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NATURAL DISASTERS

ELEVENTH EDITION

PATRICK L. ABBOTT

McGraw Hill Education

Natural Disasters

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Patrick L. Abbott
San Diego State University

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About the Author

Patrick L. Abbott Patrick Abbott is a native San Diegan. Pat earned his MA and PhD degrees in geology at the University of Texas at Austin. He benefited greatly from the depth and breadth of the faculty in the Department of Geological Sciences at Austin; this was extended by their requirement to take five additional graduate courses outside the department. Developing interests in many topics helped lead to writing this textbook.

Pat's research has concentrated on the Mesozoic and Cenozoic sedimentary rocks of the southwestern United States and northwestern Mexico. Studies have focused on reading the history stored within the rocks—depositional environments, provenance, paleoclimate, palinspastic reconstructions, and high-energy processes.

Pat has long been involved in presenting Earth knowledge to the public, primarily through TV news. He has produced award winning videos for TV broadcast. He was one of the main cast members in the TV series *The Real Gilligan's Island* on TBS, *Serial Killer Earth* on H2 (The History Channel 2), and *So You Think You'd Survive* on The Weather Channel. During part of each year, Pat works as a Smithsonian lecturer visiting all continents and oceans.

Brief Contents

Contents

CHAPTER 12

Climate Change 314

CHAPTER 13

Floods 351

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Preface

Why Study Natural Disasters?

Natural disasters occur every day and affect the lives of millions of people each year. Many students have been affected by earthquakes or tornadoes or hurricanes or floods or landslides or wildfires or other events. They are interested in lectures that explain these processes, and lively discussions commonly ensue.

During decades of teaching courses at San Diego State University, I found that students have an innate curiosity about "death and destruction"; they want to know why natural disasters occur. Initiation of a Natural Disasters course led to skyrocketing enrollments that exceeded 5,000 students per year. Some of these experiences are described in a *Journal of Geoscience Education* article by Pat Abbott and Ernie Zebrowksi [v 46 (1998), pp. 471–75].

Themes and Approach

This textbook focuses on explaining how the normal processes of the Earth concentrate their energies and deal heavy blows to humans and their structures. The following themes are interwoven throughout the book:

- Energy sources underlying disasters
- Plate tectonics
- Climate change
- Earth processes operating in rock, water, and atmosphere
- Significance of geologic time
- Complexities of multiple variables operating simultaneously
- Detailed and interesting case histories

New to This Edition

- Many of the Tables and Figures have been updated and more than 50 new ones have been added.
- Chapter 1: Extensive updating of all disaster and demographic data.
- Chapter 2: New maps of earthquake epicenters and ocean-floor ages. Expanded coverage of plumes versus hot spots.
- Chapter 3: New figures on seismic-wave velocity and amplitude; house building-code updates, 1971 versus 2017.
- Chapter 4: Expanded text on earthquake swarms. New scenario earthquakes for Hayward fault magnitudes and expected deaths.
- Chapter 5: Expanded text on short-term earthquake predictions and alerts (ShakeAlert) and Canada; animal behavior; wastewater-pumping trigger of earthquakes; Virginia earthquake. Update on L'Aquila earthquake trials of scientists.
- Chapter 6: Significant rewriting; opening compares Kilauea versus Fuego; fractional crystallization; melting of basalt rock; external water and explosions; Yellowstone future eruptions.
- Chapter 7: Added pyroclastic eruption of Eyjafjallajokull and jokulhlaup in 2010; viscous magma stored as crystal mush too cool to erupt.
- Chapter 8: Fukushima Daiichi radioactivity clean up five years later; new photo of tsunami chasing tourists out of the ocean.
- Chapter 9: Expanded discussions of convection and conduction; vertical air motions; new line art on wind origin.
- Chapter 10: Updated billion-dollar weather disasters; new figure on 2016 weather fatalities.
- Chapter 11: New sections on U.S. hurricanes 2006-2017, eyewall replacement cycle, Hurricane Harvey and inland flooding; updated tables and Accumulated Cyclone Energy; new figures on hurricane return periods, Atlantic Multi-decadal Variability. Several new figures.
- Chapter 12: Significant new updates and additions: Arctic amplification of global warming; Arctic sea-ice volume 1979-2017; global map of climate tipping points; expanded history of knowledge of carbon-dioxide effect on climate including early computer model; Yellowstone eruption of 631 kya and its effect on climate; expanded discussion of orbital forcing, eccentricity, and tilt effects; Athabasca glacier.
- Chapter 13: New sections on atmospheric rivers, Managed Retreat of buildings from floodplains, Great Mississippi River flood of 1927.

- Chapter 14: Major Reorganization. Added new sections: Fort McMurray, Canada firestorm; fire weather and winds with spotting, pyrocumulus clouds, mega-fires; smoke effects on human health. Added In Greater Depth on origin of fire on Earth as we know it. Deleted some old tables and figures.
- Chapter 15: Added new 4-page section on Landslide Mitigation including 5 new photos. New text analogy of snow avalanche and earthquake-fault movements.
- Chapter 16: Added new sections: sand, a Tragedy of the Commons; submarine canyons and effect on beach sand; tidal waves up Amazon River. Expanded text: coral reefs and coastline protection.
- Chapter 17: Added new sections on coronal mass ejections; new collection sites for micrometeorites. Added In Greater Depth on insights from spacecraft landing on a comet. Expanded dwarf planet coverage. Added images of tektites and Moon impact crater.
- Chapter 18: GREAT NEWS. The chapter on mass extinctions has returned to the print edition of the book.

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I am deeply appreciative of the help given by others to make this book a reality. The photograph collection in the book is immeasurably improved by the aerial photographs generously given by the late John S. Shelton, the greatest geologist photographer of them all. Please see John's classic book *Geology Illustrated.*

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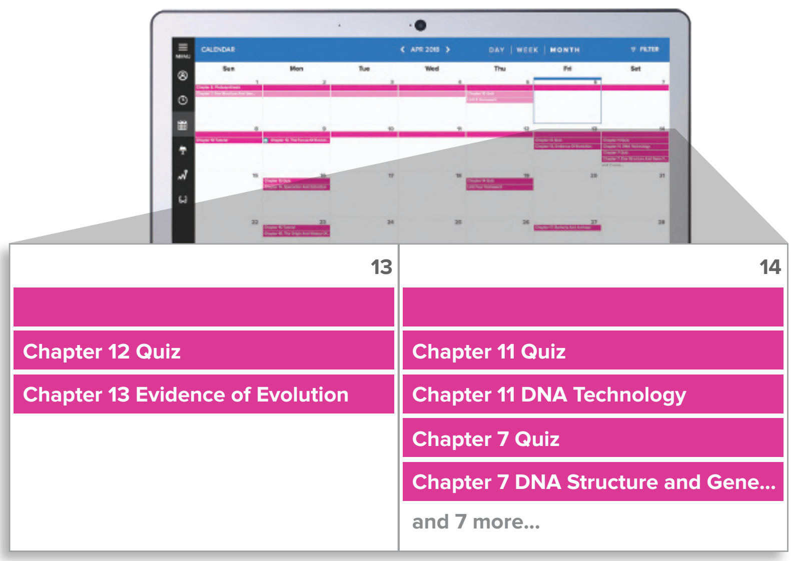

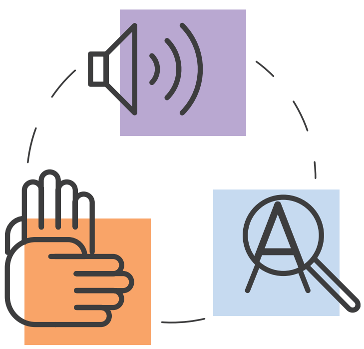

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Prologue: Energy Flows

Earth, the Blue Marble as seen from Apollo 17 in 1972.
Source: NASA

LEARNING OUTCOMES

Earth is a planet with varied flows of energy that can cause problems for humans. After studying the Prologue you should

- know the main flows of energy on Earth.
- comprehend how internal energy creates land.
- understand how external energy destroys land.
- be familiar with the rock cycle.

Disasters occur where and when Earth's natural processes concentrate energy and then release it, killing life and causing destruction. Our interest is especially high when this energy deals heavy blows to humans. As the growth of the world's population accelerates, more and more people find themselves living in close proximity to Earth's most hazardous places. The news media increasingly present us with vivid images and stories of the great losses of human life and destruction of property caused by natural disasters. As the novelist Booth Tarkington remarked: "The history of catastrophe is the history of juxtaposition."*

To understand the natural processes that kill and maim unwary humans, we must know about the energy sources that fuel them. Earth is an active planet with varied flows of energy from: (1) Earth's interior, (2) the Sun, (3) **gravity,** and (4) impacts with **asteroids** and **comets.**

Internal energy flows unceasingly from Earth's interior toward the surface. The interior of the Earth holds a tremendous store of heat accumulated from the initial impacts that formed our planet and from the heat released by the ongoing decay of **radioactive isotopes.** Over short time spans, internal energy is released as eruptions from **volcanoes** and as **seismic waves** from **earthquakes.** Over longer intervals of geologic time, the flow of internal energy has produced our **continents,** oceans, and **atmosphere.** On a planetary scale, this outflow of internal energy causes continents to drift and collide, thus constructing mountain ranges and elevated plateaus.

External energy is delivered by the Sun. About a quarter of the Sun's energy that reaches Earth evaporates and lifts water into the atmosphere. At the same time, the constant pull of gravity helps bring atmospheric moisture down as snow and rain. On short timescales, these processes bring us **hail, lightning, tornadoes, hurricanes,** and floods. Solar energy is also stored in plant tissue to be released later as fire. On a long timescale, the Sun and gravity power the agents of **erosion—glaciers,** streams, underground waters, winds, ocean waves, and currents—that wear away the continents and dump their broken pieces and dissolved remains into the seas. Solar radiation is the primary energy source because it evaporates and elevates water, but gravity is the immediate force that drives the agents of erosion.

Gravity is an attractional force between bodies. At equal distances, the greater the mass of a body, the greater its gravitational force. The relatively great mass of the Earth has powerful effects on smaller masses such as ice and rock, causing ice to flow as avalanches and hillsides to fail in landslides and **debris flows.**

An energy source for disasters arrives when visitors from outer space—asteroids and comets—impact Earth. Impacts were abundant early in Earth's history. In recent times, collisions with large bodies have become infrequent. However, asteroids and comets traveling at velocities in excess of 30,000 mph occasionally slam into Earth, and their deep impacts have global effects on life.

The sequence of chapters in this book is based on energy sources, in the following order: Earth's internal energy, external energy supplied by the Sun, gravity, and impacts with space objects.

Earth's internal energy fuels volcanism, as well as providing the energy for earthquakes. Here, lava flows from the Pu'u O'o-Kupaianaha eruption in Hawaii meet the ocean, 18 August 2010.

Source: Michael Poland/USGS

External energy from the Sun fuels tornadoes, as well as hurricanes, floods, and wildfires. Here, a powerful tornado spins down from a supercell thunderstorm and travels along an Oklahoma road.

The pull of gravity brings down hillsides. This earthquake-triggered debris flow destroyed homes and killed 585 people in Santa Tecla, El Salvador on 13 January 2001.

Source: Ed Harp/USGS

High-velocity comets and asteroids can impact the Earth and kill life worldwide. Here the Comet Lovejoy nears Earth's horizon behind airglow in the night sky.

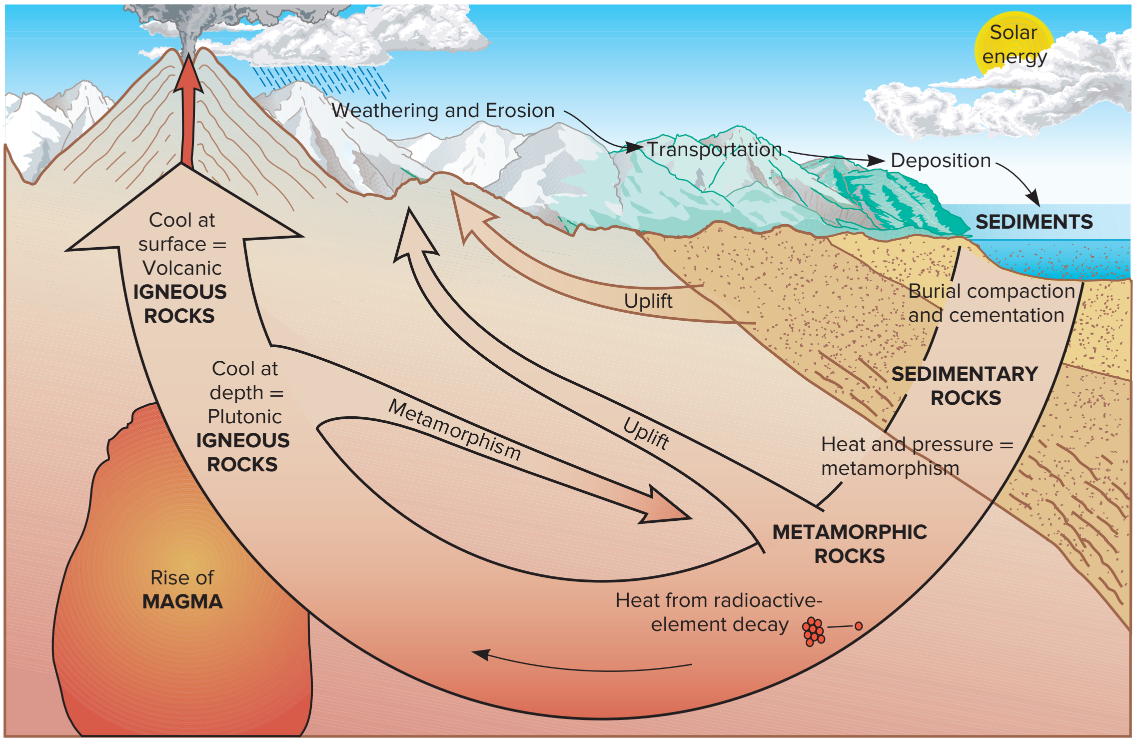
Source: Dan Burbank/NASA

Processes of Construction versus Destruction

Another way to look at energy flow on Earth is by understanding the rock cycle and the construction and destruction of land (continents). Energy flowing up from Earth's interior melts rock that rises as **magma** and then cools and crystallizes to form **igneous rocks;** they are **plutonic rocks** if they solidify at depth or **volcanic rocks** if they cool and harden at the surface. These newly formed rocks help create new land. Igneous-rock formation is part of the internal energy–fed **processes of construction** that create and elevate landmasses.

At the same time, the much greater flow of energy from the Sun, working with gravity, brings water that weathers the igneous rocks exposed at or near the surface and breaks them down into **sediments. Physical weathering** disintegrates rocks into **gravel** and **sand,** while **chemical weathering** decomposes rock into **clay minerals.** The sediments are eroded, transported mostly by water, and then deposited in topographically low areas, ultimately the ocean. These external, energy-fed **processes of destruction** work to erode the lands and dump the debris into the oceans.

These land-building and land-destroying processes result from Earth's energy flows that create, transform, and destroy rocks as part of the rock cycle. Think about the incredible amount of work done by the prodigious flows of energy operating over the great age of Earth. There is a long-term conflict raging between the internal-energy-powered processes of construction, which create and elevate landmasses, and the external-energy-powered processes of destruction, which erode the continents and dump the continental debris into the ocean basins. Visualize this: If the interior of Earth cooled and the flow of internal energy stopped, mountain building and uplift also would stop; then the ongoing solar-powered agents of erosion



The rock cycle. Follow the cycle clockwise beginning in the lower left. Magma cools and solidifies to form igneous rocks. Rocks exposed at Earth's surface break down and decompose into sediments (e.g., gravel, sand, clay), which are transported, deposited, and hardened into sedimentary rock. With increasing burial depth, temperature and pressure increase, causing changes (or metamorphosis) of rocks into metamorphic rocks.

would reduce the continents to sea level in just 45 million years. There would be no more continents, only an ocean-covered planet.

Think about the timescales involved in eliminating the continents. At first reading, 45 million years of erosion may seem like an awfully long time, but the Earth is more than 4.5 billion years old. The great age of Earth indicates that erosion is powerful enough to have leveled the continents about 100 times. This shows the power of the internal processes of construction to keep elevating old continents and adding new landmasses. And woe to human and other life-forms that get too close to these processes of construction and destruction, for this is where natural disasters occur.

Terms to Remember

asteroid 1
atmosphere 1
chemical weathering 3
clay minerals 3
comet 1
continent 1
debris flow 1
earthquake 1
erosion 1
glacier 1
gravel 3
gravity 1
hail 1
hurricane 1
igneous rock 3
lightning 1
magma 3
physical weathering 3
plutonic rocks 3
processes of construction 3
processes of destruction 3
radioactive isotope 1
sand 3
sediment 3
seismic wave 1
tornado 1
volcanic rocks 3
volcano 1

CHAPTER 1

Natural Disasters and the Human Population

"Mankind was destined to live on the edge of perpetual disaster. We are mankind because we survive."

—James A. Michener, 1978, *Chesapeake*, Random House

The world population of humans continues to increase exponentially. Photo of shopping area in New Delhi, India.

©donyanedomam/123RF

LEARNING OUTCOMES

The human population is growing rapidly. Natural disasters are causing great numbers of deaths and economic losses. After studying this chapter you should

- recognize the differences between a natural hazard, a natural disaster, and a great natural disaster.
- be familiar with the processes that cause the deadliest natural disasters.
- understand the relationship between frequency and magnitude of natural disasters.
- know the size of the human population.
- understand the significance of exponential growth.
- recognize the demographic transition of human populations.
- be able to explain the concept of carrying capacity.

OUTLINE

- Great Natural Disasters
- Human Fatalities and Economic Losses in Natural Disasters
- Natural Hazards
- Overview of Human Population
- Future World Population
- Carrying Capacity

In 2016, there were 191 **natural disasters** that claimed 20 or more human lives. They were primarily caused by floods, **earthquakes, hurricanes** (= **cyclones** = **typhoons**), and heat waves; they killed almost 7,000 people. The 14 deadliest events are listed in table 1.1; they occurred in 8 different months and 11 different countries, mostly in Asia. As horrible as the 2016 death total is, it is markedly less than in 2010, when about 286,000 people were killed in two events alone (Haiti earthquake: 230,000; Russian heat wave: 56,000). All these disasters were the result of natural processes operating at high **energy** levels for brief times in restricted areas.

Great Natural Disasters

The Japan earthquake and tsunami in 2011, the Haiti earthquake in 2010, and the Myanmar cyclone and China earthquake in 2008 combined to kill almost 500,000 people. They are examples of **great natural disasters:** these events so overwhelm regions that international assistance is needed to rescue and care for people, clean up the destruction, and begin the process of reconstruction. Great natural disasters commonly kill thousands of people, leave hundreds of thousands homeless, and overwhelm the regional economy.

Today, in earthquake-active areas of the world, several hundred million people live in buildings that will collapse during a strong earthquake. An earthquake killing more than 100,000 people could happen any day in Teheran, Iran; in Istanbul, Turkey; or in other large cities. Today, people by the millions are moving to the ocean shores, where they can be hit by tsunami, hurricanes, and floods. We need to learn how to build disaster-resistant communities to lessen the human fatalities and economic losses resulting from natural disasters.

TABLE 1.1

The 14 Deadliest Natural Disasters in 2016

Fatalities	Date	Event	Country
734	28 Sep	Hurricane Matthew	Haiti
673	16 Apr	Earthquake 7.8M	Ecuador
538	29 Aug	Typhoon Lionrock	North Korea
300	13 Apr	Heat wave	India
299	24 Aug	Earthquake 6.2M	Italy
289	30 Jun	Floods	China
289	18 Jul	Floods	China
228	15 Jul	Floods (monsoon)	India
191	15 May	Cyclone Roanu	Sri Lanka
151	1 Aug	Floods (monsoon)	India
141	9 Mar	Floods	Pakistan
137	14 Apr	Earthquake 7.0M	Japan
122	21 Jul	Floods	Nepal
117	6 Feb	Earthquake 6.4M	Taiwan
4,209 Total deaths			

Source: Data from Swiss Reinsurance Company (2017).

Human Fatalities and Economic Losses in Natural Disasters

The 40 deadliest disasters in the 47-year period from 1970 to 2016 are shown in table 1.2. The most frequent megakillers were earthquakes (23) and hurricanes (10). Notice that 30 of the 40 worst natural disasters occurred in a belt running from China and Bangladesh through India and Iran to Turkey. Nine happened in the Americas but none were in the United States or Canada.

What is the correlation between human population density and the number of natural-disaster deaths? The data of table 1.2 paint a clear picture: densely populated Asia dominates the list of fatalities. The Asian experience offers a sobering view of what may befall the global population of humans if we continue our rapid growth. Where humans are concentrated, disasters can kill many more people during each high-energy event.

THE ROLE OF GOVERNMENT IN NATURAL-DISASTER DEATH TOTALS

As the global population of humans increases, the number of deaths by natural disasters is expected to rise, but the relationship has complexities. Analyses by Gregory van der Vink and students at Princeton University show that between 1964 and 1968, about 1 person in 10,000 was killed by a natural disaster. Between 2000 and 2004, even though the population of humans doubled, the death rate by natural disaster dropped to about 1 person in 100,000. Yet, great natural disasters still result in horrific death totals in some countries. What relationships, in addition to population size, explain the locations of great natural disasters? Their study compared natural-disaster deaths to the levels of democracy and economic development within 133 nations with populations greater than 1 million that

TABLE 1.2

The 40 Deadliest Natural Disasters, 1970–2017

Fatalities	Date/Start	Event	Country
300,000	14 Nov 1970	Hurricane (Bhola)	Bangladesh
255,000	28 Jul 1976	Earthquake (Tangshan)	China
245,000	26 Dec 2004	Earthquake and tsunami	Indonesia, Sri Lanka, India, Thailand
230,000	12 Jan 2010	Earthquake	Haiti
140,000	2 May 2008	Hurricane Nargis	Myanmar
140,000	29 Apr 1991	Hurricane Gorky	Bangladesh
88,000	8 Oct 2005	Earthquake	Pakistan
87,500	12 May 2008	Earthquake (Sichuan)	China
66,000	31 May 1970	Earthquake and debris flow (Nevados Huascaran)	Peru
55,630	15 Jun 2010	Heat wave and fire	Russia
50,000	21 Jun 1990	Earthquake (Gilan)	Iran
35,000	Aug 2003	Heat wave	Europe
27,000	26 Dec 2003	Earthquake (Bam)	Iran
25,000	7 Dec 1988	Earthquake	Armenia
25,000	16 Sep 1978	Earthquake (Tabas)	Iran
23,000	13 Nov 1985	Volcanic eruption and mudflows (Nevado del Ruiz)	Colombia
22,000	4 Feb 1976	Earthquake	Guatemala
20,103	26 Jan 2001	Earthquake (Gujarat)	India
19,184	11 Mar 2011	Earthquake and tsunami	Japan
19,118	17 Aug 1999	Earthquake (Izmit)	Turkey
18,000	15 Dec 1999	Flooding and debris flows	Venezuela
15,000	19 Sep 1985	Earthquake (Mexico City)	Mexico
15,000	1 Sep 1978	Floods (monsoon rains in north)	India
15,000	29 Oct 1999	Hurricane (Orissa)	India
11,000	22 Oct 1998	Hurricane Mitch	Honduras
11,000	25 May 1985	Hurricane	Bangladesh
10,800	31 Oct 1971	Hurricane (Odisha)	India
10,000	20 Nov 1977	Hurricane (Andhra Pradesh)	India
9,500	30 Sep 1993	Earthquake (Marashtra state)	India
8,960	25 Apr 2015	Earthquake	Nepal
8,135	8 Nov 2013	Hurricane Haiyan	Philippines
8,000	16 Aug 1976	Earthquake (Mindanao)	Philippines
6,425	17 Jan 1995	Earthquake (Kobe)	Japan
6,304	5 Nov 1991	Hurricane Thelma (Uring)	Philippines
6,000	Jun 1976	Heat wave	France
5,778	21 May 2006	Earthquake (Bantul)	Indonesia
5,748	14 Jun 2013	Floods	India
5,422	30 Jun 1976	Earthquake (West Irian)	Indonesia
5,374	10 Apr 1972	Earthquake (Fars)	Iran
5,300	28 Dec 1974	Earthquake	Pakistan
2,059,281 Total deaths			

Source: Data from Swiss Reinsurance Company (2017).

experienced five or more natural disasters between 1964 and 2004. Democracy is assessed by the World Bank's Democracy Index, and economic development by gross domestic product (GDP).

The Princeton researchers state that more than 80% of deaths by natural disasters between 1964 and 2004 took place in 15 nations, including China, Bangladesh, and Indonesia. For these 15 countries, 87% are below the median democracy index and 73% are below the median GDP. The correlation between high GDP and low death totals shows exceptions in Iran and Venezuela, two oil-rich nations with significant GDP but low democracy indices. These exceptions suggest a greater importance for democracy than GDP: the stronger the democracy index, the lower the death totals from natural disasters. The mega-killer natural disasters of recent years fit this trend also: Pakistan earthquake in 2005 (88,000 dead), Myanmar cyclone in 2008 (140,000 dead), China earthquake in 2008 (87,500 dead), and Haiti earthquake in 2010 (230,000 dead).

In a thought-provoking paragraph in their conclusion, van der Vink and students state: "Deaths from natural disasters can no longer be dismissed as random acts of nature. They are a direct and inevitable consequence of high-risk land use and the failures of government to adapt or respond to such known risks."

HUMAN RESPONSES TO DISASTER

Decades of social science research help us understand how most human beings react to natural disasters, and the news is good. Our behavior in ordinary times changes following disasters. In day-to-day life, most people are primarily concerned with their own needs and those of their immediate families; other relationships tend to be more superficial. After a natural disaster, many people change from inward-directed concerns to outward-directed actions. After an initial response of shock and disbelief, our emotions of sympathy and empathy tend to dominate. Personal priorities may be set aside and humanitarian and community-oriented actions take over. People reach out to others; they give aid and comfort to strangers; they make great efforts to provide help. Following a natural disaster, people become better connected and cohesive; they experience a heightened and compelling desire to add to the common good.

ECONOMIC LOSSES FROM NATURAL DISASTERS

The deaths and injuries caused by natural disasters grab our attention and squeeze our emotions, but in addition, there are economic losses. The destruction and disabling of buildings, bridges, roads, power-generation plants, and transmission systems for electricity, natural gas, and water, plus all the other built works of our societies, add up to a huge dollar cost. But the economic losses are greater than just damaged structures; industries and businesses are knocked out of operation, causing losses in productivity and wages for employees left without places to work.

In 2016 there were 191 natural disasters that each caused losses greater than $US95 million. The total economic losses were around US$166 billion. The economic losses were 0.24% of global domestic product.

Insured Portion of Economic Losses

The 40 greatest disasters between 1970 and 2017 from the insurance company perspective of dollar losses are listed in table 1.3. Notice that 39 of the 40 most expensive disasters were due to natural processes. The list of most expensive events is dominated by weather events (31 of 40), whereas earthquakes contributed eight. Compare the events on the 40 deadliest disasters list (see table 1.2) with table 1.3.

The locations of the worst dollar-loss disasters for the insurance industry (table 1.3) are different from the worst locations for fatalities (see table 1.2). The highest insurance dollar losses occurred in the United States (23 of 40), Europe (6), and Japan (6). Wealthy countries are better insured and their people live in safer buildings.

The extent of economic and insured losses may take years to become known. For example, the insured losses from the January 1994 Northridge earthquake were listed at $2.8 billion in February 1994, but they grew to $10.4 billion in January 1995 and increased to $15.3 billion in April 1998.

Natural Hazards

Many sites on Earth have not had a natural disaster in recent time, but are hazardous nonetheless. **Natural hazards** may be assessed as the probability of a dangerous event occurring. For example, people migrate and build next to rivers that are likely to flood, on the shoreline of the sea awaiting a powerful storm, and on the slopes of volcanoes that will eventually erupt. Decades, or even centuries, may pass with no great disasters, but the hazard remains.

Sites with natural hazards must be studied and understood. Their risks must be evaluated. Then we can try to prevent natural hazards from causing natural disasters. Remember: *Natural hazards are inevitable, but natural disasters are not.*

In the process of **mitigation,** we make plans and take actions to eliminate or reduce the threat of future death and destruction when natural hazards suddenly become great threats. The mitigating actions taken to protect us may be engineering, physical, social, or political.

Another need for mitigation occurs after great disasters, because people around the world tend to reoccupy the same site after a disastrous event is done. Earthquakes knock cities down, and then the survivors may use the same bricks