better protection and therefore modification of the event. In the great Asian tsunami of 2004, for example, science has indicated that fewer people might have died if coasts had been protected by mangroves or other types of dense coastal forest.

Yet there is still considerable debate as to the effectiveness of these so-called buffer zones. Mangroves are known to be effective at dissipating energy from waves whipped up by the wind. Modelling studies also suggest that shore vegetation can reduce the flow speed and height of an oncoming tsunami, but there is limited field evidence to back this claim up.

Volcanoes

In some instances it may be possible to modify a volcanic event once the eruption and lava flows have started, either by diverting or chilling the flows. The 1973 volcanic eruption on the island of Heimaey, off the southwest coast of Iceland, threatened to destroy a whole community (Figure 3.13). Seventy homes and farms were buried under tephra and 300 buildings were burned by fires or buried under lava flows.

The lava flow was heading towards the fishing port and harbour – the economic lifeline of the island. Loss of the harbour would have resulted in financial ruin for the community. The Icelanders sprayed seawater on to the lava to slow its movement by chilling. More than 30 km of pipe pumped 6 million cubic metres of water on to the flows. The effort saved the port and the residents returned to rebuild their town.

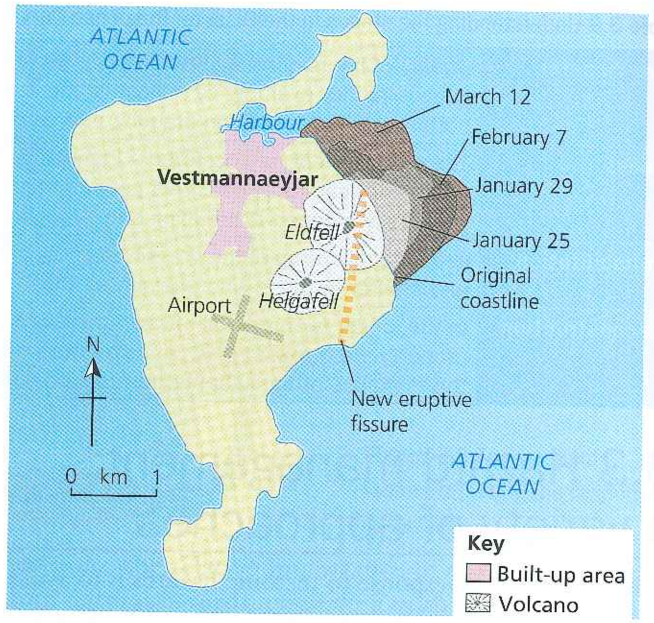

Figure 3.13 The classic 1973 volcanic eruption 'timeline' on the Icelandic island of Heimaey

Modifying vulnerability and resilience

Modification of the hazard event, as shown in Figure 3.11, can involve a number of approaches and adaptations including:

- prediction, forecasting and warnings
- improvements in community preparedness
- working with groups and individuals to change behaviours (to reduce the disaster risk), for example, better land-use planning.

With the advent of better technology, prediction, forecasting and warning are becoming increasingly important parts of disaster preparation and management. For example, a tsunami warning system (TWS) is used to detect tsunamis in advance and issue warnings to prevent loss of life and damage to movable possessions. It is made up of two components: a network of sensors to detect tsunamis and a communications infrastructure to quickly issue alerts to allow evacuation of the coastal areas.

Adaptation and preparedness is essential to ensure an effective response to disaster. It usually involves the planning and testing of hazard reduction systems on timescales that may operate from seconds (for example, tsunami warnings) to years (for example, improvements in land-use planning and zoning).

One of the complexities with adaptation and increasing resilience is the fact that there are a range of interest groups that have some role to play in modification of vulnerability (Figure 3.14).

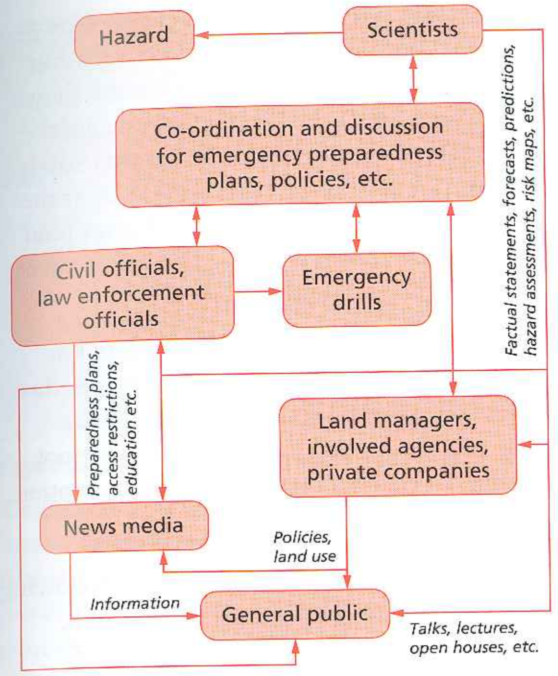

Figure 3.14 Interest groups that have roles to play in modification of vulnerability

Governance, for example, is important but it has limitations in terms of the affordability of prediction and prevention measures, especially in the management of mega-disasters immediately after the event. This means that other factors such as poverty may hamper any top-down efforts to reduce impact and adapt.

Volcanoes: a hazard vulnerability success story?

Volcanologists have an advantage over seismologists in that volcanoes usually do not erupt without warning. The warning signs typically take the form of numerous small earthquakes and a swelling of the ground surface, which reflect the passage of magma to the surface. But it is difficult to predict exactly when activity will take place, especially the timing of a major eruption. Technology in the form of a network of sensors is now being used to help predict eruptions and allow more sophisticated modelling to be undertaken. Monitoring may give time for the area under threat to be evacuated.

Looking at data on deaths, the volcanic hazard threat seems to have been successfully mitigated: only two eruptions since 1980 have caused more than 1000 deaths. Eruptions still affect large numbers of people but prediction and evacuation have reduced the death toll enormously.

An exception to this is was the Mount Ontake eruption in Japan on 27 September 2014. It is a popular area with hikers and walkers, who became the victims. There was no warning and the VEI 3 eruption killed 56 people, the first deaths in Japan from eruptions since 1991 (Mount Unzen). It was the highest death toll from an eruption in Japan since 1902.

Science to reduce earthquake vulnerability

Following the 1995 Kobe earthquake in Japan, the National Research Institute for Earth Science and Disaster Prevention (NIED) deployed 1000 strong-motion accelerometers throughout the country. This is the Kyoshin Network, or K-NET. The average distance between stations is 25 km. During an earthquake, primary and secondary wave velocities are measured at each site and logged. Data is then sent to the local municipality (via the internet). The municipality can use the information for local emergency management and response.

Figure 3.15 shows how the UN World Food Programme uses a range of strategies and players to modify loss and vulnerability. Importantly, new technology and communication, for example social media such as Facebook and Twitter, are used to help people adapt and improve their resilience.

So, adaptation is really about modifying resilience, which is a measure of how well an individual, community or country might absorb and recover from a hazard. This approach to disaster reduction is seen as very important nowadays, especially in the world's poorer communities where the disaster focus had traditionally been on seeing people as vulnerable victims and therefore recipients of external support (a 'top-down' model).

Now attention is focusing on supporting affected communities to prepare and manage themselves, and strengthening this local capability before, during and after a hazard event.

Modifying the loss

Mitigation is about modification of the loss burden. Insurance to cover the cost of earthquake damage, for example, is an important part of wider earthquake protection. Seismologists work with computer risk analysts to help the insurance industry calculate premiums and risks. Computer simulations are used to estimate the probability of damage from different earthquake events, based on:

- seismicity: the raw information about how frequently earthquakes affect a particular location
- seismic hazard: the probability that a certain strength of shaking will occur
- seismic risk: the probability that a certain amount of risk will occur.

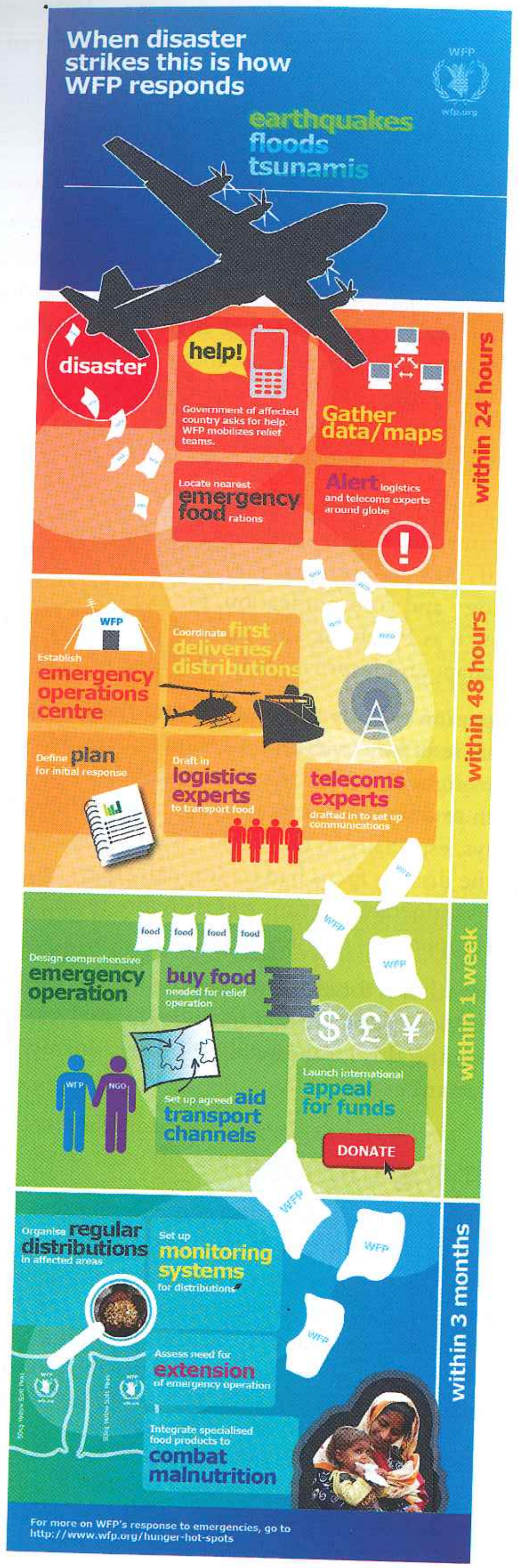

Figure 3.15 Response to hazards – the stages over time

Figure 3.16 shows that, since 1980, Japan's earthquakes (1995, 2004 and 2011) have been costly, with a total cost of over $280 billion. Other tectonic events are also shown to be expensive. Since 2000, the UNISDR estimates the total economic cost of all disasters to be approximately $1.3 trillion. Even in developed economies such as the USA and Japan, insured losses for tectonic events tend to be relatively low, at approximately 25 to 30 per cent, meaning many people are unprotected.

Most insurance policies provide cover for property loss caused by a volcanic blast, airborne shock waves, ash, dust or lava flow. Fire or explosion resulting from volcanic eruption is also usually covered, however some may not cover shock waves or tremors caused by volcanic eruption.

Disaster aid and internal governmental aid

Disaster aid is the result of humanitarian concern following severe loss. This aid is all about protecting life, health, subsistence and a person's physical security. Table 3.7 compares disaster aid and internal governmental aid.

Disaster aid is often criticised, however: there may be poor or corrupt distributions systems, and it doesn't encourage self-help or a more bottom-up management of the disaster at a local level. In the 2010 Haiti earthquake the Nepalese disaster relief workers were implicated in the introduction of cholera – see Chapter 2, page 22.

A complex risk environment

Despite considerable efforts to improve scientific understanding and better risk-management approaches, in general governments and businesses remain insufficiently prepared to confront many tectonic hazards and effectively manage their economic, social, political and humanitarian consequences. This is often true irrespective of a country's level of development. In certain high-threshold events, governments are the responders of last resort, but they may not have the resources or technical expertise to deal with such events.

Table 3.7 Disaster aid compared to internal governmental aid

Disaster aid	Internal governmental aid
Aid flows to countries and victims via governments, NGOs and private donors. In the longer term aid is used for relief, rehabilitation and reconstruction. This type of aid is often appropriate to middle- and lower-income countries.	This is typically used in emerging and developing countries where the disaster mitigation is achieved by spreading the financial load throughout the tax payers of the country. This may include a national disaster fund and release of funds may require a political declaration.

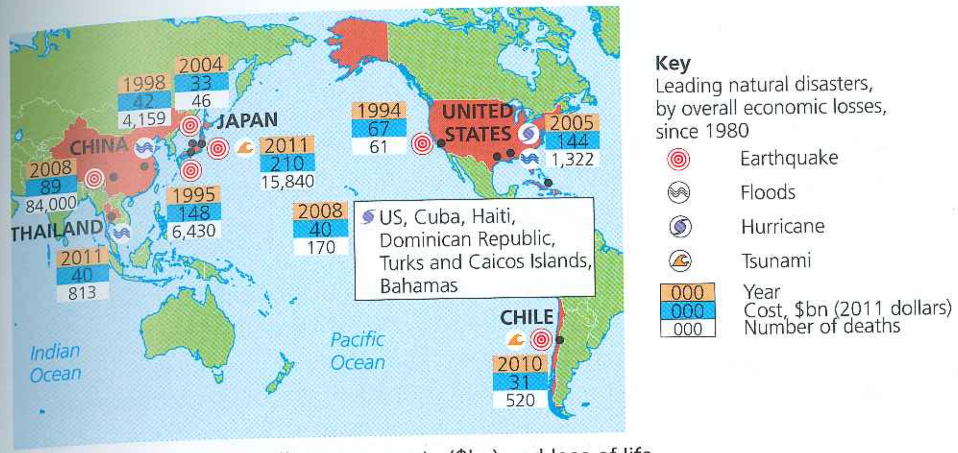

Figure 3.16 Major natural disasters – costs ($bn) and loss of life

To get the right balance between planning for specific 'known' events and creating generic responses for events that are rare or unexpected, governments and agencies must strengthen planning processes to anticipate and manage shock events. This includes clarity of process in the chains of command (especially where multi-jurisdictions are involved), activating and connecting independent local experts with policymakers, as well as building common approaches in the management of complex risks.

Hyogo and Sendai approach to disaster management

The World Conference on Disaster Reduction was held in 2005 in Hyogo (Kobe), Japan, and established a 'Framework for Action'. Its aims were to promote a strategic and systematic approach to reducing vulnerability and risks to hazards through building the resilience of nations and communities to disasters.

Review questions

1 Summarise the main trends in tectonic natural hazards in recent decades, including deaths, numbers affected and economic costs.
2 What are the characteristics of a mega-disaster?
3 Outline the spatial variation in disasters by both region and level of economic development.
4 Explain the differences in the modification of hazard events for different tectonic hazards.
5 Compare the hazard management cycle to the Disaster Response Curve.
6 Why is there a complex risk environment?
7 Summarise the reasons why volcanoes pose a much lower disaster risk than they have historically.

Synoptic themes:

Players

NGOs and insurers have a role to play in helping to modify the loss.

This was replaced by the Sendai Framework in March 2015. It set out four priorities:

1 Understanding disaster risk.
2 Strengthening governance to manage disaster risk.
3 Investing in disaster-risk reduction for resilience and enhancing disaster preparedness for effective response.
4 'Build back better' in recovery, rehabilitation and reconstruction.

Importantly the framework emphasised the need to tackle disaster risk reduction and climate change adaptation when setting Sustainable Development Goals, particularly in light of an insufficient focus on risk reduction and resilience in the original Millennium Development Goals (MDGs). There is also a focus on emergency preparedness. In the case of international disaster relief, the framework recognises that distribution is complex, fragmented and disorganised. This is because there are various separate institutions, mechanisms and approaches defining where the funding is directed and how it is spent.

Further research

Research and select a *Credcrunch* relevant to tectonic disasters and develop a case study from its findings: http://cred.be/publications?field_publication_type_tid=66&field_cred_staff_authors_nid=All

Use this link to research and summarise the key points relating to the 2010 Haiti earthquake: www.gfdrr.org/sites/default/files/publication/Haiti_August_2014_Summary.pdf

Research the most expensive tectonic hazards in the last 30 years online. How do tectonic hazards compare to hydrological, meteorological and climatological hazards?

Research the differences between the Hyogo and Sendai approaches to disaster management.

Exam-style questions

AS questions

1. Define what is meant by the term **disaster**. [1]
2. Study Figure 1. State the mode and range of earthquake risk magnitude. [2]
   a. Mode:
   b. Range:
3. Explain **two** reasons how a government might influence a community's resilience. [4]
4. Explain why some earthquakes generate secondary hazards. [6]
5. Assess the factors that contribute to increased impacts from some tectonic hazard events. [12]

A level questions

1. Assess the factors which influence the effectiveness of responses used by different groups of people to cope with tectonic hazards. [12]
2. Assess the physical and human factors which cause some tectonic hazards to have a more disastrous impact than others. [12]
3. Assess the different challenges tectonic activity poses for the communities who experience its effects. [12]
4. Study Table 1. Calculate the mean, median and interquartile range of **property damage** for the earthquake data. [4]

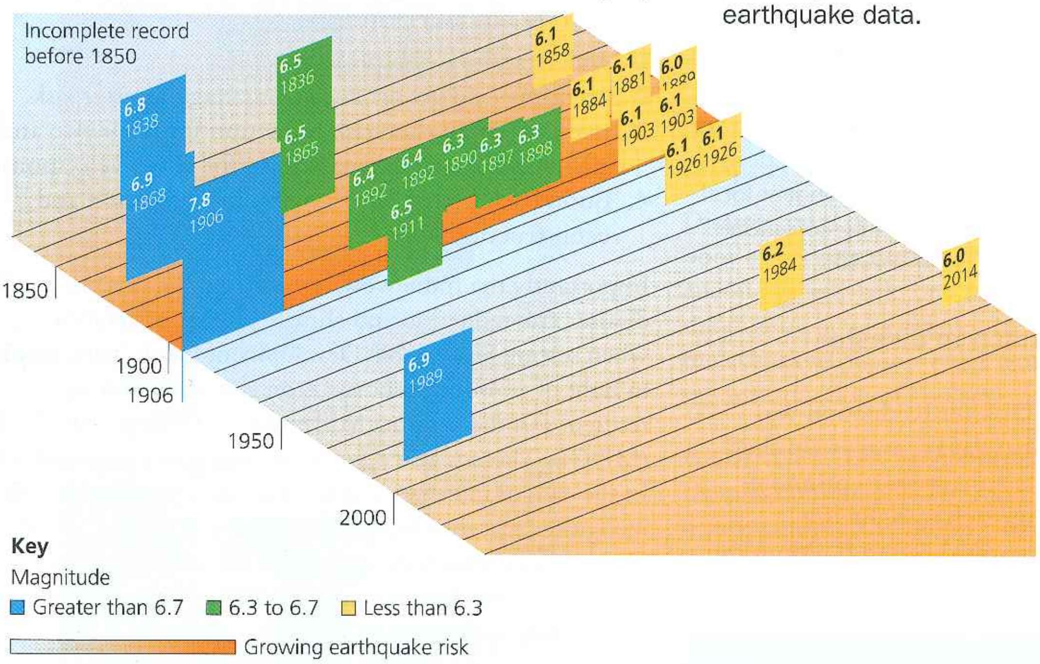

Figure 1 Earthquakes in the San Francisco area since 1850 (Source: Munich Re, based on USGS Earthquake Hazard Program, 2004)

Table 1 Earthquake data

Year	Name	Magnitude	Property damage: $billion (inflation-adjusted)
1923	Great Kanto earthquake	7.9	8
1976	Tangshan earthquake	7.8	42
1989	Loma Preita	7.1	21
1994	Northridge earthquake	6.7	67
1995	Great Hanshin earthquake	6.9	312
1998	Sichuan earthquake	8.0	95
1999	921 earthquake Taiwan	7.6	10
1999	Izmit earthquake	7.6	29
2010	Chile earthquake	8.8	30
2011	Japan earthquake and tsunami	9.0	249
2015	Nepal earthquake	7.8	11