

ROLE OF TECHNOLOGY
IN MANAGING VULNERABILITY TO NATURAL DISASTERS,
WITH CASE STUDIES
OF VOLCANIC DISASTERS ON NON-INDUSTRIALIZED ISLANDS

by

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A thesis submitted in conformity with the requirements
for the degree of Master of Applied Science

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Role of Technology in Managing Vulnerability to Natural Disasters,
With Case Studies of Volcanic Disasters on Non-Industrialized Islands.

Master of Applied Science 1998
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Abstract

Technology is one tool used and misused for managing society's vulnerability to natural disasters. Many of the difficulties encountered result from neither technical problems nor the specific natural disaster event, but manifest because society errs in applying technology or in assessing the natural hazard's severity. This study examines, critiques, and suggests improvements in this area.

One of the most challenging steps for an engineer is defining the design criteria which should be used to anticipate a system's response during a natural disaster, because the design load input from a natural disaster is difficult to predict and select properly. An examination of non-technological influences, preventive engineering, and relevant boundaries and scales illustrates how to prevent vulnerability to natural disasters.

The concepts and models developed are applied to case studies of volcanic hazards on non-industrialized islands. The eruptions of Mount Pinatubo in the Philippines (initial eruption in 1991) and Soufrière Hills in Montserrat (initial eruption in 1995) are examined.

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- A paper entitled "A Critical Analysis of the Reaction to the 1991 Eruption of Mount Pinatubo in the Philippines" written by this author for the course IES1202S (Environmental Issues in Developing Countries) at the University of Toronto under the supervision of Professor Rodney White and submitted on April 21, 1997. This paper particularly influenced Chapter 11 in this thesis.
- A paper entitled "Natural Disasters and Human Activity", a report for the North American Commission on Environmental Cooperation (NACEC) by David Etkin (Environmental Adaptation Research Group, Environment Canada), Maria Teresa Vázquez (National Disaster Prevention Centre, Mexico City), and this author. This paper particularly influenced the tables and figures in Chapter 2, section 5.2.3, section 5.2.4, and Table 9-2 in this thesis.

Any errors or misinterpretations in this thesis are solely the responsibility of this author and do not reflect the support provided by those listed above and on the previous page.

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1. Introduction

This thesis is in the field of environmental engineering and thus examines how humanity interacts with--i.e., responds to, is affected by, and affects--the environment. Natural disasters are an important part of the environment, an important part of society, and have strong interactions with technology. Thus, they are an important part of environmental engineering.

1.1 Natural Disasters and IDNDR

Natural disasters occur when natural phenomena--such as lava, earth tremors, strong winds, high river levels, large waves, and temperature extremes--kill or injure people, damage property, and/or interfere with society's expected day-to-day life. Although the production of complete and accurate data sets is fraught with difficulty, natural disasters are reported to have killed 144,000 people, injured 46,600 people, rendered homeless 4.61 million people, and affected 121 million people on average, per year between 1969 and 1995 (IFRC, 1998).

To investigate and mitigate the natural disaster problem, the United Nations (U.N.) has declared the decade of the 1990's--though it actually covers 1990 to 2000--to be the International Decade for Natural Disaster Reduction (IDNDR). The U.N.'s General Assembly passed Resolution 44/236 on December 22nd, 1989 stating (IDNDR, 1998):

The objective of the Decade is to reduce, through concerted international action, especially in developing countries, the loss of life, property damage, and social and economic disruption caused by natural disasters, such as earthquakes, windstorms, tsunamis, floods, landslides, volcanic eruptions, wildfires, grasshopper and locust infestations, drought and desertification, and other calamities of natural origin.

This objective will be tackled through the goals (IDNDR, 1998):

- To improve the capacity of each country to mitigate the effects of natural disasters expeditiously and effectively, paying special attention to assisting developing countries in the assessment of disaster damage potential and in the establishment of early warning systems and disaster-resistant structures when and where needed;*
- To devise appropriate guidelines and strategies for applying existing scientific and technical knowledge, taking into account the cultural and economic diversity among nations;*
- To foster scientific and engineering endeavors aimed at closing critical gaps in knowledge in order to reduce loss of life and property;*
- To disseminate existing and new technical information related to measures for the assessment, prediction and mitigation of natural disasters;*
- To develop measures for the assessment, prediction, prevention and mitigation of natural disasters through programs of technical assistance and technology transfer, demonstration projects, education and training, tailored to specific disasters and locations, and to evaluate the effectiveness of those programs.*

The IDNDR's home page on the world wide web is at <http://hoshi.cic.sfu.ca/~idndr> (last accessed by this author on January 4th, 1998). IDNDR activities include research projects, internet conferences, symposia, periodicals, and informational and educational programs. Targets are:

- the achievement of national risk assessments of natural disasters;
- development and implementation of national and/or local prevention and preparedness plans; and
- developing and providing access to warning systems.

The activities of the IDNDR have helped to inspire and justify this thesis, because both seek to produce original research in, increase awareness of, and educate society about natural disasters. This thesis, however, is not an official publication of the IDNDR or any of its affiliated agencies. Recommendations in this thesis assume few changes to society, the environment, and technology, and so may not be valid beyond about a decade after submission. This timeframe, approximately 1998-2008ish, covers the immediate post-IDNDR period and therefore somewhat examines and assesses the results of the IDNDR.

1.2 Importance of Technology

Engineers are interested in and involved in natural disaster issues because many of their technologies--encompassing inventions, systems, approaches, and techniques--are used to manage natural disaster issues. This thesis examines these roles by looking at how society uses and misuses technology for managing vulnerability to natural disasters. Technology is not the only tool for managing vulnerability (for example, economic, psychological, and educational tools exist), but technology is the focus of this thesis, in order to contribute to the environmental engineering field and the engineering profession. This thesis examines, critiques, and suggests improvements in this realm by noting that:

- technology hinders and helps in managing vulnerability to natural disasters;
- how society develops and implements technology affects the successes of managing vulnerability to natural disasters;
- society's wish to manage vulnerability to natural disasters drives the creation and implementation of technology.

1.3 Case Studies

The ideas and models presented for the role of technology in managing vulnerability to natural disasters are applied to specific case studies in order to put the theory into practice. The case studies are focussed on one particular type of natural disaster in one particular type of geographical area: volcanic eruptions on non-industrialized islands. The intention of this thesis is to examine, and

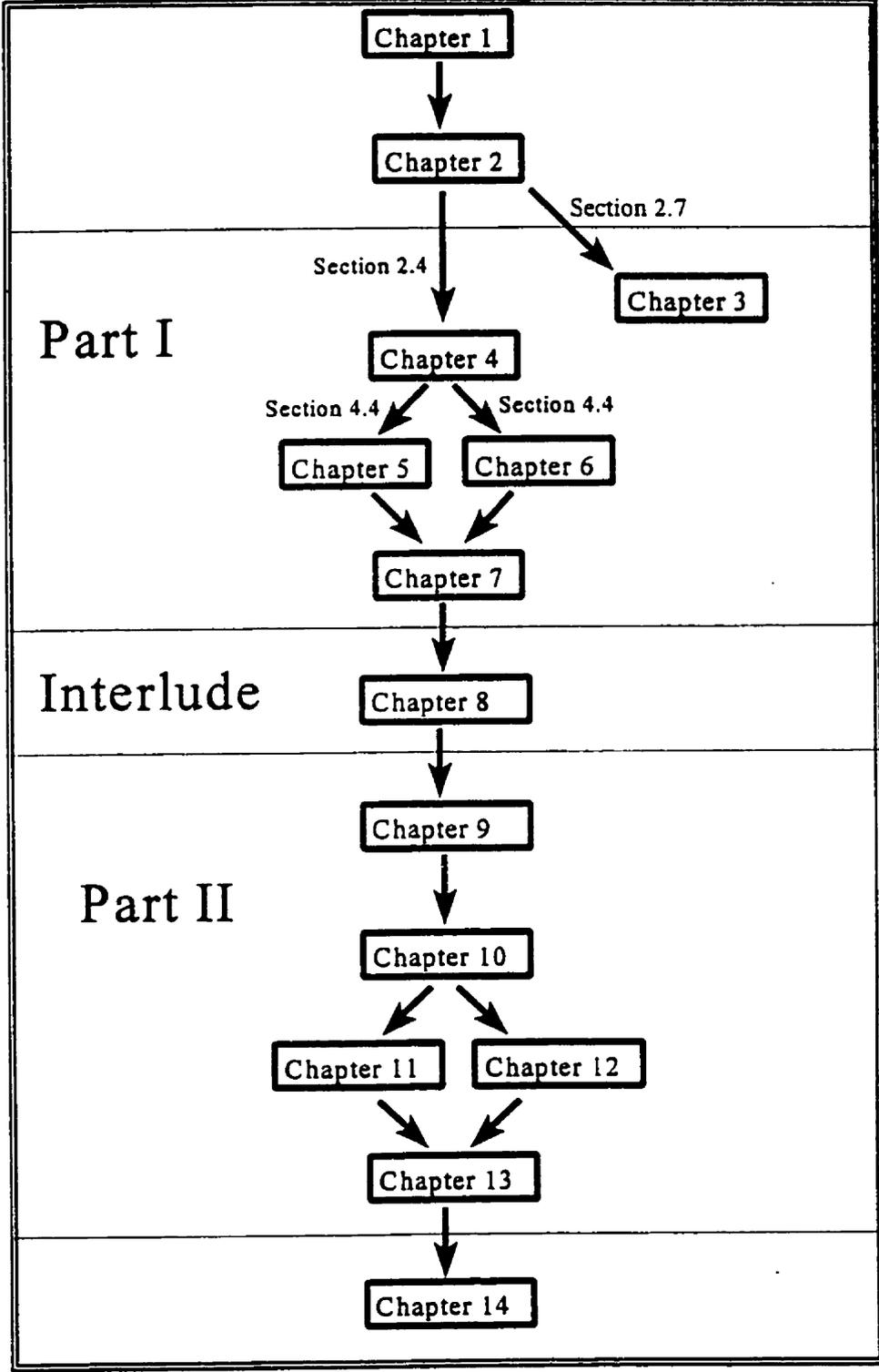
to apply to, society's contemporary situation--as the IDNDR (section 1.1.) does--and so the case studies are events which occurred during the IDNDR: Mount Pinatubo, the Philippines (initial eruption 1991) and Soufrière Hills, Montserrat (initial eruption 1995). The examples in other parts of this thesis are also concentrated on contemporary events, although the importance of learning from history should not be understated and historical examples and attitudes are an inevitable component of any study.

1.4 Structure and Audience

The chapters of this thesis are not a purely linear sequence, although that is the most convenient manner of presenting them. Figure 1-1 is a schematic of the structure of this thesis with arrows indicating where one chapter follows directly from another. As well, many of the ideas presented in this thesis overlap or reinforce each other and so there is extensive cross-referencing.

The topic and assumed audience of this thesis are interdisciplinary. Technology relates directly to engineers (amongst others) and vulnerability to natural disasters relates directly to planners, environmental scientists, sociologists, emergency workers, and community workers (amongst others). Combining the two areas will work towards breaking down inhibitions and boundaries between these fields to demonstrate the importance of a wide breadth and depth of knowledge and experience. With so many stakeholders attempting to sort out such a complex problem, collaboration and cooperation are essential. Hopefully the reader will be inspired by this work to further explore and stimulate contributions of engineers and technology to natural disasters.

Figure 1-1: Schematic of Chapters



2. Terminology and Context

2.1 Introduction

This chapter provides working definitions for the terminology used in this thesis. The goal is to yield clear indications of how vocabulary is used in further discussions. The definitions are not intended to be applied ubiquitously or to be exact and indisputable interpretations of the words. Instead, they provide a framework and a context for discussing issues and ideas. Words and language are used carefully in this thesis, and this chapter helps to set up that usage as well as to indicate the boundaries of this work. The terminology discussed in this chapter, and the relationships between them, are represented in schematic form in Figure 2-1.

2.2 Society

Society refers to the gestalt of individuals, groups of individuals, and cultures of *homo sapiens sapiens* (modern humanity) along with the interaction between these components. This thesis especially focusses on societies which are at risk from or are affected by natural disasters.

2.3 Environment

The environment refers to nature and nature's actions; i.e., the events or activities which originate in natural processes. This thesis especially focusses on the aspects of the environment relevant to natural disasters. Although human beings originate in natural processes, they are covered by society (section 2.2) and so the term "the environment" excludes humanity and society, unless otherwise indicated. Implications of this separation are explored in section 6.4.1.

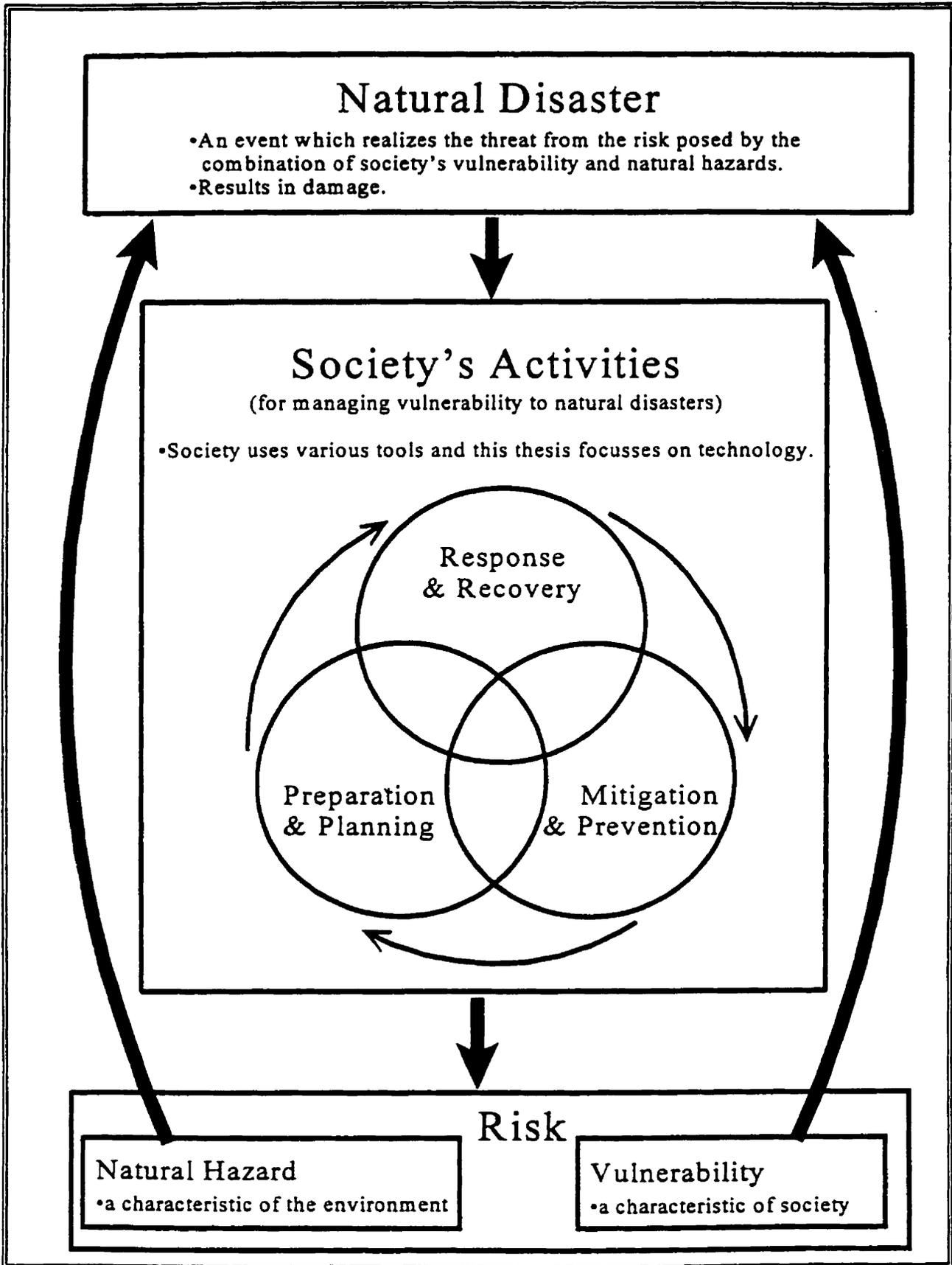
2.4 Technology

Technology refers to the tools created and used by engineers. Systems, techniques, designs, and approaches are all applicable. This thesis especially focusses on the technology applied to managing society's vulnerability to natural disasters. The choice to use minimal technology and the choice not to use technology--which occur rarely in contemporary society--are regarded as viable methods of using technology to manage society's vulnerability to natural disasters.

An important set of technologies is society's lifelines: the systems which are vital to the health and safety of society, namely those used for energy, fuel, transportation, communication, waste management, and food/water production. The manner in which engineers design and use these technologies has immense impacts on society's vulnerability.

Non-technological tools are also available to society for managing vulnerability to natural disasters. Economic tools include insurance and governmental programs for disaster financial assistance. Psychological tools include belief systems, which are often identified with a specific

Figure 2-1: Schematic of Terminology
(Modified from Etkin *et al.*, 1998)



religion or culture. Specific examples are praying to or making sacrifices to deities believed to control natural events, and certain mindsets, such as fatalism, which impact on one's decision-making ability. Educational tools include providing information and teaching appropriate behaviour and values. Legal tools can mandate actions such as the use of other tools in specific ways for specific purposes. Policy tools are often used for implementing other tools and, in areas such as fire suppression in parks and land-use planning, prominently involve scientists, engineers, and technology.

None of the categories of tools are independent sets. For example, educational and psychological tools overlap when teaching behaviour and values results in doctrines, such as ceremonies honouring rain deities, being passed down through generations. Legal and economic tools overlap when purchasing a certain type of insurance for an activity is required.

If technology and other tools overlap, they are relevant to this thesis because technology is a component of the tool. For example, educational and psychological tools can be used to influence society's view and use of technology, as examined in sections 3.3 and 6.4. As well, technology can enhance, or make more accessible, an educational experience. Multimedia approaches to education about natural disasters have improved the accessibility of information about natural disasters, where the technology is readily available. Examples include the World Wide Web (Table 2-1) and compact discs such as the Disaster Preparedness and Mitigation Library freely distributed on compact disc by the Federal Emergency Management Agency in the U.S.A. Technology can also assist in providing a superficial public education through mass media, such as the special effects used for the American films *Twister* (1996), *Dante's Peak* (1997), *Volcano* (1997), *Deep Impact* (1998), and *Armageddon* (1998). These films provide a general frame of reference for interest in, awareness of, and understanding certain natural disasters which otherwise might never be experienced or thought about by those who do not encounter such incidents.

The tool of technology is explored further in Chapter 4.

2.5 Natural Hazard

A natural hazard is an event or activity with root causes in the environment which is interpreted by society as posing a threat or danger to society; i.e., it has the potential to damage (section 2.6) society. Such a description tends to give natural hazards a negative connotation, but threats and dangers to society can be opportunities, trivialities, or major concerns and influences depending on the exact natural hazard and the exact context in which it is viewed. Natural hazards change the environment and change society, or have the potential to cause such changes. Change is feared and welcomed by society and thus so are natural hazards.

Table 2-1: Samples of Natural Disaster Sites on the World Wide Web
(accessed between September 1997 and June 1998)

Organization	URL
CDERA (Caribbean Disaster Emergency Response Agency)	http://www.cdera.org
CRID (Centro Regional de Información Sobre Desastres)	http://www.netsalud.sa.cr/crid/spa/index.htm (Spanish) http://www.netsalud.sa.cr/crid/eng/index.htm (English)
Disaster Connection	http://www.itn.is/~gro/disaster/disintro.html
DPRA (Disaster Prevention & Recovery Alliance)	http://www.dpra.net
EERI (Earthquake Engineering Research Institute)	http://www.eeri.org
Environment Canada's Environmental Adaptation Research Group	http://www.tor.ec.gc.ca/earg
GHDNet (Global Health Disaster Network)	http://hypnos.m.ehime-u.ac.jp/GHDNet
IFRC (International Federation of Red Cross and Red Crescent Societies)	http://www.ifrc.org
INCEDE at the University of Tokyo (International Center for Disaster-mitigation Engineering)	http://incede.iis.u-tokyo.ac.jp/incede_home.html
International Hurricane Center	http://www.fiu.edu/~hurricane
National Lightning Safety Institute (U.S.A.)	http://www.lightningsafety.com
Natural Hazards Mitigation Group at the University of Geneva	http://www.unige.ch/hazards
Nordic Volcanological Institute	http://www.norvol.hi.is
<i>Tephra</i> , published by the Ministry of Civil Defence, New Zealand	http://inform.dia.govt.nz:8080/moccd/tephra/tephra_index.txt.html
The Tornado Project	http://www.tornadoproject.com
Tsunami Society	http://www.cclamr.ogi.edu/STH/society.html
U.K. Volcanologists' Home Page	http://exodus.open.ac.uk/volcano/volc_index.html
WXP Hurricane and Tropical Storm data	http://www.wxp.atms.purdue.edu

There are four categories of natural hazards, which are usually classified as shown in Table 2-2. The categories in Table 2-2 are not free from ambiguity or inconsistency. For example:

- Avalanches and glacial surges could be classified as either geological or hydrometeorological hazards.
- Tsunamis are clearly hydrological hazards, yet they originate mainly from the geological hazards of earthquakes, landslides/rockslides, and volcanoes.
- Jökulhlaups (glacial floods) can be either volcanic or purely hydrological in origin.
- Fire is an ecosystem characteristic, albeit abiotic, and thus could be classified as a biological hazard; but, similar to drought, one of its causative factors is a lack of water and so it could be classified as a hydrometeorological hazard. As well, fire can be of volcanic origin.
- Any danger from extraterrestrial creatures would be both astronomical and biological.

A typology of natural hazards can be developed, with the following characteristics (after Burton *et al.* (1993)):

- Physical, chemical, and/or energy description of the hazard:
e.g., rapid motion (from an earthquake or landslide), heat (from lava or air temperature), or mass (from hail or lahars).
- Magnitude and intensity.
- Temporal characteristics: speed of onset, duration (temporal extent), frequency (temporal dispersion).
- Spatial characteristics: areal (spatial) extent, pattern of distribution (spatial dispersion).
- Predictability of the above characteristics and the quality of these predictions.

2.6 Damage

Impacts or consequences on society which would not have occurred in the absence of a specific event or activity are termed "damage to society". Damage incorporates a wide range of impacts and consequences. Society can be affected directly through deaths, physical and psychological injuries; loss of information and personal opportunities; and destruction, displacement, or partitioning of cultures and communities. Society can also be affected through impacts on surroundings—including technology and the environment—such as changes (normally losses) to infrastructure, property, natural resources, and lifelines. Thus, individual life, individual quality of life, and collective quality of life can be affected by damage due to natural disasters. Damage is usually interpreted as being detrimental to society, and while this interpretation is usually correct in the short-term, placing a value judgment on the long-term implications of most damage can be more difficult.

Table 2-2: Classification of Natural Hazards

Hazard Category	Origins	Examples of Hazards
astronomical (extraterrestrial hazards)	hazards with origins in space	collision of celestial bodies with Earth, geomagnetic storms, solar flares
biological (biospheric hazards)	hazards with origins in living organisms, ecosystems, or other levels of the ecological hierarchy (see footnote 1 in section 2.6)	fire; microbial pathogens; poisonous, aggressive, or otherwise dangerous plants and animals
hydrometeorological (atmospheric and hydrological/hydrospheric hazards)	hazards with origins in the air or water	avalanches, drought, erosion, floods, fog, glacial surges, hurricanes, icebergs, lightning, precipitation (e.g., freezing rain, hail, ice, rain, sleet, snow), storm surges, temperature extremes or fluctuations (cold and heat), tornadoes, waves, wind
geological (lithospheric hazards)	hazards with origins in the earth	earthquakes (and associated hazards such as tsunamis and landslides), landslides/rockslides (and associated hazards such as tsunamis), poison gas, volcanoes (and associated hazards such as fire, fumaroles (gas emissions), lahars (mudflows), jökulhlaups (glacial floods), and tsunamis)

Damage to the environment occurs when natural disasters kill biota; destroy and divide ecological hierarchical levels¹; and alter physical geography, such as transforming a river's course, modifying a watershed, or changing altitude contours and peaks. Since this thesis generally focusses on the modern Western philosophical and scientific viewpoints (section 6.4.1), such losses are damage from the anthropocentric point of view: there is a loss of natural resources which could have been used for society. One proviso for this statement is that identifying an environmental loss of physical geography due to a natural disaster is often inappropriate, because natural disasters tend to create as much as they destroy.

For example, orogeny--the process of mountain building--occurs only due to tectonic forces and illustrates the continual balance of creation and destruction achieved by nature. Ever since the explosion of the volcano Krakatoa, Indonesia on August 27, 1883, that region of the Selat Sunda (Sunda Strait) has witnessed the births and deaths of many islands due to volcanic activity. The island of Surtsey, Iceland was created by a series of volcanic eruptions in 1963--though this creation process "destroyed" a section of the ocean. The Good Friday earthquake in Alaska (March 27, 1964) changed the elevation of more than 250,000 km² of land, with large portions of land dropping into or rising from the ocean. Floods inundate tracts of land, often destroying much of the land and vegetation, but creating a new, fertile layer of soil. Changes to physical geography from natural disasters may be damaging, but are not necessarily detrimental.

2.7 Vulnerability

Vulnerability is the level of susceptibility to damage. With respect to natural disasters, vulnerability reflects the characteristics of the protection which society has developed against damage from natural hazards, and so vulnerability also indicates the degree of difficulty of protecting society from specific natural hazards.

Vulnerability is often indicated qualitatively as high or low, or quantitatively on a relative scale, rather than being assigned an absolute measurement or description. Therefore, it is more meaningful to look for levels of minimal or maximal vulnerability rather than for levels of zero or

¹The ecological hierarchy (after Begon, Harper, and Townsend, 1990) is the series of levels--1. individual, 2. population, 3. community, 4. ecosystem, 5. biome, and 6. biosphere (planet)--which denote increasing levels of ecological interaction and generally increasing spatiotemporal scales of survival and influence farther up the hierarchy.

saturated vulnerability. The higher society's vulnerability, the higher the expected damage from a natural disaster. Influences on vulnerability are explored in Chapter 3.

2.8 Risk

Various definitions of "risk" grace the literature, including:

- Alexander (1991, p. 210), who cites UNESCO (United Nations Educational, Scientific, and Cultural Organization) and the Office of the United Nations Disaster Relief Coordinator:

Total risk = Impact of hazard × Elements at risk × Vulnerability of elements at risk

- Blaikie *et al.* (1994, p. 25):

Risk = Hazard + Vulnerability

- Blong (1996, p. 675), who cites UNESCO:

Risk = Hazard × Vulnerability

- De La Cruz-Reyna (1996, p. 600), who cites E.M. Fournier d'Albe:

Risk = Hazard × Vulnerability × Value of threatened area ÷ Preparedness

- Helm (1996, p. 8):

Risk = Probability × Consequences, although "this simple product is not sufficient in itself to fully describe the real risk, but...it provides an adequate basis for comparing risks or making resource decisions".

- Smith (1996, p. 5):

"Risk is the actual exposure of something of human value to a hazard and is often regarded as the combination of probability and loss...risk (or consequence) [is] 'the probability of a specific hazard occurrence'"

- Stenchion (1997, p. 41):

"Risk might be defined simply as the probability of the occurrence of an undesired event".

An alternative approach is taken by Burton *et al.* (1993) who avoid the use of the term "risk", preferring to focus on "hazard" and "vulnerability". Risk, risk analysis, and risk management are briefly mentioned on page 248 following their observation that "natural hazard research [has recently] melded with the field of risk assessment...[y]et this melding has spurned less reciprocity than might have been expected by researchers and managers concerned with reducing the threat of technological hazards" (p. 247).

The purpose of this thesis is not to enter the debate on the definition of "risk"; however, introducing a concept of risk which encompasses most of the themes mentioned in the literature is desirable. A suitable concept of risk is a combination of hazard and vulnerability (though not necessarily as the sum favoured by Blaikie *et al.* (1994) or as the multiplication favoured by Blong (1996)). The definition of natural hazard (section 2.5) includes the concept of probability while the definition of vulnerability (section 2.7) includes the concept of potential consequences. By viewing

risk as the integration of and the interaction between vulnerability and hazard (as illustrated at the bottom of Figure 2-1), the most popular ideas from the literature are covered.

Risk is often indicated qualitatively as high or low, or quantitatively on a relative scale, rather than being assigned an absolute measurement or description. Therefore, it is more meaningful to look for minimal and maximal risk levels rather than for levels of zero or saturated risk. The phrases "a risk", "at risk", and "risky" imply "a high or significant risk", which in turn implies that damage from a natural disaster would be augmented.

2.9 Natural Disaster

The manifestation of the threat or danger from a natural hazard in an occurrence that causes damage to society is a natural disaster. A natural disaster is a specific event, in contrast to a chance or probability, and usually is clearly delineated in space and time. Some examples of natural disasters are listed in Table 2-3.

Similar events in different locations or at different times can have radically differing outcomes, so defining a natural disaster in terms of exact economic or societal losses does not assist in developing a clear definition. The scale of damage necessary for producing a disaster, rather than an unfortunate incident or an inconvenience, is subjective. One community's overwhelming disaster (such as flooding sweeping away a hamlet) has negligible impact on many other communities (such as a province, a country, and villages far away from the affected hamlet) or may provide opportunities for other communities (such as carpenters from the surrounding region).

The term "natural disaster" is in some ways a misnomer, because it implies that the disasters originate entirely in the environment. As illustrated in Figure 2-1, the vulnerability characteristics of society and the natural hazard characteristics of the environment are both required as inputs to yield a natural disaster. The term "natural disaster" simply implies that environmental input is necessary, though not sufficient. Drunk drivers and terrorists incorporate minimal environmental input to produce a hazard and can be accepted as being non-natural disasters (sometimes referred to as technological or anthropogenic disasters). Table 2-4 lists examples of disasters with minimal input from the environment.

Even with this distinction, differentiating between natural disasters and other disasters can be challenging, especially in the realm of transportation incidents. Some examples are listed in Table 2-5. Human beings can forget a procedure (March 10, 1989 on Table 2-5) or can make poor decisions (April 15, 1912 on Table 2-5). As well, an event can require environmental input, even when the disaster is clearly a problem of anthropogenic origin (December 1952 on Table 2-5). This thesis

Table 2-3: Examples of Natural Disasters

(Tables 9-1, 11-1, and 12-1 list volcanic eruptions; Table 9-2 lists some high-fatality natural disasters)

(References listed are the main source of information for the example, although comparison with other sources may have resulted in some of the details being altered; unsourced examples were gleaned from media reports and this author's experience).

Date	Location	Disaster	Comments
October 10-16, 1780	Martinique, St. Eustatius, and Barbados (offshore)	Tropical cyclone	The most lethal recorded Atlantic storm to date, killing more than 20,000 people (Rappaport and Fernández-Partagás, 1997).
January 10, 1962	Peru	Avalanche	3,000 people died (Maloney, 1976).
Summer 1988	Central and eastern Canada and U.S.A.	Drought and heat wave	Deaths were estimated at 5,000 to 10,000 with more than US\$40 billion (1988 dollars) of damage (NOAA, 1997).
1989	near Dhaka, Bangladesh	Tornado	The most lethal recorded tornado to date, killing 1,100 people and leaving 100,000 homeless (National Geographic, 1997).
July 1993	Hokkaido, Japan	Tsunami	The tsunami, triggered by an earthquake, killed more than 200 people (National Geographic, 1997).
January 17, 1995	Kobe region, Japan	Earthquake	The Hyogo-Ken Nanbu earthquake is the most expensive recorded natural disaster to date, estimated to have caused damage of US\$125 billion (1995 dollars); the casualties were 5,426 dead and 26,804 injured (Kuribayashi <i>et al.</i> , 1996; Lekkas <i>et al.</i> , 1996).
May 1995	Dallas/Fort Worth, Texas	Hail storm	Insured property losses were estimated to be US\$1.125 billion (1995 dollars; Renick, 1997).
1997-1998	World	ENSO (El Niño-Southern Oscillation)	This periodic phenomenon has been blamed for droughts, floods, tornadoes, landslides, storms, and insect infestations around the world. Estimates of damage are several thousand deaths and US\$ several billion.
January 1998	Eastern Canada and U.S.A.	Ice storm and cold wave	More than two dozen people were killed, from falling ice chunks and, because the ice storm downed power lines, from fire and carbon monoxide asphyxiation from faulty heaters, and also from hypothermia.

Table 2-4: Examples of Disasters with Minimal Input from the Environment

(References listed are the main source of information for the example, although comparison with other sources may have resulted in some of the details being altered, unsourced examples were gleaned from media reports and this author's experience).

Date	Location	Disaster	Comments
January 18, 1915	Guadalajara, Mexico	Train crash	A train derailed into a gorge allegedly killing more than 600 people (Nash, 1976).
1939-1945	World	World War II	Some estimates put the final death toll as high as 55 million (Nash, 1976).
January 30, 1945	near Danzig, Poland	Ship sinking	The German cruise ship <i>Wilhelm Gustloff</i> was torpedoed by a Soviet submarine killing 7,700 people (1,000 survived) in the most lethal ship sinking to date (Nash, 1976).
September 1971	Al Basrah, Iraq	Poisoning	Grain contaminated with mercury was stolen and distributed, officially killing 459 people and injuring 6,071, but the true toll could have been 6,000 dead and 100,000 injured (Nash, 1976).
December 3, 1984	Bhopal, India	Methyl Isocyanate leak	The most lethal industrial disaster to date occurred when the chemical methyl isocyanate leaked from a Union Carbide plant, killing 6,400 people and injuring approximately 200,000 (Smith, 1996).
April 26, 1985	Chernobyl, Ukraine	Explosion and fire at a nuclear power plant.	After safety systems were shut down in order to test the limits of the reactor's operating capability, the reactor core exploded starting a fire and sending radioactive material high into the atmosphere. 31 people died in order to contain the fire and material release (IAEA, 1986).
August 12, 1985	Mount Otsuka, Japan	Airplane Crash	Structural failure caused the airplane to crash, killing 520 people although 4 survived (Lisk, 1997).
July 2, 1990	Mecca, Saudi Arabia	Stampede	During a heat wave, thousands of people in a tunnel panicked, killing 1,426.
September 28, 1994	Baltic Sea	Ferry sinking	The roll-on/roll-off ferry <i>Estonia</i> sank in less than 15 minutes killing 912 people (141 survived) after water penetrated the bow door.

Table 2-5: Examples of Disasters Difficult to Classify as Either Natural or Non-Natural

(References listed are the main source of information for the example, although comparison with other sources may have resulted in some of the details being altered; unsourced examples were gleaned from media reports and this author's experience).

Date	Location	Disaster	Comments
April 3, 1856	island of Rhodes, Greece	Lightning strike	Lightning struck the Church of St. John, which had a gunpowder vault, and 4,000 people died in the explosion (Nash, 1976).
May 31, 1889	Johnstown, Pennsylvania	Flash flood	Heavy snowfall and rain during 1889 coupled with 20 cm of rain on May 29-30 caused a poorly made dam, which was known to be damaged and deteriorating, to collapse, drowning 2,209 people (Maloney, 1976).
1930	St. Lawrence River, Canada	Lightning strike	Lightning hit the <i>John B. King</i> , a freighter carrying explosives, causing an explosion which killed 30 people (Jones, 1997).
April 15, 1912	northwest Atlantic ocean	Ship sinking	The <i>Titanic's</i> captain chose to travel at high speed through iceberg-infested waters and 1,513 people died after the ship struck an iceberg and sank (Maloney, 1976).
December 1952	London, England	The London Fog	Anthropogenic pollution was trapped by a naturally occurring warm air mass, killing 4,000 people in the short-term, and possibly up to 8,000 people in the long-term (Nash, 1976).
March 27, 1977	Tenerife, Canary Islands	Airplane collision	In dense fog, one airplane accelerating for takeoff collided with another airplane taxiing down the runway, killing 583 people (dozens survived) in the most lethal airplane disaster to date (Lisk, 1997).
August 2, 1985	Dallas-Fort Worth Airport, Texas	Airplane crash	Wind shear during a thunderstorm forced a landing jet onto an Interstate highway killing 140 people; 21 people on board the airplane survived (Lisk, 1997).
March 10, 1989	Dryden, Ontario	Airplane crash	The pilot forgot to de-ice the airplane's wings and in the subsequent crash, 24 people died and several were seriously injured (Lisk, 1997).
August 26, 1990	Yugoslavia	Mine explosion	Naturally-occurring methane in a mine exploded killing 178 miners.

views such disasters as being non-natural for two reasons. The first reason is that the models and concepts developed in this thesis are being applied mainly to hazards and disasters which are unambiguously natural: volcanoes (see chapter 9). During volcanic events, the environment is clearly the source of the hazard, and so the issue of the hazard's origin is settled.

The second reason is that it is important to highlight society's role in disasters, because society can and should take responsibility for managing vulnerability to disasters. The assumption that disasters are "acts of a deity" or "the fault of nature" ignores the contribution of society to vulnerability and ignores the control which society has over its own fate. Without ensuring that society understands its role, it becomes easy to start blaming nature or fate for as much as possible while avoiding society's responsibility. For example, forest fires started by careless campers should not be blamed on the environmental hazard of a lack of precipitation or dry trees. Similarly, the bus crash into a gorge following brake failure near St.-Joseph-de-la-Rive, Québec on October 13, 1997, which killed 44 people and was Canada's worst land transportation accident to date, should not be blamed on the environmental hazard of a steep hill.

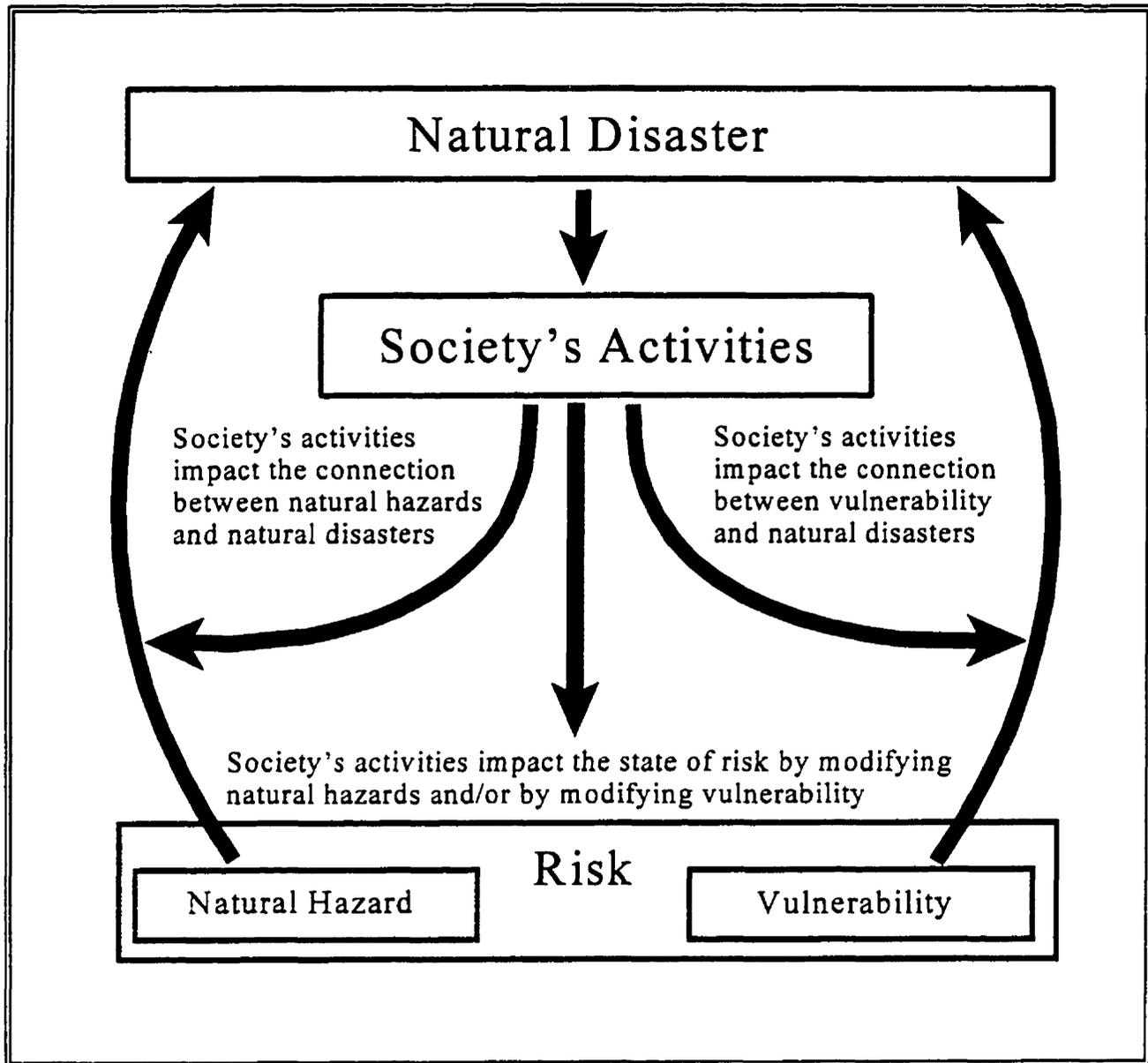
2.10 Management of Vulnerability to Natural Disasters

Management refers to the actions which society takes in order to deal with the risk of natural disasters. Without society, there is no reason to manage any aspect of the environment, including aspects of natural disasters (and there would be no one to do the managing anyway). Managing is done for society by society and generally implies deliberate and conscious actions, although involuntary or incidental actions do contribute to management. As well, inaction and avoiding action are feasible, and at times appropriate, management strategies.

Referring to Figure 2-1, management (i.e., human activity) occurs only in the box "Society's Activities". Vulnerability is a state which exists; natural hazards are events and activities of purely environmental origin; and a natural disaster is a specific event. Society can modify risk (vulnerability or natural hazards) and natural disasters, but such modification occurs in the "Society's Activities" box, which then alters the state of risk and/or the connections between vulnerability/hazards and the natural disaster event (Figure 2-2). Managing risk, managing natural hazards, and managing vulnerability are all potentially viable management strategies which could be conducted independently or together. Discussion of why managing vulnerability is the most appropriate approach is deferred to Chapter 5, with this question specifically addressed in section 5.4.

Mitigation and/or minimization of vulnerability tends to be the implied objective in managing vulnerability; however, other possibilities include:

Figure 2-2: Impacts of Society's Actions



- An exact level of vulnerability is deemed to be desirable.
- Reducing vulnerability below a specific threshold is deemed to be desirable.
- A dynamic vulnerability, changing in space and/or time, is deemed to be desirable.
- Increasing vulnerability is deemed to be desirable, perhaps to allow for exciting news or to cause a political or economic rival to suffer.

An example relating to the fourth point above is that there have been at least three instances in history when winter in Russia contributed significantly to the defeat of invading armies (those of Charles XII of Sweden, Napoleon Bonaparte, and Adolf Hitler), and from the Russian perspective, high vulnerability of those armies to winter natural hazards was advantageous. Similarly, the key victory of England's navy over the Spanish navy in 1588 has been attributed as much to bad weather as to English military tactics, an advantage from the English perspective of high vulnerability of the Spanish navy to meteorological hazards.

The activities of management, as shown in Figure 2-1, are the cycle of response and recovery, mitigation and prevention, and preparation and planning. These activities often blend into one another without being clearly delineated, and often the same action could be placed under more than one of the headings. Accordingly, the circles overlap.

2.10.1 Post-disaster Actions: Response and Recovery

Response and recovery are post-disaster actions. Response usually refers to shorter-term actions and involves dealing with a disaster event's consequences as it occurs or immediately after it has occurred. Examples of response actions are:

- initiating previously developed emergency plans;
- summoning emergency services (police, firefighters, ambulances/paramedics) and their activities;
- evacuating threatened populations;
- first aid treatment, triage, and transport to hospitals of casualties;
- first-order assessment of losses and prevention of further losses; and
- securing lifelines for the affected population.

Recovery usually refers to longer-term actions, particularly rebuilding damage (physical and psychological) caused by the disaster event. Recovery tends to begin after the threat of further damage from the disaster event has abated, and includes rebuilding infrastructure and lifelines, evaluating preparedness for and response to the past disaster event, and treating post-traumatic stress disorder.

One example of the overlapping of response and recovery actions occurred during the ice storm in eastern Canada in January 1998. The emergency response to the widespread destruction of power lines in the affected region included the shipment and setting up of gas-powered generators along with calling in hydro crews from across eastern North America to repair power lines. Repairing power lines, though, is also part of the recovery process, as it is categorized as rebuilding lifelines.

2.10.2 Pre-disaster Actions: Mitigation/Prevention and Preparation/Planning

Mitigation and prevention attempt to avoid the occurrence of, and attempt to reduce the damage caused by, a disaster event. Preparation and planning activities assume that a disaster will occur (i.e., it cannot be completely prevented or mitigated) and attempt to make society ready to deal with the disaster. Mitigation and prevention activities tend to be longer-term and more difficult to implement than preparation and planning activities, although there is considerable overlap.

Examples of pre-disaster actions are:

- implementing and enforcing building code designs for seismic events and strong winds (mitigation/prevention);
- legislating and enforcing land-use planning and land-zoning measures to avoid heavy settlement in flood-prone areas (mitigation/prevention);
- education in schools in such areas as first aid, drills for earthquakes and tornadoes, and safety for skiing and boating (mitigation/prevention and preparation/planning);
- creating triage and emergency response plans (preparation/planning);
- setting up special communication networks, such as (i) the dial 911/311² systems in North America and the dial 999 system in the British Isles to speed the reporting of disasters, and (ii) the use of personal transponders to locate avalanche victims (preparation/planning); and
- anticipating an imminent disaster, such as by monitoring an approaching hurricane or upstream flood waters, issuing evacuation notices, boarding up windows, and building dykes and levees (preparation/planning).

²Dial-911 systems in some areas of the U.S.A. were being used so frequently that on February 19, 1997 the Federal Communications Commission in the U.S.A. permitted the 311 code to be used for non-emergency police-related calls, and also defined uses for other N11 codes. Despite attempts from American emergency services to reverse the ruling, because they believe that a single emergency number is important for consistency and simplicity, the dial-311 service has been implemented in Baltimore.

2.11 Summary

In the context of using technology to manage society's vulnerability to natural disasters:

- the environment introduces natural hazards, one of two necessary components of the risk which leads to natural disasters;
- society introduces vulnerability, one of two necessary components of the risk which leads to natural disasters;
- Technology introduces an important component of the management of vulnerability to natural disasters, although it is not the only component.

In order to understand how technology can manage vulnerability, a more detailed examination of vulnerability (chapter 3) and technology (chapter 4) is necessary. Then, chapter 5 describes how technology can be used for preventing natural hazards (section 5.2) and for preventing vulnerability (section 5.3) followed by an examination of how these preventive techniques are impacted by boundaries and scales (chapter 6).

PART I
Concepts and Models for Technology in Managing Vulnerability to Natural Disasters

3. Society's Vulnerability to Natural Disasters

3.1 Introduction

Chapter 2 noted that one of the reactions or responses of society to its interaction with the environment is to use and misuse technology in managing the interaction. Society's risk from natural disasters, a combination of natural hazards and vulnerability, is an interaction which society usually wishes to manage. Section 5.4 demonstrates that managing natural hazards is generally not as feasible or as desirable as managing vulnerability, and so society's focus should be on managing vulnerability.

This chapter examines society's vulnerability to natural disasters in order to build upon the concepts introduced in section 2.7 and to better understand the role of technology. The influences discussed in sections 3.2 through 3.5 are all characteristics of society and at times they intersect and influence each other. The separation suggested in this chapter is for improving the clarity of the discussion rather than for establishing distinct categories.

3.2 Demographic Influences

3.2.1 Individuals' Characteristics

An individual's physical and cultural characteristics influence the individual's vulnerability to death or injury from natural hazards. Such characteristics include age, gender, linguistic ability and background, ethnicity, race, and state of physical and mental health. An individual's state of health incorporates physical mobility, speed of reaction, intelligence, and medical history. The following illustrative examples of how these characteristics influence vulnerability have been collated and adapted predominantly from Brenner and Noji (1993), Carter *et al.* (1989), Ewald (1993), and Pearce (1994):

- Race: Individuals of black African heritage are more susceptible to sickle cell anaemia than those of other heritages, but having sickle cell anaemia greatly reduces an individual's vulnerability to the biological hazard of malaria.
- Linguistic ability (oral and reading comprehension):

Individuals who do not understand warnings and safety instructions--due to educational background, youth, hearing impediments (state of health), intelligence, or a

linguistic background different from the language of the community--are more vulnerable to rapid-onset hazards such as tornadoes and flash floods.

Individuals who speak a language with an absence of words describing certain hazards (e.g., in Spanish, "lahar" (a mudflow) is usually translated as "avalanche") may be more vulnerable to that hazard due to improper communication and comprehension of the hazard.

- Gender and age:

Elderly females are more susceptible to osteoporosis than males and younger females and thus are more vulnerable to bone injuries during structural collapse caused by natural hazards such as tornadoes and earthquakes.

Elderly people of both genders are more vulnerable to some biological hazards than younger people such as the bacteria which cause tuberculosis and the viruses which cause influenza, and also have decreased mobility (state of health) which increases vulnerability to rapid-onset hazards.

- State of health:

As a person's state of health declines, physical mobility is impaired, linguistic ability may regress, and ability to respond appropriately to warnings or situations may be compromised. Alcoholism, multiple sclerosis, and asthma are examples where vulnerability is increased in situations requiring rapid response due to decreased mobility.

Vulnerability to biological hazards is heavily influenced by state of health and medical history. Immunodeficient individuals, due to an illness such as AIDS (acquired immune deficiency syndrome), are highly vulnerable to other microbiological hazards, such as the bacteria which cause tuberculosis and the viruses which cause influenza. Hospitalized patients are also highly susceptible to microbiological hazards.

3.2.2 Populations' Characteristics

Characteristics of a population influence vulnerability of that population to natural hazards. The predominant influences are that populations are increasing, urbanizing, and mobile. Encroachment into areas of higher vulnerability occurs when a larger population seeks new places to live. Soil in volcanic areas or along river banks can be especially tantalizing as good farmland, particularly to subsistence farmers, yet these areas are dangerous due to their respective hazards. Subsistence farmers in tropical areas are also becoming increasingly vulnerable to biological hazards. As populations increase and old farmland becomes barren, population pressures force farmers into

destroying and settling previously unexplored areas of wilderness which not only brings them into contact with new microbial pathogens¹ but also reduces the range, food supply, and patience of large mammals. Coastal areas are another highly vulnerable area experiencing rapid population increases (Burton *et al.*, 1993).

Urbanization affects vulnerability in a complex fashion. Urbanization implies increasing population densities concentrated in relatively small areas compared to generally sparse but equal distributions over large rural districts. If there is an evenly distributed probability of a natural hazard occurring over a large area, the urban population in a smaller area will experience less frequent natural hazards than the rural population, but when a natural hazard does strike the urban area, more people will be impacted. Furthermore, because the natural hazard strikes urban areas less frequently than rural areas, the urban population has less experience in coping with the situation and so has augmented vulnerability (see section 3.3). On the other hand, urban areas tend to have much better resources for response and recovery, such as quick access to high-quality emergency services and medical care, than rural areas.

If the probability of a natural hazard occurring is not evenly distributed, then the location of an urban area determines the impact of urbanization on vulnerability. An expanding city which is more vulnerable to a natural hazard than the surrounding countryside will augment the population's vulnerability because of the increased population exposed to, and the comparative lack of experience of coping with, the natural hazard. An expanding city which is less vulnerable to a natural hazard than the surrounding countryside will reduce a population's vulnerability by drawing the rural population away from hazardous areas. The impact on vulnerability of urbanization is significant, but the factors determining the final result are complex.

As well, the expansion of cities upwards (i.e., apartment blocks and skyscrapers) affects vulnerability. Tornado vulnerability can be reduced (McCulloch, 1994) while earthquake vulnerability can be augmented (Bolt, 1993). Concentrated populations also assist the spread of microbiological hazards, a fact known throughout European history when people would depart cities for rural areas to escape plague outbreaks. Furthermore, urban areas promote socioeconomic

¹This influence has been implicated in the recent explosions of malaria, yellow fever, and dengue fever along with the emergence of other diseases, particularly those caused by filoviruses, arenaviruses, and arboviruses (e.g., see Culliton, 1990; Epstein, 1995; Gibbons, 1993; Real, 1996; Walsh *et al.*, 1993).

disparity and socioeconomic class influences vulnerability (section 3.4, with some examples under "State of Mind" in section 3.3).

Urbanization is an example of large-scale, rapid population mobility, a relatively new phenomenon for the global population. Analogous, small-scale mobility occurs globally, primarily in richer populations: convenient, global transportation systems permit families and individuals to be highly mobile between communities. People frequently travel between cities or countries for reasons such as taking holidays, conducting business, and changing jobs. Being in an unfamiliar environment increases vulnerability to unfamiliar natural hazards, because without an awareness of potential natural hazards, one will not likely know how to watch out for or respond to a natural disaster. Linguistic ability and knowledge of community emergency procedures and safe locales will also be obstructed.

3.3 Attitude and Belief System Influences

Characteristics of individuals and populations help shape, and are shaped by, their psychological characteristics, so attitudes and belief systems influence vulnerability. Some influences are culturally focussed--through religion, language, and past collective experience--and some influences are individually focussed--through personality and available opportunities. Much of the discussion on how the psychological state of mind influences vulnerability is better explored in the context of psychological boundaries, and so it is deferred until section 6.4. Illustrative examples of how these psychological characteristics, and other attitudes and belief systems, influence vulnerability are:

- Lifestyle:

- Substance intake:

- Diet and drug use (including nicotine, alcohol, banned substances, and prescriptions) impact one's mental and physical health which influences vulnerability to natural disasters (section 3.2).

- Sexual practices:

- Multiple sexual partners and non-use of barrier prophylactics increase vulnerability to sexually-transmitted microbiological hazards. The use of oral contraceptives increases a female's vulnerability to gonorrhoea (Madigan *et al.*, 1997).

- Outdoor activities:

Outdoor activities such as hiking, skiing, camping, and canoeing bring individuals into more frequent contact with storms, landslides, avalanches, insects, and large mammals thereby increasing vulnerability; however, they also tend to improve one's level of fitness, health, and ability to cope with extreme situations, thereby decreasing vulnerability.

-Activities at historical sites:

Individuals in buildings preserved for historical reasons (such as churches, tourist pioneer villages, and forts) tend to be more vulnerable to atmospheric hazards because the buildings are unlikely to have been retrofitted to modern standards (Pearce, 1994). The same argument holds for vulnerability to seismic hazards.

-Occupation:

Health care workers tend to be frequently exposed to microbiological hazards, although frequent, low-level exposure to microbial pathogens does induce a level of immunity.

Farmers' incomes are highly vulnerable to floods, droughts, and temperature extremes.

Volcanologists, seismologists, atmospheric scientists, microbiologists, biologists, and geologists will encounter their respective hazards more frequently than other occupations.

•State of Mind

-Religion:

One factor identified in the surprisingly high rate of tornado fatalities in the Bible Belt in the southern U.S.A. is fatalism, the doctrine that all events are inevitable and humanity should submit to fate without dispute (Brenner and Noji, 1993).

Keeping the Aeta (Filipino aboriginal people) outside the danger zone of the volcano Mount Pinatubo is difficult, because the Aeta believe that the mountain is their protector/saviour and that they are not permitted to live anywhere but on its slopes (England, 1993a & 1993b; Goertzen, 1991; Shimizu, 1989; see also section 11.3.2).

-Past experience:

Toronto continues functioning as a city through snowstorms which would bring Glasgow or Dublin to a standstill. Torontonians are used to, and are generally

prepared for, dealing with heavy snowstorms while Glaswegians and Dubliners do not expect large snowfalls. Torontonians, however, would generally deal with a major earthquake poorly compared with San Franciscans, Los Angelenos, or Tokyoites.

-Factors which supersede vulnerability to natural disasters:

A geodesic dome or sphere section would likely be the safest building in a tornado, yet society continues to construct rectangular prisms which are dangerous. Aesthetics and familiarity of shape and construction practices supersede vulnerability to tornadoes.

Many of the fatalities during Chicago's 1995 heat wave were attributed to a legitimate fear that opening windows would increase vulnerability to crime. Personal and property safety concerns superseded concerns about the heat's health impacts.

Wealthier socioeconomic classes sometimes choose to live in areas vulnerable to natural hazards for prestige, isolation, climate, and lifestyle concerns. California--vulnerable to landslides, earthquakes, and brush fires--and Florida--vulnerable to hurricanes, tornadoes, and alligators--are popular locales in the U.S.A.

Many of the aforementioned examples can be placed in one link of a chain of factors connecting attitude and belief systems to vulnerability (adapted from accident avoidance factors described by Wilde (1994)):

- Society (or an individual) must be aware of the state of vulnerability by:
 - being conscious (awake);
 - being attentive;
 - possessing the necessary sensory capabilities (a state of health influence);
 - and having an accurate perception of vulnerability.
- Then, society must:
 - be motivated to manage the vulnerability;
 - possess the necessary decision-making skills for taking action;
 - possess the necessary analytical skills for choosing appropriate action;
 - and enact appropriate action before a natural disaster occurs.

If any of these links fail to connect, then society's vulnerability will be increased.

3.4 Economic Influences

Even when the vulnerability chain described at the end of section 3.3 is intact, the desire to take appropriate action before a natural disaster occurs might be unfulfillable due to economic factors. Tackling vulnerability might not be affordable, or decision-makers might label the actions as being unaffordable. Technology inevitably has an economic cost, and measures designed to manage vulnerability to natural disasters could be deemed too expensive by the government, business, organization, or individual which must pay the immediate cost. For example, Harris *et al.* (1992) design schools and public buildings in tornado-prone areas in the U.S.A., yet emphasize that added costs for tornado protection must be virtually insignificant or else they will not be awarded contracts.

Developing, implementing, and enforcing adequate standards or regulations to demand adequate protection are often deemed too expensive.

As will become evident throughout this thesis--particularly in Chapter 5 on preventive engineering, section 6.3 on temporal boundaries, and aspects of the case studies--the "immediate cost" tends to be emphasized as being too expensive, even though avoiding the immediate cost of preventive and mitigative measures often incurs future costs which are far greater than this initial, immediate cost. Nonetheless, the bias towards avoiding immediate costs, however misguided, is a dominant economic influence on vulnerability. At other times, especially for individuals, the immediate cost truly cannot be covered. For example, even if the need had been recognized in advance, many of the fatalities during Chicago's 1995 heat wave could not have afforded the installation of either air conditioning or security systems which would have permitted window screens with crime prevention devices. Similarly, many deaths in urban homes from cold temperatures are attributed to "fuel poverty", where residents cannot afford adequate insulation or heating.

These examples also illustrate how socioeconomic class influences vulnerability. Generally, poverty breeds vulnerability. Lower socioeconomic classes tend to have increased vulnerability because they:

- occupy more inadequately constructed and maintained dwellings;
- live in more dangerous locales, which others prefer to avoid;
- have poorer nutrition and less access to appropriate water supplies and sanitation;
- have a poorer state of health and less access to proper medical care;
- have fewer resources for solving these problems, through techniques such as acquiring technology, social activism, purchasing insurance, and legal proceedings.

Wealthier socioeconomic classes have more control over their vulnerability because lifestyle and residence preferences are more easily affordable. Other influences, such as urban problems (section 3.2.2) and attitude (section 3.3), can lead to preferences which increase vulnerability, but wealth permits these wishes to be fulfilled. For example, section 3.3 discussed how vulnerable areas of California (and Florida) are prestigious locales and hence are desirable for settling: in San Francisco's Marina District, chic residences built on reclaimed land prone to liquefaction succumbed during the 1989 Loma Prieta earthquake, and expensive homes built near Californian bluffs proved disastrous during several El Niño-induced landslides in the first few months of 1998. Similarly, lifestyle choices such as outdoors activities are available with wealth. A lower socioeconomic class forces vulnerability in many aspects of lifestyle, but a higher socioeconomic class provides choice, which includes the choice to be vulnerable.

3.5 Political Influences

One method for reducing the impetus of choosing vulnerable lifestyles is education, demonstrating how political influences can affect vulnerability. Communicating information about all aspects of natural disasters, including the importance of vulnerability, will educate society about the problems and potentially motivate society into developing solutions. These actions can be carried by any sector of society--government, academia, community groups, industry, and businesses--but may be hampered by economic restrictions. Engineers should use education to complement the technology they provide, in order to ensure proper development and application of their technology.

Another political influence on vulnerability is effective leadership and decision-making. A lack of these qualities can result in devastating natural disasters. In countries such as Canada, France, Ireland, Japan, and the U.S.A., incompetence ranging from wilful negligence to unfortunate ignorance have spread microbiological hazards amongst people who use products from publically-donated blood for medical reasons, such as transfusions during operations and surviving with haemophilia. Westphal *et al.* (1990), for example, describe protozoal, bacterial, viral, and rickettsial infections which have been transmitted by blood transfusions. Corruption and mismanagement also led to the failure of dykes designed to protect surrounding communities from Mount Pinatubo lahars (mudflows) in the Philippines, following the 1991 eruption ("Like Pompeii", 1996; Tiglao, 1996; see also section 11.3.4).

Even when the political will exists to promulgate procedures or regulations to deal with the influences on vulnerability discussed in this chapter, further political will is required to monitor and enforce the standards or statutes. In 1992, Dade County, Florida had one of the toughest building

codes in the U.S.A., but much of the damage caused that year by Hurricane Andrew occurred because buildings were not designed in accordance with the code and because poor enforcement practices failed to uncover the problems (Coch, 1995). During various tornadoes in eastern Canada, "buildings in which well over 90% of the occupants were killed or seriously injured did not satisfy two key requirements of [Canada's] National Building Code" (Allen, 1992, p. 361).

The chain of political influences on vulnerability is:

- educate and inform society about the issues involved;
- enact appropriate decision-making and management; and
- monitor and enforce the decisions which are taken.

As with the chain described at the end of section 3.3, a difficulty at any stage in this process can have detrimental impacts on vulnerability.

3.6 Conclusions: Vulnerability and Technology

The examples in this chapter foreshadow the many challenges in managing vulnerability to natural disasters. Vulnerability arises from a combination of diverse factors and there are sequences of conditions which must be satisfied before society will have an appropriate grasp on all aspects of vulnerability. Technology plays an important role in these issues, particularly as it permits society to expand and explore: to settle new, and at times vulnerable, areas (Burton *et al.*, 1993); to partake in new, and at times vulnerable, lifestyles; and to try out new, and perhaps vulnerable, policies and procedures. Technology provides a strong degree of protection to society, yet society accepts this protection with few questions. Eventually, however, technology will fail at some level, such as being overwhelmed by an inevitable extreme natural hazard event, and then society does question its vulnerability and the role which technology played in achieving that state of vulnerability. The role of technology in influencing and solving challenges of vulnerability are detailed in the following chapters.

4. Tool of Technology

4.1 Introduction

As discussed in Chapters 2 and 3, society is highly vulnerable to natural disasters and the vulnerability arises from numerous sources. As discussed in section 2.4, there are many tools which society uses, individually and in combination, for managing vulnerability to natural disasters and one of these tools is technology. Using the tool of technology lies in the realm of engineering. This chapter explores that realm by examining the role of engineers (section 4.2), the framework used by engineers for managing vulnerability to natural disasters (section 4.3), and the main challenges inherent in using the framework (section 4.4).

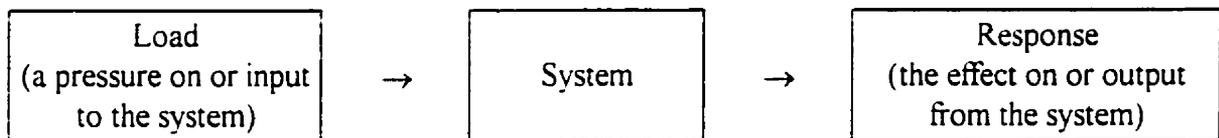
4.2 Role of Engineers

Technology refers to the systems, techniques, designs, and approaches created and used by engineers (section 2.4). Engineers play roles throughout the entire process of creating and using technology, including basic research, development, testing, implementation, operation and maintenance, monitoring, decommissioning, and analysis of these stages.

4.3 Framework Used by Engineers

Figure 4-1 illustrates the framework which engineers apply in the case of designing for natural disasters (Adams and Karney, 1989).

Figure 4-1: Framework which Engineers Apply in Designing for Natural Disasters
(Adams and Karney, 1989; see text for details)



The elements of Figure 4-1 are described in sections 4.3.1 (system), 4.3.2 (load), and 4.3.3 (response); the system is described first for reasons of clarity. Table 4-1 lists examples of the framework.

4.3.1 System

The system can comprise any combination of the three following components:

- the environment, or a subset such as a waterway, a watershed, an ecological hierarchical level, or a forest;

Table 4-1: Examples of Loads, Systems, and Responses for Natural Disasters

Possible Load	Possible System	Possible Response ¹
Horizontal and vertical shaking loads on structural supports due to an earthquake.	Technology: bridges.	Loss of the transportation lifeline (i.e., collapse of the bridges).
Ice loads on above ground power lines or heat loads on underground power lines.	Technology: the power conduit.	Loss of the energy lifeline (i.e., blackouts).
Wind loads on and air pressure gradients across walls and roofs due to a tornado.	Technology: houses, mobile homes, and recreational vehicles.	Loss of shelter (i.e., destruction of the buildings).
A heavy rainfall.	Technology: dams.	Loss of the water supply or lifeline (i.e., failure of the dam and flash flooding).
A newly emerging microbial pathogen transferred through contact with body fluids.	Society: people who have been given blood products or who practice unsafe sex or unsafe drug use.	Loss of human health and/or life (i.e., an epidemic of the pathogen's disease).
Several days of cold air temperature.	Society: people who cannot afford adequate heating.	Loss of human health and/or life (i.e., hypothermia casualties).
A collision between a large asteroid and the Earth.	Environment: the biosphere	Loss of ecosystem health and/or life (i.e., a global, mass extinction).
Underwater volcanic eruption.	Environment: area surrounding the volcano.	Loss of stability in the ocean (i.e., a tsunami).
Tsunami.	Society: people at the affected coast. Technology: structures built on the affected coast.	Loss of human and ecosystem health and life, shelter, and property (i.e., flooding).

¹All the responses listed here imply a failure of the system under the load. Other possibilities include no response, alteration of the system without failure, or alteration of the system under the load followed by a return to the original state (or to almost the original state). The possible responses listed in the table essentially describe potential losses from, or the threat to, the system by the load.

- society, or a subset such as a country, a town, an ethnic group, a linguistic group, an age group, a socioeconomic class, or an occupational group; and
- technology, or a subset such as bridges, information systems, energy lifelines, high-rise buildings, or schools.

Engineers generally have responsibility for, and play a role in, systems of technology, or systems of the environment and society which are closely related to technology. Discussions relating to engineers assume that such systems are being considered.

4.3.2 Load

The load is a pressure on or input to the system, and can be of either internal or external source. The load can originate in the environment, in which case it is a natural hazard. The load can also originate in society, in which case it is vulnerability. If the load originates in technology, then the situation would normally be considered to yield "non-natural" responses, such as a non-natural disaster (Table 2-4). Even when the technological load is transferred to the environment or society, the disaster would be considered to be non-natural. This situation is discussed in section 2.9 with reference to Table 2-5; for example, a technological load was transferred to the environment to produce the London fog in December 1952. This thesis does not regard such events as natural disasters.

The same load can often be viewed as being generated from either within or outside of the system. Earthquakes are ostensibly external to the system of Tokyo and blizzards are ostensibly external to the system of Moscow, yet the inhabitants of those cities are aware of these potential loads. Engineers, along with other sectors of society, have put immense effort into helping these systems deal with the potential load. The system changes with these actions. The inhabitants have adapted their surroundings and lifestyles based, among other factors, on the perceived threat from the natural hazard.

Thus, an "external" load is not entirely external; most natural hazards are part of the system of the planet Earth and all natural hazards are part of the system of this universe, or all universes--a rather large system which is difficult to analyze. Therefore, labelling a load as "external" actually means that the load is perceived to be external to the system, especially for design purposes. This externality for design purposes is somewhat artificial because it is the subjective selection of the system which determines whether the load is internal or external. This subjective decision, though, enables the selection of a system which is of reasonable size for assessing, describing, and analyzing vulnerability and the impact of technology.

4.3.3 Response

The response is the output from the system or the system's effect on the environment which arises due to the influence of the load.

4.3.4 Using the Framework

Engineers select objectives for design along with methodologies of selecting these objectives.

The three-stage framework in Figure 4-1 is used as follows:

- | | |
|----------------|--|
| Load/Response: | Engineers select objectives for what response is desired for a given load. |
| System: | Engineers select a design which they believe fulfils the load/response objectives. |

Engineers understand and can predict what occurs throughout the sequence in Figure 4-1 relatively well. Given a beginning (a load), the system can often be designed to achieve a desired response with a reasonable level of accuracy and precision. Therefore, engineers have generally adopted the approach of stating "Tell me the problem--define it for me--and I will solve it according to your definition". Usually engineers do a good job of solving the problem according to the given definition, so that the results are accurate and appropriate, but only for the given problem.

Finding a "beginning"--i.e., a load--is the main challenge for the engineer, although this issue is seldom recognized. The engineer might not have the opportunity of assisting the definition of the problem because it is usually the engineer's client who approaches the engineer after the client has identified a problem. The client explains to the engineer the problem, and hires the engineer to solve that problem. Doing otherwise is not always an option, because it is the client who pays the engineer.

As part of the job, the engineer certainly should include a critical analysis of the problem as defined by client, and possibly make suggestions on improvements, but the client might not be willing to listen or might not be able to afford additional services.

The largest community of engineers who would have the opportunity to explore the nature of problem definition would be those in research careers or positions, particularly those in academia and government. As well, other sectors of society have a responsibility to convince engineers of the need to spend time ensuring that design loads are properly selected. Such action need not be altruistic; considering that the society's safety is affected by the engineer's behaviour, other sectors of society have a clear selfish need to ensure that design loads are determined appropriately. In the end, though, the engineer is ultimately (morally and legally) responsible for the work s/he undertakes. If society or the client is unaware of the problem or refuses to try to solve it, then the engineer should venture, as

much as possible, to warn and to educate. The challenges of understanding the load are deep and require immense innovation to solve.

4.4 Challenges in Understanding the Load

The predominant challenges which engineers must overcome in order to properly understand the load are that:

- there are currently gaps in knowledge about natural disasters (section 4.4.1);
- past experience is normally used to design for future events, but it might not always be appropriate (section 4.4.2); and
- taking into account every potential scenario is a formidable task (section 4.4.3).

Many aspects of the above challenges, and some new ones (such as that society tends to plan for the short-term rather than the long-term), can be described as the difficulty of choosing boundaries and scales for the engineering problem (Chapter 6).

4.4.1 Understanding Natural Disasters

The state of knowledge about many properties of natural disasters contains large gaps, even with respect to the causes and origins of natural hazards. Thus, predictions of natural disaster behaviour often include surmises, and the subsequent load input during the natural disaster can be equally hypothetical.

For example, there is no accepted definition for a tornado and the formation mechanisms of tornadoes are not precisely understood. Discussions in Doswell III & Burgess (1993), and several other papers in Church *et al.* (1993), describe some of the ambiguities. The environment's persistent habit of producing multitudinous, complex phenomena also makes interpretation of these phenomena difficult. In addition to tornadoes, related phenomena are termed waterspouts, landspouts, funnel clouds, fair weather vortices, gustnadoes, and dust devils, although dust devils have a different manner of formation than the preceding phenomena (Woodcock, 1991). Although the load produced by all of these phenomena can be similar, the engineer must be aware that any differences amongst the phenomena (rather than just amongst the terminology) could lead to real differences in the load.

These knowledge gaps lead to statements such as "we don't design for tornadoes...because we don't know what to design for" (by Alan Davenport, quoted by McCulloch, 1994). As a fundamental fact, the veracity of this statement is questionable, but it does provide an appropriate summary of the problems which engineers face when selecting loads for tornado design. Similarly, there is still a debate about how likely it is for a tornado to hit the centre of a large urban area, as the

influences on tornado behaviour from urban heat islands and from surface roughness due to skyscrapers is not well-known (McCulloch, 1994).

A geological example of the challenges in understanding natural disasters is earthquakes. Generally, the model of tectonic plates covering the Earth yields good long-term predictive capabilities in terms of the probability of an earthquake with a certain magnitude striking a geographical area. The short-term predictive capabilities, though, are fairly poor, particularly for high-magnitude earthquakes. Therefore, for long-term planning, engineers have a reasonable idea of the geographical areas subjected to loadings caused by earthquakes, yet there are problems. Predictions for earthquake location can only be as good as the model of tectonic plates. Strong earthquakes strike far from known tectonic plate boundaries, in supposedly aseismic zones such as the Australian outback and northern Québec (Ungava). Either there are undiscovered faults or at least some earthquakes are being caused by another mechanism. Any weakness in seismologists' understanding may become a weakness in engineering design.

The "undiscovered faults" hypothesis also applies to the issue that the load from earthquakes in known seismic areas can be surprising (Bolt, 1993). On January 17, 1994 near Los Angeles, a previously unknown fault caused an earthquake which killed 61 people and resulted in approximately US\$20 billion (1994 dollars) of damage (FEMA, 1997; Klebs and Sylvies, 1996). The Northridge earthquake, as the event is known, was also surprising in that most of the damage resulted from vertical shaking, whereas most earthquake designs had assumed horizontal shaking loads (Coch, 1995). Exactly one year after the Northridge earthquake, on January 17, 1995, a region in Japan which was not thought to be too vulnerable to earthquakes was hit by one. The city of Kobe and the surrounding area were devastated by 5,426 dead, 26,804 injured, and approximately US\$125 billion (1995 dollars) in damage (Kuribayashi *et al.*, 1996; Lekkas *et al.*, 1996). The damage was exacerbated by building codes written to protect structures from typhoons, which were assumed to be the main natural hazard of concern in that region (Smith, 1996).

The lesson from tornadoes is that the understanding of the causes of a natural hazard phenomenon is not always complete. The lesson from earthquakes is that a good understanding of (some aspects of) a natural hazard phenomenon does not necessarily yield a good predictive capability for that phenomenon. Analyzing the potential of predictive capability for a phenomenon is also not necessarily straightforward. For example, even if precise predictions are not feasible, it might be known (or believed) that a certain precision of prediction is achievable or that the limits of prediction could be well-defined. Predictions can apply to any spatiotemporal scale (such scales are

discussed in sections 6.2 and 6.3) and indicating the limits and limitations of predictive capability for a phenomenon² provides useful information, even if the phenomenon itself cannot be predicted. In fact, stating that a phenomenon is inherently unpredictable is a precise prediction of the phenomenon's behaviour.

Furthermore, even if a natural hazard phenomenon is well-understood and can be accurately and precisely predicted, there is no guarantee that the ability or desire to engineer for managing vulnerability will exist. For example, the causes, physical behaviour, and consequences of tsunamis are well-known, but the most effective solution currently available is to monitor the formation of tsunamis, warn the population, evacuate, and rebuild. Otherwise, large-scale coastal engineering with severe environmental implications would be necessary to protect populations and property from tsunamis.

The challenge in understanding the load which this section discusses can be summarized as:

- knowledge gaps exist;
- knowledge does not imply predictability; and
- neither knowledge nor predictability imply successful engineering for managing vulnerability.

4.4.2 Using Past Experience to Define Problems

As occurred in the Kobe, Japan area where buildings were designed for typhoons leaving them vulnerable to earthquakes (section 4.4.1), design load problems are often defined based on past experience in a region. The historical record of design loads which would have been required to prevent a disaster form the basis for contemporary designs. The legal/political sector of society tends to implement regulations based on previous failures/disasters or near-failures/disasters, and thus engineers (are required to) design in this manner. The problem is defined for the engineer based on previous incidents. For example, Jamaica, Japan, and Los Angeles promulgated their first building codes for seismic protection after extensive damage from earthquakes in 1907, 1923, and 1933 respectively (Levy and Salvadori, 1995). In Manitoba, flood plain protection is based on the worst historical flood on record (IJC, 1997).

²The importance of knowing limits and limitations of predictability manifests in relation to the fascinating worlds of quantum mechanics, chaos, and randomness. These topics are so vast as to preclude even a brief discussion, which would necessarily be too simplistic to be worthwhile. They are mentioned in this footnote simply to provide a frame of reference outside of natural disasters for predictability issues.

This approach is frequently reactive or after-the-fact engineering. Following a natural disaster, there is an impetus from society to ensure that a recurrence of that event producing similar damage cannot occur. In contrast, preventive engineering tends to be more sustainable, as described in Chapter 5.

The focus on using past events is related to the theory of uniformitarianism, which assumes that environmental processes of the past are similar to those of today and the future. This assumption is reasonable, since the current understanding of physical laws is that they do not change perceptibly on Earth over time, even though society's understanding and interpretation may change. The application of uniformitarianism, however, can be flawed.

In contrast to Manitoba, the U.S.A. implements flood plain protection based on the 100-year event (IJC, 1997); i.e., the flood which has a probability of 0.01 of striking in any given year. The 100-year event is calculated using statistics of past events. The problem with this approach is that a natural hazard usually comprises a combination of different events each of which has its own return period, and each return period is only somewhat dependent on the other events' return periods. For example, a flood can be simplistically described as a certain water level or a certain flow rate, and observations of these levels and flow rates over many years could be statistically analyzed to yield return periods for certain water levels and flow rates. There are, however, several methods of attaining a certain water level or flow rate and some methods have many steps. For example, heavy rainfall or a quick snow melt upstream could each produce the same water level or flow rate. Floods due to heavy rainfall are also influenced by soil saturation and runoff properties. Floods due to snow melt are influenced by air temperature, surface temperature, insolation, and snow depth (which is influenced by prior precipitation rate, air temperature, surface temperature, and insolation). Each meteorological, hydrological, or pedological variable has its own set of statistics and its own set of return periods with varying degrees of independence from each other.

There are correlations, but a 100-year snowfall does not necessarily imply a 100-year snow melt, and a 100-year snow melt or a 100-year rainfall does not necessarily imply a 100-year water level or a 100-year flow rate. Each event of this natural hazard chain has its own return period. Furthermore, the same maximum water level or flow rate does not necessarily produce the same design loads for engineering works. The rate of change of water level and flow rate, the amount of sediment in the water, the time period of maximum value, and the total water throughput all influence the ultimate design load experienced. Similarly, during an earthquake, a 100-year fault slippage distance or a 100-year moment magnitude does not necessarily imply 100-year vibration loads.

Numerous variables and rates of change define a natural hazard, so determining a return period for a natural hazard is complex, requiring several inputs.

The problem is the separation between the initial natural hazard event and the design load. Designs tend to be based on the event at the end of the natural hazard chain, such as water level, flow rate, or vibration load. Designing for the event near the start of the natural hazard chain--such as rainfall, snow melt, or fault slippage--is not always practical. The transition from the statistics of these hydrometeorological and geological data to the statistics of design loads must be completed.

Even if statistics for natural hazard events could be accurately translated into statistics for design loads, plans based on the 100-year event would still incorporate an implicit assumption that the 100-year event of the past equals the 100-year event of the future; i.e., statistical properties of natural hazard events are unchanging (uniform) in time. This assumption is ostensibly reasonable, provides a useful rule-of-thumb, and might actually be correct. If the assumption happens to be inappropriate, there can be devastating consequences in the case of underestimating the expected flood, or society may have wasted resources in implementing protective solutions which are not needed, in the case of overestimating the probable flood.

There is a particular danger that natural disaster properties are changing relatively rapidly, due to either anthropogenic or natural processes. For example, changes in global climate, deforestation, and engineering waterways all affect the transport of water through a watershed, implying that future flood statistics could be radically altered from those of the past. The past is certainly a good model for the future, but judgement is required when deciding whether or not the past is a good enough model for the future. In selecting design loads, the engineer should be aware of these problems, and should be prepared to propose innovative and flexible solutions which could be appropriate for a wide range of, or even changing, design loads.

4.4.3 Designing for Every Potential Scenario

Furthermore, the arbitrary selection of a return period for design leaves society susceptible to any event which exceeds the return period. As alluded to previously, a N -year event has a probability of $1/N$ of occurring in any given year. Thus, although a 500-year event is unlikely to be witnessed for several generations--there is approximately a $2/3$ probability that it will not occur in the next 200 years--it could occur tomorrow. Similarly, there is more than a $1/3$ probability that a 100-year event will not occur within the next century. An additional problem is interpreting the meaning of a N -year event for data sets which span less than N years, since the validity of a statistical model beyond the realm of the statistics used to develop the model is questionable. There are particular concerns when

outliers, particularly near the limits of the data set, are eliminated. Such outliers might represent non-linearities in nature³ rather than anomalies. Furthermore, a data set which spans less than N years would miss peaks or troughs in an environmental cycle with a period greater than N years, and the statistical analyses would be correspondingly flawed. Predicting which design loads will and will not be necessary on the basis of return periods involves a great deal of uncertainty.

Conjunctive, or simultaneous, events present another realm which involves a great deal of uncertainty. Conjunctive events tend to have long return periods, and the discussion in the previous paragraph also applies to designing for conjunctive events. Conjunctive events could be multiple natural disasters. For example, in 1991 in the Philippines, the climactic eruption of Mount Pinatubo occurred hours before a typhoon made landfall (Chapter 11). The combined load of volcanic ash, wind, and water would not necessarily be an anticipated design load. A hypothetical scenario of conjunctive natural disasters would be a major earthquake striking Vancouver in the middle of a blizzard or during heavy flooding from the Fraser River. Conjunctive events could also be a combination of natural and non-natural disasters such as terrorists attacking military relief operations during a flood or an earthquake in the midst of a fire at a tire dump.

Another multiple-event category is disasters which occur in linear sequence. Such events can also be challenging to predict, even though later events are directly caused by the caused by earlier ones. An earthquake leading to a flash flood from a dam failure and a jumbo jet crashing into a residential neighbourhood during a blizzard are two examples. Disease often follows natural disasters, particularly in the developing world where damage to the water treatment and distribution system often leads to outbreaks of cholera and typhoid. An example from California was the outbreak of coccidioidomycosis (the flu-like "valley fever") following the Northridge earthquake of January 17, 1994; victims had inhaled the pathogenic fungal spores with dust which had been stirred up by the earthquake, the aftershocks, and the cleanup (Coch, 1995). Famine frequently follows floods and droughts, particularly in the developing world. An example of unrelated multiple disaster events in linear sequence occurred in northern Afghanistan: on May 30, 1998 a strong earthquake

³Non-linearity as an expectation rather than as an exception in nature is another characteristic revealed by explorations into chaos (see also the discussion in footnote 1 in section 4.4.1). Gleick (1987) writes "The mathematician Stanislaw Ulam remarked that to call the study of chaos 'nonlinear science' was like calling zoology 'the study of nonelephant animals'" (p. 68).

flattened dozens of villages, killing thousands of people, but in the aftermath, relief operations were hampered as torrential rains washed out roads and prevented helicopters from flying to the region.

There are a few instances of multiple events assisting the mitigation of natural disaster effects. For example, a volcanic eruption or an earthquake during a period of heavy rain would result in less damage from fire than normally would be expected. Most multiple-event scenarios, though, add significantly to the consequences of a disaster event, not only in the combination of hazards but also in their unexpectedness which can derail effective plans, introduce unanticipated challenges, and induce confusion.

Therefore, predicting rare events (conjunctive or otherwise) for design loads is extremely challenging. At some point in the design process, however, a scenario for the design load has to be selected in order to proceed with the design. Given the uncertainties, it might seem reasonable to err on the side of caution by, for example, designing for a 1000-year event or detailing many conceivable multiple-disaster scenarios. There would also likely be a substantial margin of safety even if the return period statistics were incorrect or if the problems with calculating return periods (as discussed earlier in this section and in section 4.4.2) were to manifest. Such an approach requires an immense amount of resources, potentially to the point where creating the proposed system is not affordable, in terms of time, money, labour, or environmental resources. As well, the design might provide reasonable protection from or during natural disasters, but might have detrimental impacts on other facets of society. For example, underground dwellings provide superb protection against tornadoes, but severely impact both the environment and society's quality of life.

Moreover, the most exacting designs cannot provide absolute protection. Designs for a 1000-year event will be susceptible to a 1500-year event while underground, tornado-proof abodes could be highly vulnerable to flooding. Designing to eliminate vulnerability to every conceivable natural disaster event is not possible. The engineer must investigate and prominently indicate the limitations of their designs while attempting the immense challenge of designing systems which produce desired responses to a variety of loads individually and in combination.

4.5 Conclusions

Engineers are faced with design load specifications which are developed under extensive uncertainty. At some point in deciding which set of design loads to consider and which design loads to assume, arbitrary and subjective decisions must be made. During this process, the engineer must be aware, and explicitly acknowledge, that the predominant challenge in the framework which engineers use lies in the design load. The engineer must also perceive the limits of knowledge and

professional capability: natural disasters are not all well-understood phenomena, past experience is not entirely appropriate for defining desired design loads, and the ability to predict and take into account all possible events is limited.

Avoiding the difficult and subjective decisions about design loads is not possible, but it is possible to design with the uncertainty in mind and to design so that deleterious impacts are reduced, if unexpected events occur. As well, the engineer should lucidly describe uncertainties and should indicate how society can deal with the uncertainties. The engineer should be active in educating society that engineers do not have all the answers.

Considering every potential scenario is impossible, and it is certainly not an effective use of resources to try. The engineer does not have to anticipate every possible scenario, but should aim for adaptable, flexible designs which are appropriate for a wide range of scenarios. By choosing appropriate design loads, the engineer will ensure that the creation of the system, and the system's response to a wide range of design loads, assist in properly managing society's vulnerability to natural disasters.

5. Preventive Engineering

5.1 Introduction

Preventive engineering involves tackling a problem at its root cause or causes. In contrast to alleviating detrimental consequences which have occurred, preventive engineering techniques aim to anticipate detrimental consequences and avoid their occurrence. In reference to Figure 2-1, the focus for society's activities with respect to natural disasters would be on mitigation and prevention activities. Preventive engineering tends to be the best approach to engineering problems, since a problem tackled at its root often yields the most effective, sustainable solution.

As discussed in section 4.4, especially section 4.4.3, there are many difficulties in correctly anticipating all potential natural disaster situations, and so response/recovery and preparation/planning activities are still necessary components of society's activities. Proper mitigation/prevention techniques, though, can be powerful in reducing the need for, and resource use of, these other activities, hence it is important to focus a significant portion of efforts on mitigation/prevention.

From Chapter 2 and Figure 2-1, the root cause of natural disasters is based in risk, the combination of natural hazards and vulnerability. Therefore, there are two potential areas to implement preventive engineering: preventing natural hazards (section 5.2) and preventing vulnerability (section 5.3).

5.2 Preventing Natural Hazards

Society's activities continually influence natural hazards, both intentionally and unintentionally. Sometimes natural hazards are caused or augmented and at other times natural hazards are curtailed or prevented.

5.2.1 Preventing Astronomical Hazards

Preventing astronomical hazards involves astronomical challenges, and there have not yet been formal attempts. Manipulating stellar properties to prevent flares or geomagnetic storms would be an immense engineering undertaking and excessive care would have to be taken to ensure that solar radiative properties were not affected too much. There is a strong movement to monitor space for celestial objects on a collision course with the Earth, with at least four long-term, continuous programs in operation (see Part II in Gehrels, 1994), but such actions do not prevent the hazard. The idea which most closely resembles collision prevention is using technologies such as nuclear weapons and lasers to destroy or alter the course of incoming objects, but such ideas are still in the conceptual stage (see Part VII in Gehrels, 1994).

5.2.2 Preventing Biological Hazards

Habitat destruction and species extinction is one method which society has used, deliberately and unwittingly, to eliminate biological hazards. Sometimes the extinction is local (e.g., wiping out malaria from the southern U.S.A. by exterminating the *Anopheles* mosquito vector) and sometimes it is global, as in the case of small pox. Engineers often play prominent roles, through contributions such as developing production processes and equipment for manufacturing, transporting, and applying biocides.

This approach to preventing biological hazards is inappropriate for managing vulnerability to biological disasters. The disadvantages of anthropogenic habitat destruction and species extinction are well-documented in practical and theoretical ecology (see, for example, Begon *et al.*, 1990; Jeffries, 1997; Noss, 1995; Wilson, 1988) because areas such as food production, medicine, recreation, and materials development are impacted detrimentally (see also Bell, 1993; Dobson and Carper, 1993). The biological hazard itself is often advantageous to society, such as venom from a saw-scaled viper used to produce drugs which combat heart attacks (Eliot, 1998a), the poisonous nightshade (*Atropa belladonna*) used to detoxify PCBs (Eliot, 1998b), and the large amount of meat and hide which can be obtained from large and often dangerous game animals.

In the microbial realm, many preventive techniques are developed with significant engineering input, but medical scientists, politicians, doctors, social scientists, and geographers, among others, play prominent roles too. Standard preventive techniques are developing vaccines (which often are developed using genetic engineering) and implementing vaccination programs; preparing other public health measures such as modern health facilities, quarantine plans, and educational programs; considering disease prevention as one factor in appropriate urban and rural planning; and supporting socioeconomic policies which aim for poverty reduction.

Encompassed in these techniques are the engineering areas of providing a clean water supply and proper waste treatment and disposal. Examples are:

- Following separate cholera epidemics in the 19th century, London and Paris constructed their first sewage systems in order to prevent further outbreaks of this biological hazard (Viessman and Hammer, 1993).
- Deficiencies in Peru's drinking water treatment system (exacerbated by bickering between Peruvian and American governmental agencies) permitted the *Vibrio cholerae* bacterium, which causes cholera, to establish itself in Peru in 1991, whereupon it spread throughout South and Central America (Anderson, 1991).
- Stagnant water collected by discarded tires and coconut husks are used for egg-laying by some *Aedes* species, the mosquito vector of the dengue fever virus, and so appropriate

waste management of tires and coconut husks would be a factor in preventing incidences of dengue fever (Innes, 1995).

5.2.3 Preventing Geological Hazards

Methods of using technology to control seismic events were often discovered accidentally. An underground nuclear bomb test in Nevada in 1968 induced an earthquake of Richter magnitude 6.3 and aftershocks up to Richter magnitude 5.0, which led to suggestions of inducing more frequent, lower-magnitude earthquakes with underground explosions in order to prevent a single high-magnitude shock (Waltham, 1978). The influence of underground nuclear explosions on seismicity is still a subject of debate with some authors claiming that the correlation can be skewed by tides or atmospheric pressure (see Console and Nikolaev, 1995).

Filling reservoirs for inducing low-magnitude earthquakes, or draining a reservoir to prevent a large earthquake, represents another earthquake prevention technique. In Arizona in 1935, the artificial reservoir Lake Mead on the Colorado River was accidentally discovered to induce earthquakes through the weight of the water on fault lines (Smith, 1996; Waltham, 1978). Reservoirs also increase the groundwater pressure which would reduce friction along a fracture, causing low-magnitude shocks. Such "lubrication" of a fault can be achieved by manipulating the groundwater levels in any fashion, including the injection of water into deep boreholes. In the 1960's, using injection to induce earthquakes was discovered inadvertently near Denver and afterwards, the United States Geological Survey (USGS) conducted reasonably successful experiments in Colorado (Bolt, 1993).

The amount of damage reduction which can be achieved through altering earthquake patterns is not clear. Structures can fail due to fatigue from numerous, small shocks as well as failing due to one large shock, and it is disputable as to which scenario would actually cause more damage or how vulnerability would be influenced by each scenario. This concern illustrates the separation between an initial natural hazard event and the design load experienced from the natural hazard event, as discussed in section 4.4.2. The fear of inadvertently causing a major earthquake is another powerful restraint on implementing techniques of earthquake prevention. The Koyna Reservoir near Bombay, India was filled in 1967 and caused an earthquake which killed 177 people (Waltham, 1978).

Volcanically-induced seismic events could conceivably be controlled by providing an artificial outlet for the gases or magma which cause earthquakes. Excavating surface material or drilling holes are possible techniques for creating the outlet. The amount of material needed to be moved and the depth of the holes required would often be far beyond that which could be achieved quickly and

cheaply, and so success might be limited. There is also the danger of inducing an unwanted volcanic explosion since complete control of the volcanic processes could never be attained.

Although engineers currently do not have techniques for stopping or controlling volcanic eruptions, affiliated hazards can often be controlled. Lahars (mudflows) and water from jökulhlaups (flash floods from a glacier, sometimes caused by a volcanic eruption melting ice) can be directed by hydrological engineering techniques, including dams, levees, and floodways. Lava flows can also be diverted with analogous barriers and diversions. Barriers can be built, but can also be created by blowing up solidified lava walls thereby blocking the lava with debris. As well, an advancing lava flow can be doused with water, cooling it and forcing the lava to spread sideways. Even if such techniques do not divert the lava flow, they usually slow it down, providing more time for evacuation and for natural cooling of the lava. Barriers were both built and created with explosives during a 1983 eruption of Mount Etna in Sicily, successfully protecting tourist areas from damage (Coch, 1995). On the island of Heimaey in Iceland in 1973, seawater was pumped onto a lava flow, possibly preventing the blockage of the town of Vestmannaeyjar's harbour (National Geographic, 1997).

Barriers and landscape engineering could be used to prevent landslides, rockslides, and poison gas emissions. The effectiveness of these solutions cannot be entirely assured, particularly in the long-term, because, just as with seismic energy and rising magma, the material from landslides and rockslides along with poison gas must be released at some point. Barriers will rarely block these hazards completely since gas pressure would build up and rocks and earth would pile up behind the barrier. Barriers and landscape engineering, as with lava, would serve to redirect or control the release of these hazards.

5.2.4 Preventing Hydrometeorological Hazards

Engineers have been at the centre of attempts at preventing floods through projects such as dams, levees, floodways, and reconstructing the courses of waterways. Sometimes these efforts have been successful, such as the floodway built in 1968 to divert Red River waters around Winnipeg, Manitoba. This floodway was used 18 times in the thirty years following its construction, most notably during the 1997 Red River flood in which Winnipeg sustained minimal damage while other communities along the Red River were inundated causing CAN\$ several hundred million (1997 dollars) of damage (IJC, 1997). At other times, poor planning and poor use of technology augmented a flood disaster, as occurred along the Mississippi River, U.S.A. in 1993 (Changnon, 1996) and along the Saguenay River, Québec in 1996 (Environment Canada *et al.*, 1996).

Cotton and Pielke (1995), Kahan *et al.* (1995), and Kriege (1984) describe cloud seeding experiments around the world for suppressing hail, enhancing precipitation (to prevent water shortages and droughts), and affecting the path and severity of hurricanes. No experiments have yielded a success which has been generally accepted, and debates continue with respect to the effectiveness of cloud seeding. Intensive efforts at cloud seeding have dwindled recently, partly due to the contemporary environmental ethic of minimizing potential environmental impacts during experimentation, and partly due to the fear of litigation if weather is apparently modified and causes damage. One of the first such cases occurred in 1947 when General Electric Corporation seeded a hurricane which subsequently changed direction and made landfall on Georgia, prompting lawsuits for hurricane damage. Programs have also been impeded by a lack of understanding of the physics behind cloud seeding. Scientists and funding agencies are reluctant to support large-scale experiments without being able to compare theoretical results with experimental results.

Anthropogenic climate change could influence hydrometeorological hazards, potentially preventing some of the hazards. Contemporary experience with rapid climate change (which might be either anthropogenic or natural), however, illustrates the disadvantages of likely scenarios. Most literature on climate change and natural hazards (see for example Burton *et al.*, 1993; Environment Canada *et al.*, 1996; Etkin and Brun, 1997; Vellinga and Tol, 1993) warns of large uncertainties, but indicates the strong likelihood of increases in both the frequency and severity of extreme events due to global warming, particularly with respect to storms, floods, and heat-related disasters, but not necessarily with respect to cold-related disasters. The biological hazards of vector-borne diseases--including malaria, schistosomiasis, onchocerciasis, dengue fever, and yellow fever--are expected to affect larger spatial ranges due to global warming (Environment Canada *et al.*, 1996). These examples mainly relate to the augmentation of natural hazards, thus current trends in climate change will be unlikely to assist in natural hazard prevention.

5.2.5 Challenges in Preventing Natural Hazards

Sections 5.2.1 through 5.2.4 have identified significant problems in implementing natural hazard prevention. In any case, preventing natural hazards is not a particularly appropriate approach to managing environmental processes, because many natural hazards processes are extremely important to the environment, and thus to society. For example, section 2.6 discussed how tectonic activities are forces of both construction and destruction; preventing tectonic activity to avoid the destructive aspects will also prevent the constructive aspects. As well, volcanoes contribute significantly to biogeochemical cycles of metals, including aluminum, arsenic, cadmium, copper, iron.

lead, mercury, and zinc; assist the sulphur, chlorine, and nitrogen cycles through gas emissions; and contributed enormously to the atmosphere's evolution (Butcher *et al.*, 1992; Schlesinger, 1991). Decker and Decker (1998) estimate that about "25 percent [by mass] of the water, chlorine, and nitrogen in the Earth's atmosphere was reworked by subduction and volcanic eruption and about 75 percent [by mass] of the carbon was recycled" (p. 204). Tectonic subduction and spreading processes also cycle minerals and elements by eliminating old rock and creating new rock.

Hydrometeorological hazards involve the transfer of mass, heat, and linear momentum through the atmosphere and hydrosphere, and so are responsible for air flows, ocean currents, weather, and climate. The water cycle, incorporating precipitation, heavily influences most biogeochemical cycles (Butcher *et al.*, 1992; Schlesinger, 1991). Hydrometeorological hazards also contribute to non-chemical ecological and geological processes. Floods often deposit fertile soil layers or scour out stagnant waterways while winds knock down dead trees permitting the wood to be decomposed (recycled) and leaving spaces for new growth. Glacial movement has been responsible for the good farming till, along with much of the topography, in places such as southern Ontario and Orkney, Scotland.

Some advantages of biological hazards were described in section 5.2.2. Astronomical hazards also have advantages in bringing materials to Earth, such as the Sudbury Igneous Complex near Sudbury, Ontario which is the world's largest and richest known nickel ore deposit and which is the remnants of a meteor strike approximately four billion years ago (Erickson, 1994). Natural hazard processes are based on balances amongst, interaction between, and cycles throughout the atmosphere (air), hydrosphere (water), lithosphere (Earth's surface), and biosphere (life). They are unavoidable--and essential--components of the Earth's characteristics which make the planet habitable through the provision and recycling of environmental resources. Thus, even if it were possible, significantly preventing natural hazards would severely impact the resources available to society, particularly over the long-term.

Another major concern of preventing natural hazards is effectiveness: the consequences could be a natural disaster far more deleterious than any natural disaster in the absence of such interference. Examples have already been provided with respect to the prevention of earthquakes, rain, hailstorms, and floods, and with respect to anthropogenic climate manipulation. Tradeoffs will always be present, yet they are difficult to model, analyze, and predict.

Since natural hazards are difficult to prevent, and successful prevention can lead to new dangers, preventing natural hazards is not currently appropriate for managing vulnerability to natural

disasters. Society at present should therefore not rely on prevention of natural hazards. Understanding the origins, behaviour, and consequences of natural hazards is the most important "root of the problem". This knowledge can be used for properly applying the tool of technology for managing vulnerability to natural disasters.

5.3 Preventing Vulnerability

Since managing vulnerability generally implies preventing excessive damage from natural disasters due to vulnerability, the prevention or reduction of vulnerability tends to be paramount. Vulnerability is a characteristic of society (section 2.7), so society should be able to use its activities to manage vulnerability. Technology can be used effectively for managing vulnerability, which also includes knowing when not to use technology (or using minimal technology).

5.3.1 Technology Used for Managing Vulnerability

Engineers develop technology for use during each stage of society's activities, as illustrated in Table 5-1. The development and implementation of many of the technologies are often interdisciplinary and collaborative efforts, hence not all the examples involve practising engineers¹. Because this thesis emphasizes the role of technology, and is not a treatise that compiles all technologies, only illustrative examples are provided in Table 5-1. More examples, both specific and general, are used throughout this thesis.

5.3.2 Pre-Disaster and Post-Disaster Engineering

Three points arise from the examples in Table 5-1.

First, the pre-disaster technologies and systems tend to be more event-specific than the post-disaster technologies and systems. Designing buildings for tornadoes is different than designing buildings for earthquakes--and there are even wide variations in designs used for different types of earthquakes (Bolt, 1993). The engineer has the design purpose clearly defined and implements engineering techniques for this purpose, as per the three-stage framework discussed in section 4.3 (Figure 4-1). Conversely, post-disaster technologies and systems are more similar, irrespective of the

¹This point is indicative of the dependency which society has on engineers, and the dependency which engineers have on society. As one sector of society, engineers should always be listening to, advising, and working with other sectors of society. The field of natural disasters draws on input from particularly disparate sectors of society (such as firefighters, psychologists, anthropologists, community leaders, doctors, and engineers) and the engineer must always be aware of the differences in background, training, and perspective amongst those who need and those who will be using the technology.

Table 5-1: Examples of How Technology is Used for Natural Disasters

Disaster Phase	Monitoring, Predicting, and Warning	The Built Environment	Information and education about technology and natural disasters	Equipment and devices for rescue operations	Medical technologies and systems	Models, systems, and simulations to analyze disaster events
Loose Categorization		Specific Example				
Pre-disaster (mitigation and prevention along with preparation and planning)	Models for and simulations of the behaviour of natural hazards.	Finding a chaotic strange attractor in traits of volcanic tremors (Scholz, 1989).				
	Rapid communication networks.	Cellular phones and ham radios.				
	Models, systems and simulations for disaster prediction and response.	Predicting which wind speeds will damage or destroy which buildings (Liu, 1993).				
	Technologies for monitoring and tracking natural hazards.	Doppler radar for thunderstorms and tornadoes; satellites for hurricanes and volcanic ash clouds.				
	Hydrological and landscape engineering.	Barriers and channels for landslides, avalanches, floods, lava, and lahars.				
	Materials and construction engineering.	Building codes (e.g., NRCC, 1995).				
	Land-use planning, land zoning, and community design.	Creating and enforcing no-settlement flood zones; engineering lifelines to maintain their integrity during and following an earthquake.				
	Dispelling false beliefs about natural disasters.	Teaching that rubber footwear will not protect against lightning strikes.				
	Generating knowledge and awareness about natural disasters.	CD-ROMS and WWW sites (see section 2.4) along with information pamphlets.				
	Education how to appropriately develop and use technology.	This thesis.				
Post-disaster (response and recovery)	The "Jaws of Life" for rescuing people trapped in crushed vehicles.					
	Wheelchairs, prosthetic limbs and defibrillators.					
	Mapping earthquake damage to lifelines onto fractals (Nakagawa and Satake, 1991).					

cause. Rescue operations tend to invoke similar principles for people trapped under collapsed buildings irrespective of the cause of the collapse. Medical technologies and systems respond to the observed injuries rather than the cause(s) of these injuries.

Second, the engineer's role is much more dominant during the pre-disaster phase than during the post-disaster phase. The engineer works with others to determine how much mitigation/prevention and preparation/planning is desired (the load/response objectives) and how to best achieve the desired level (the system design). The engineer is involved in assessing the needs, analyzing potential solutions, and implementing the solutions. Following a disaster event, non-engineers have the dominant roles and the technologies and systems are used as tools when and how the non-engineers choose to use them.

Third, managing vulnerability is achieved more easily during the pre-disaster phase. The post-disaster technology is important to society, but most of it patches up damage which occurred because of vulnerability. For example:

- rescue and medical technologies attempt to prevent casualties from ending up in a worse condition whereas building codes attempt to prevent casualties occurring;
- models and analyses of disaster events occur following a disaster whereas models and analyses of disaster preparations attempt to eschew a disaster event; and
- information and educational material, which is often disseminated with technology, aims to reduce the number of people who understand natural disasters through personal experience.

Pre-disaster engineering, which embodies the preventive principle, achieves more effective management of vulnerability than post-disaster engineering.

5.3.3 Challenges in Using Technology to Prevent Vulnerability

The predominant challenge which arises in using technology to prevent vulnerability to natural disasters is that society's actions are not always focussed on managing such vulnerability, and society's activities for other purposes could unintentionally increase vulnerability. For example, many people build large houses near cliffs along California's Pacific Ocean coastline, because through either ignorance or choice, they have rated a prestigious location and a beautiful view as being more important than preventing vulnerability to landslides induced by earthquakes or storms. Another example is that mobile homes and recreational vehicles are highly vulnerable to destruction by tornadoes, but are attractive--or necessary--for economic reasons. More than half of all tornado deaths in Canada and the U.S.A. occur in these dwellings ("Tornado!", 1995). Chapter 3 described various non-technological influences on vulnerability.

Even when properly managing vulnerability is the intention of society's activities, mistakes--such as poor analysis, poor judgement, or ignorance--may make this goal elusive. The eruption of the Nevado del Ruiz volcano in Colombia (summarized from Mileti *et al.*, 1991) illustrates this problem in demonstrating how one broken link in the cycle of society's activities can create a devastating natural disaster. At Nevado del Ruiz, scientists and civil defence authorities had a reasonable evacuation plan, knew what volcanic hazards were present and the vulnerable locations, were monitoring the volcano, and correctly identified the threat following an eruption on the evening of November 13, 1985. Communication and attitude difficulties at the local level caused the failure of evacuation warnings to be disseminated to the populace, and between 22,000 and 24,000 people died in the town of Armero when it was obliterated by lahars (mudflows of volcanic origin). People who received and acted upon warnings, sometimes minutes before the disaster, tended to survive. The mayor of Armero and Armero Red Cross officials were reportedly swept away as they were discussing the situation with others by radio. Approximately 1,800 more deaths occurred throughout the region, but survivors from Armero numbered around 5,000.

Another relevant case study occurred in California in 1982 when volcanologists predicted that a volcano in the tourist resort of Mammoth Lakes, California would likely erupt. Tourists stayed away and property values fell, but the volcano failed to erupt and the scientists received death threats from angry residents (WGBH, 1992). Because of this incident, any similar warnings in the future would likely be met with heavy scepticism, to the detriment of managing vulnerability by preventing volcanic disasters in the community.

Another concern is that appropriate vulnerability management might not be achievable for all natural hazards in a given location. As mentioned in section 4.4.1, building codes for Kobe, Japan deliberately reduced vulnerability to typhoons but inadvertently increased vulnerability to earthquakes. Where vulnerability tradeoffs occur, innovative and flexible solutions will be needed to determine whether or not vulnerability prevention can be well-managed despite the apparent need for vulnerability tradeoffs, and if not, to decide how to manipulate the tradeoffs. This problem is similar to the issue raised in section 4.4.3, that it is not possible to anticipate every potential scenario, particularly for multiple-event scenarios.

The solution is also similar: as many factors as possible should be taken into account to achieve the best overall solution and to achieve as much vulnerability prevention as possible. Alternatively, there are many occasions when technology for preventing vulnerability coincides with technology used for other goals, such as sustainable resource management. For example, the

vulnerability of energy lifelines to natural disasters can be reduced by implementing sustainable energy techniques, such as demand reduction and developing small-scale, renewable sources, because:

- less demand for energy implies fewer problems when energy lifelines are cut;
- decentralization implies fewer people are affected if an energy system, such as a switching station or power plant, is ruined;
- an emphasis on renewable sources implies fewer links in the source-to-consumer chain which could be impacted by a natural disaster (such as transportation networks for bringing coal to a fossil fuel plant); and
- small-scale energy systems permit locals to operate and maintain them so that if a natural disaster causes damage, there will be less need for outside help and supplies to reestablish the energy lifeline.

Engineers can alleviate many of the problems in preventing vulnerability to natural disasters by developing and implementing integrated solutions which impact beneficially on other goals of society.

5.4 Does Managing Risk Prevent Natural Disasters?

Section 5.2 illustrated the challenges and, at times the inappropriateness, of preventing natural hazards. Section 5.3 demonstrated the possibilities for preventing vulnerability. For preventing damage from natural disasters, managing vulnerability through prevention would seem to be more effective than managing natural hazards. Although risk, the combination of vulnerability and natural hazards, feeds into natural disasters (Figure 2-1), society's activities should be concentrated on preventing vulnerability rather than on preventing risk.

Risk prevention can actually lead to increased vulnerability (Green *et al.*, 1993) if the hazard is prevented but vulnerability is augmented. Wilde (1994) describes how engineering and other safety measures give people such a sense of security that, at times, they will undertake behaviour which increases their vulnerability so much that their risk level is higher than before the safety measure was implemented. Because people do not always estimate their risk correctly, behaviour which appears acceptable with the safety measure in place might actually leave people at a higher risk than they realize. Wilde (1994) presents detailed evidence from the transportation sector.

A natural disaster analogy would be if hydrological engineering reduces the impact of annual spring flooding along a river. Inhabitants downstream will become inured to the absence of floods. Because there are few floods, they will tend have decreased interest in flood-proofing activities, decreased awareness of the potential flood hazard, decreased understanding of how to predict and react to floods, and decreased ability to psychologically cope with any flood events. Monitoring and warning systems may also lapse. The hazard is minimal, but vulnerability is immense. This

phenomenon was discussed in section 3.3 with respect to psychological impacts on vulnerability: Torontonians are more familiar with blizzards and thus are less vulnerable to their impact than Dubliners. When a snowstorm hits Dublin, or a flood hits these unprepared communities, the high vulnerability can result in devastating consequences.

The difference between the snowstorm example and the flood example is the human influence. The absence of snowstorms in Dublin is naturally occurring; the absence of floods is anthropogenic and anthropogenic design must always select somewhat arbitrary design criteria, as discussed in section 4.4. When an extreme event occurs which exceeds those design criteria--as must happen eventually--the high level of vulnerability and the psychological unpreparedness create a "natural" disaster with worse consequences than could have occurred without the hydrological engineering. The natural disaster causes more damage because technology was used to prevent risk rather than to prevent vulnerability. As well, it is conceivable that the physical properties of the event are more extreme than would have occurred in the absence of the hydrological engineering. As Green *et al.* (1993) write, "In some cases, the effect of reducing the risk of some events is to increase the challenge which will be presented by more extreme events".

Using technology to prevent vulnerability of society to natural disasters helps to avoid such pitfalls. Cases where natural hazard prevention leads to risk reduction but increased vulnerability would be identified and avoided, because vulnerability would be the key characteristic in natural disaster risk management. Green *et al.* (1993) also create a scenario where, following intervention by society, damage from floods actually increases, but vulnerability decreases and economic output from the land increases. Although this scenario is hypothetical, it again supports the importance of preventing vulnerability and of integrating vulnerability prevention with other goals of society, such as increasing economic wealth and sustainable resource management (which are not necessarily opposite goals).

The achievement of sustainable practices in society is not exclusive of preventive engineering. Using technology to prevent vulnerability is useful for sustainability, even though preventing risk, preventing natural hazards, and preventing damage are less suitable (and section 2.6 also pointed out that damage is not necessarily detrimental). Preventive techniques, in vulnerability management and other areas, form a large component of achieving sustainability, because the preventive approach examines the root of problem thereby enabling a clear understanding of how to define the problem--the key challenge identified in Chapter 4.

Managing risk can prevent natural disasters to some extent, but a more suitable objective is preventing vulnerability. There are elements of managing natural hazards and managing risk, but care is required to ensure that the focus is on vulnerability. Preventing vulnerability prevents natural disasters and prevents subsequent damage--when it is appropriate to do so.

5.5 Conclusions

Preventive engineering should focus on managing vulnerability, rather than on managing natural hazards or managing risk. Preventing vulnerability implies implementing plans over a scope which is narrow enough to be dealt with realistically and effectively, but which is broad enough to encompass all necessary areas. Chapter 6 discusses boundaries and scales and suggests those which should be used for using technology to manage vulnerability to natural disasters.

6. Boundaries and Scales

6.1 Introduction

This section examines boundaries and scales for the tool of technology in managing vulnerability to natural disasters. Boundaries and scales are characteristics of natural hazards, as mentioned in section 2.5, but they also manifest through vulnerability. Explicitly recognizing them assists in determining the applicability and manner of use for technology. Determining boundaries and scales is not simple and, as with most engineering problems, subjective boundaries and scales must be used at some level of scoping the problem; i.e., defining the load (as implied by section 4.4.3). Boundaries and scales manifest spatially (section 6.2) and temporally (section 6.3). Psychological boundaries (section 6.4) and technological boundaries (section 6.5) also have significant impacts.

6.2 Spatial Boundaries and Scales

A natural disaster occurs over a spatial area delineated by boundaries which are created:

- by humanity (political-legal boundaries, such as country borders, or social-geographical boundaries, such as a religious or ethnic group settling in one area);
- by nature (geological or physical geographical boundaries, such as rivers and mountain ranges); or
- by the natural hazard event (such as a tornado's path width and length, or the region of ashfall from a volcanic eruption).

Thus, spatial aspects of natural disasters are generally given and technology is applied within those spatial limits.

Difficulties can arise if the spatial boundaries or scale of the hazard differ markedly from the spatial boundaries or scale of society. Hazards do not obey society's boundaries, yet society's boundaries can outline regions of disparate vulnerabilities. For example, Brown *et al.* (1997) concluded that Ontario's flood damage reduction program (enacted in the mid-1950's) kept non-agricultural damages to under CAN\$500,000 (1986 dollars) during the August-September 1986 floods as compared to similar floods in Michigan which produced damage of approximately US\$200 million (1986 dollars; a factor of approximately 500 more), even though Ontario had higher flood yields.

Volcanoes provide another example of disparate vulnerabilities across the Canadian-American border. Unlike the U.S.A., Canada has not had a major volcanic eruption for more than a century (Smithsonian Institute, 1997). Consequently, "few resources of money and time are devoted to the study of active volcanoes" in Canada (Basham *et al.*, 1995) compared to the extensive volcano

programs run by the United States Geological Survey (USGS) and the Global Volcanism Program (GVP) at the Smithsonian Institute. Canada's complacency leaves the nation highly vulnerable to volcanic threats, not only from the 20 Canadian volcanoes which have erupted in the past 10,000 years including two in the 19th century and one in the 18th century (Smithsonian Institute, 1997), but also from American eruptions, the main volcanic threat to Canada. Several pre-historic eruptions from American volcanoes devastated large expanses of Canadian forest, but more recently, drifting tephra from American eruptions has caused aviation and air quality concerns for Canadians at least four times since 1980 (Basham *et al.*, 1995). Despite the need, an engineer seeking contracts in Canada in volcanic hazard consultancy or volcanic disaster prevention would find little work--although a career in this area could be successful in other countries--because political boundaries have imposed spatial constraints which are not obeyed by the natural hazard.

Spatial constraints are often placed on, or selected by, the engineer for design, but the spatial constraints are not always the most appropriate with the result that the design is not always the most appropriate. Unfortunately, resolving problems related to selecting an appropriate spatial scale for managing vulnerability to natural disasters is not straightforward. The example of building codes demonstrates how selecting different spatial scales leads to different problems.

The Constitution of the U.S.A. prohibits the federal government from enacting building codes, so they are the responsibility of local authorities states, counties, and cities (Levy and Salvadori, 1995). Tornadoes, earthquakes, and hurricanes--common hazards in many areas of the U.S.A.--usually traverse numerous local authorities, and the difference in spatial scales of the hazard and the building codes could lead to discrepancies in regulations without adequate communication amongst local authorities.

In Canada, the Constitution Act places the responsibility for regulating buildings on provincial and territorial governments which (except perhaps for eastern coast hurricanes) are generally larger than most natural hazards. Provincial and territorial building codes, though, are often based on the National Building Code of Canada which is "a code of minimum regulations for public health, fire safety and structural sufficiency with respect to the public interest" (NRCC, 1995). If these minimum regulations, designed for a vast country with disparate environmental regions, are assumed to be adequate for all of Canada, then local hazards might not be accounted for in local regulations--until a disaster occurs.

Conversely, overzealousness in building codes can be wasteful. Tornadoes and hurricanes recorded in Ontario occurred in or south of Sudbury, and requiring structures less vulnerable to

destruction by strong winds seems reasonable for this region. Unless there is sufficient concern that strong wind hazards could affect all cities in the province, requiring buildings far north of Sudbury to adhere to the same standards as buildings in or south of Sudbury might seem unnecessary. This attitude is reminiscent of the trap of only preparing for a hazard which has been previously experienced (section 4.4.2); yet if studies are carried out appropriately and determine that there is a low probability of threats from wind hazards, then there is a strong argument for avoiding unneeded building code regulations. Determining what "appropriate" studies are, what a "low probability" is, and how to monitor for changes to the hazard are part of the challenges of managing vulnerability to natural disasters.

To resolve the problems of spatial boundaries and scales, innovative and flexible solutions are needed. Engineers working in various authorities have the ability to communicate with each other in order to establish suitable codes and regulations for each authority--assuming that their superiors or contracts provide them with enough resources. Past, present, and potential future natural hazards at varying spatial scales can be mapped and the information can be disseminated--assuming that there is funding for such research. Society's spatial boundaries are constraining, but society can choose to overcome them. For example, following the January 1998 ice storm in eastern Canada which downed power lines serving approximately three million people, hydro crews from several Canadian provinces and American states travelled to these areas to cooperate in rebuilding the energy lifeline. Similarly, one hundred firefighters from the U.S.A. assisted in battling forest fires which ravaged Alberta and British Columbia in the first week of May 1998. There are challenges in overcoming spatial boundaries--notably the political and legal implications--but appropriate use and sharing of technology can be inhibited by yielding to unnecessary spatial boundaries.

6.3 Temporal Boundaries and Scales

Since a natural disaster is a combination of vulnerability and natural hazards, its temporal scale is not always clear. Natural hazards tend to have relatively precise temporal scales. The start and finish of a natural hazard event can usually be pinpointed to at least within a day, and often to within less than a second for hazards such as seismic events, meteor strikes, flash floods, and tornadoes. The length of time of a natural hazard event ranges from seconds, for some earthquakes and tornadoes, to years, for some droughts and pandemics. Contrastingly, vulnerability is a characteristic of society, so it is not often feasible to indicate when vulnerability began. After all, vulnerability commences with human settlement. As well, society's activities for managing that

vulnerability never really end, since natural hazards and hence vulnerability (and hopefully society) are continual and evolving.

Despite the absence of definitive temporal scales for natural disasters, temporal scales and boundaries are often selected by or imposed on the engineer for design purposes. Short-term thinking is contrary to sustainability, yet is prevalent throughout society, particularly with respect to consequences which will not be felt before the next generation. The engineer should be wary of short-term thinking and should consider both short- and long-term effects of designs.

Irrespective of the engineer's intention towards long temporal scales and indefinite temporal boundaries for designs, at times temporal boundaries or scales are dictated by the natural disaster event. Response and recovery activities are the most likely of society's activities to be constrained by a natural disaster's temporal characteristics. For example, eastern Ontario and southern Québec experienced an ice storm in the first week of January 1998 and approximately 3 million people were left without electricity after power lines were downed both by the weight of ice and by tree branches which collapsed due to the weight of ice. The main engineering task, to restore the broken energy lifeline, could not proceed until ice stopped falling, which in some places was five days. Even if response/recovery plans had planned for power restoration within 48 hours of any outage, the natural disaster's temporal characteristics would have prevented completion of this goal. Similarly, pre-disaster actions, especially those which require a long time for implementation, can be temporarily curtailed if the expected natural disaster strikes.

Some temporal characteristics of natural hazards can also provide challenges for managing vulnerability. Accurately knowing the frequency characteristics or return periods of extreme events and of the applied loads is rare (sections 4.4.2 and 4.4.3), hence errors will occur in selecting hypothetical events and loads for engineering design. For example, the ice storm in Canada discussed in the previous paragraph was not unprecedented (Etkin and Maarouf, 1995):

- in March 1958, St. John's experienced 43 hours of continuous freezing rain;
- in February 1961, areas of Montréal lost power for a week after an ice storm snapped wires;
- in January 1968, three days of falling ice and snow caused widespread power outages in southern Ontario;
- in April 1984, St. John's lost electricity for several days after an ice storm caused blackouts; and
- in December 1986, 25% of homes in Ottawa lost power during a 14-hour ice storm.

These incidents are scattered in both space and time (and each event even occurred in a different month), which made the January 1998 event described in the previous paragraph seem surprising and, even in retrospect, unpredictable. Moreover, as alluded to in section 4.4.2, not all ice storms are entirely similar and taking into account previous ice storms for designs might have aided, might have been detrimental to, or might not have affected the situation in January 1998.

An aid for the predictability of many hydrometeorological hazards--such as ice storms, tornadoes, and spring floods--is that they are (almost) certain to occur during a specific season; i.e., within specific temporal boundaries. Many biological hazards also manifest seasonally, such as mammals and birds protecting their young during the spring, and in locations where insects and their associated microbiological hazards do not threaten during winter. Astronomical and geological hazards rarely have even this amount of temporal specificity, although there are exceptions. Certain meteor showers occur on or close to a certain date every year, such as the Lyrids (April 21), the Perseids (August 11), and the Leonids (November 17). Statistical analyses of earthquake time series have yielded models for mathematical attractors, some of them chaotic, which might help to predict earthquakes temporally, although so far there has been little success (Julian, 1990; Lomnitz, 1994).

Temporal scales also create problems for engineers in managing vulnerability to natural disasters because society's temporal scales and natural hazards' temporal scales are radically different.

Modern society has existed only since the start of the Holocene period, 10,000 years ago, and Western society's widespread development and systematic use of technology have occurred only for approximately 300 years. By contrast, natural hazards on Earth have existed throughout the planet's lifetime of 4.6 billion years, and so regular events can occur every few million years--a length of time foreign to society's experience and far beyond society's collective memory. Such events have been of such high magnitude and intensity over the global spatial scale that they have caused rapid, mass species extinctions. Engineers and society have immense challenges in anticipating and managing vulnerability to events which are rare on society's temporal scale. Certain regular events for the Earth's temporal scale would be overwhelming.

6.4 Psychological Boundaries

The psychological state of society is impacted by boundaries which both inhibit and enhance the ability to understand and react to outside stimuli. Psychological boundaries are shaped and influenced by culture, religion, language, the environment, past experience, current events, and personal physical and emotional characteristics, such as intelligence and health. The amount of influence, the susceptibility to change, and the rate of change of psychological boundaries vary widely

and incorporate a continuum of states between extremes. A classification into two broad, and at times overlapping, areas eases discussion. The two areas are cultural/philosophical boundaries (Section 6.4.1) which refer to the underlying state of mind that shapes overall life, and mental/emotional boundaries (Section 6.4.2) which refer to the current state of mind that shapes day-to-day functioning.

6.4.1 Cultural/Philosophical Boundaries

Chapter 2 discussed the environment, society, and technology separately. The explicit separation of these components derives from the modern Western approach to philosophy, which originates from modern Western society's foundation in Judaeo-Christian ideals. Other philosophies argue that society--and even technology--are encompassed by the environment. This separation is an example of a psychological boundary: the society in which most engineers practice places boundaries between the three elements. Although the engineer may wish to contradict society's viewpoint, there are two reasons for maintaining the separation, as this thesis tends to do.

First, most engineers' work, such as this thesis, is produced by and for people with a strong modern Western influence. Accepting the embedded, fundamental philosophy facilitates communication of ideas. The emphasis of the work undertaken is on managing vulnerability to natural disasters and producing design solutions for this goal, rather than focussing on a critique of modern Western philosophy. Since a critique could be labelled as offensive, irrelevant, and/or confusing, the intended emphasis would be lost or ignored. Second, the environment, society, and technology can be defined and discussed specifically for any context--as this thesis does in Chapter 2--and while such definitions are models and could be open to interpretation or counterargument, the separation is also useful, as it provides a foundation for discussion and clarifies arguments.

There is a danger, however, of becoming too constrained by these psychological boundaries. The attitude and belief system influences in Section 3.3 provide examples of how a society can act in what would be a non-rational manner to the modern Western view. Recognizing that people may not act "rationally" within a belief system is important for the engineer to consider. Any technological solution has underlying assumptions about the society which uses the technology. If the assumptions are incorrect, the technology is likely to fail.

The discussion by Wilde (1994) and Green *et al.* (1993), mentioned in Section 5.4, on how engineering safety measures can actually increase vulnerability, can now be explained in terms of psychological boundaries. Modern Western society tends to place a high degree of faith in technology. People are taught and become inured to the concept that technology can solve society's

woes, and engineers are habitually advocates of this view. Ingrained psychological boundaries develop which block queries about the limitations or negative influences of technology. Safety measures are assumed to improve safety, and so individual actions change under the assumption that technology is protective (Wilde, 1994).

Irrespective of the problems, technology has brought numerous advantages to society and plays a principal role in managing vulnerability to natural disasters. Therefore, this thesis maintains a modern Western perspective, but does identify problems with this perspective while acknowledging, and attempting to understand and be sensitive to, other perspectives. Engineering work in this field will be much more successful if implemented with a similar attitude. Cultural and philosophical states and boundaries are deep-rooted and not easily subject to change. The recognition of this statement while attempting long-term education to eliminate dangerous beliefs, balanced with the preservation of indigenous cultures and beliefs, is not facile, yet will be necessary to use technology properly.

6.4.2 Mental/Emotional Boundaries

In contrast to cultural/philosophical boundaries, mental/emotional boundaries can change rapidly over time and space, and may have different forms for different situations or events. For example, Lopes (1997) and Schmidlin (1997) describe how many mobile home and recreational vehicle residents do not wish to leave their dwelling during a tornado because it would seem safer than exposing oneself to the elements, even though such residences are highly vulnerable to destruction by tornadoes ("Tornado!", 1995). Conversely, Lopes (1997) points out that during earthquakes, most people inside buildings wish to run outside, even though it is safer to stay indoors, take cover, and hold on. Although Western cultural/philosophical views might have faith in technology as an underlying belief, specific circumstances--such as the feeling of imminent building collapse during an earthquake--can affect the mental/emotional state and traverse these boundaries. The appropriate use of technology, and society's reaction to a natural hazard, are affected by similarities and contrasts in cultural/philosophical and mental/emotional characteristics.

The rapidity with which mental/emotional boundaries can change is another point of which the engineer should be aware. For example, an individual's reaction to a severe earthquake would likely be quite different if s/he were awakened in the middle of the night rather than if s/he had just completed practice drills for earthquake response. The reaction would also likely be quite different if s/he were on the top floor of a skyscraper, which amplifies earthquake motion, rather than in an open field, with few dangers from falling objects. Similarly, if a major earthquake were to strike California during the annual American football game of the Super Bowl or during the annual movie awards

event of the Oscars, communication lifelines would likely suffer more failures than if the earthquake were to strike in the middle of the night. The reason is that newswatches are generally broadcast over instant media about major, domestic disasters, and the instant media audience in the U.S.A. during the Super Bowl and the Oscars is far larger than in the middle of the night. There would be a large number of people simultaneously telephoning friends and relatives in California, thereby taxing communication networks.

Designing for multiple scenarios in which society has such varying mental/emotional states is challenging. Engineers cannot anticipate every potential scenario (as in Section 4.4.3), but systems can be designed with flexibility and adaptability.

6.5 Technological boundaries

Technological constraints may limit what can actually be achieved, irrespective of what other boundaries and scales permit or what society desires. The functional feasibility of technology must be balanced with the constraints of society and the environment to ensure that what is desired from the engineer can actually be accomplished technologically. The engineer should be afraid of neither admitting that technological boundaries exist nor attempting to overcome them.

History has already demonstrated the consequences of overconfident engineers, through the "unsinkable" ship *Titanic* which struck an iceberg and sank in 1912 (see Table 2-5) and the "earthquake-proof" San Francisco city hall which was shattered by an earthquake on April 18, 1906. Nonetheless, engineers still tout "Strasbourg's Earthquake-Resistant Parliament Building" (Engineering Dimensions, 1997) and the only two types of walls which are "truly safe" against wind-borne debris during tornadoes (Harris *et al.*, 1992, p. 78)². The engineer should always realize and communicate that technological boundaries do actually exist and should not be lulled into assuming that technology can solve any problem--even though this perception is widely held in modern Western culture.

¹Ironically, despite "guaranteeing earthquake resistance", Engineering Dimensions (1997, p. 14) states that Strasbourg's parliament is in the third-safest category out of five on the French earthquake regulatory scale. Therefore, the parliament could actually have been constructed two categories safer.

²The two types of walls promoted are a 15.2 cm (6") moderately reinforced concrete wall and a 20.3 cm (8") thick concrete masonry wall with reinforced and grouted cells. Their claim that "Studies show only [these] two types to be truly safe" is somewhat bizarre considering that thicker and more heavily reinforced walls would clearly provide more protection from windborne debris, albeit at increased aesthetic, environmental, and economic cost.

6.6 Conclusions

When using technology to manage vulnerability to natural disasters, engineers are generally justified in assuming a modern, Western perspective. The modern, Western perspective, though, should constrain neither examinations of the limitations imposed by this perspective nor consideration and discussion of other viewpoints. The significance of spatiotemporal boundaries and scales, psychological boundaries, and technological boundaries should be important aspects of any discussion and should be explicitly recognized and communicated when developing solutions. These issues include an awareness of what society thinks of technology, how society reacts to technology in varying circumstances, and how societies differ in these respects.

Innovation, flexibility, and adaptability should be characteristics of solutions, not only in attempting to prevent failure of the technology, but also in understanding how to anticipate and respond to failures, and even in extracting advantages from a failure (or as Green *et al.* (1993) entitle their article, "Designing for Failure"). Otherwise, boundaries may become barriers to implementing technology for managing vulnerability to natural disasters.

7. Recommendations and Conclusions

7.1 Review and Discussion

Technology can assist in managing vulnerability to natural disasters. Technology needs to be developed and applied properly, part of which is ensuring that technology is used as one of many tools. These tools can be used in combination or separately, but they usually interact in some fashion, and so engineers and non-engineers should play a role in ensuring that each tool is used for tasks appropriate to that tool. Technology is not always the most appropriate tool, thus an important component of any solution in managing vulnerability to natural disasters is recognizing how technology can be used in conjunction with other tools, when technology should be used, and when technology should not be used.

Moreover, in order for technology to work, the technology must be available, affordable, usable, and useful, and society must desire to implement the technology. These five characteristics must exist essentially independently and the existence of any one characteristic or combination of characteristics does not necessarily imply the existence of the others. Even if all five characteristics are present, the technology might not function as expected (i.e., as designed) because of errors in the design or errors in the application.

Errors might arise from incompetence or negligence, but they more often occur due to the inherent challenges in design: the lack of theoretical knowledge (section 4.4.1), the assumptions necessary for using past experience to define problems (section 4.4.2), and the inability to anticipate every potential scenario (section 4.4.3). These challenges arise particularly when engineers attempt to predict the load from natural disasters, the most difficult step of the design process.

Furthermore, apparent mistakes in the design of technology might not be entirely accidental or completely the fault of the engineer. Society often has goals other than the perfect functioning of technology (section 5.3.3), such as minimizing resource use, maintaining a certain lifestyle, or conducting tradeoffs in applying technology to manage vulnerability to different natural disasters. Anticipating and effectively communicating as many of these problems as possible will assist in ensuring appropriate decision-making. There is no guarantee, though, that anticipation will be all-encompassing and accurate, that communication will be effective (either the communicator, the listener, or both could be ineffective), or that complete information will lead to appropriate decision-making. Nonetheless, engineers should do as much as feasible to ensure that technology is appropriately used for managing vulnerability to natural disasters.

Despite the problems, technology has advantages and can assist immensely in managing vulnerability to natural disasters and in meeting the IDNDR's objectives (section 1.1). In fact, four out of the five of the IDNDR goals mention technology, engineering, or technical knowledge. Engineering has already prevented much damage from natural disasters through activities including designing and maintaining lifelines and other structures, developing land-zoning techniques, developing modelling techniques and technologies, and developing and distributing devices used by other professions for pre-disaster and post-disaster activities (sections 5.3.1 and 5.3.2). Although the challenges continue and there could be much improvement, contributions from engineers have been prominent and useful in managing vulnerability to natural disasters.

Throughout the discussions in this thesis, various themes are presented, such as preventing vulnerability, achieving sustainability (i.e., sustainable resource use), and reaping the advantages and benefits of natural hazards. There are also other themes which society has followed and may wish to continue following, such as economic growth and efficiency, fatalism, and zero tolerance for any environmental modification. These themes are not always appropriate for meeting the vulnerability goals set out by the IDNDR and this thesis. Dictating which ideas should be embraced by society can be counterproductive to achieving an engineering goal, and engineers need to strike a balance between respecting society's contemporary views and cultures and pushing for change that would permit the effective use and functioning of the technology desired by society. Determining where the balance lies is complicated, is confrontational at times, and varies depending on the particular individuals and situations.

Decisions about society's priorities and directions generally result from society's prevailing ethics and values. Specific decisions are often made by the most powerful decision-makers: those with economic and/or political power (political power loosely encompasses social and religious power) and could be individuals, organizations, or specific sectors of society, including engineers. Prevailing ethics, the decision-makers, and themes for society are sometimes in conflict, though at other times they yield common goals or support each other. Even though this thesis promotes the prevention of vulnerability as its paramount theme, there is always the proviso that this theme should be viewed in context and should be pursued along with other goals and themes, as determined by society with engineering input. This thesis does not and should not resolve the issues of which themes should dominate over the others and when and how this dominance should occur. Society must resolve these issues and--because ethics, decision-makers, and ideas change--the resolution will be dynamic and unlikely to ever be set down firmly and permanently.

Similarly, problems will continue to be present with respect to managing vulnerability to natural disasters. For example:

- knowledge, theoretical understanding, and predictive capabilities are rarely complete or absolute;
- anticipating every possible factor and scenario is impossible;
- criteria other than the effect of decisions on vulnerability, such as political and economic factors, may dominate discussions;
- communication is essential but permits misunderstandings and incompleteness in transferring ideas;
- psychological boundaries inhibit individual and societal actions; and
- unjust or poorly motivated practices due to callousness or ignorance exist.

Flexible and innovative solutions from engineers and the rest of society are required to mitigate these problems and to complete what is possible. Through creativity and adaptability, techniques and solutions can be modifiable to suit new challenges and situations as they arise. Technology will therefore be able to continue and improve its positive role in managing vulnerability to natural disasters.

7.2 Recommendations

Recommendation I: **Engineers should factor in non-technological influences on vulnerability when designing (Chapter 3's lesson).**

Non-engineers should also attempt to avoid detrimental impacts on technology's effectiveness from other influences, where appropriate. Obstructive political and economic influences can be particularly frustrating, since society could often choose to avoid them. These influences tend to reflect society's values, and so they are unlikely to be completely overcome--in fact, society often feels that such influences are desirable. Engineers should be aware of these influences, since designs will have to alter the impact of, or cope with, them. Understanding undesired influences and incorporating them into designs (or designing to change the influences) entails participation and input of engineers and non-engineers at most stages of the development and application of technology. The availability of resources might continually restrict such activities, but there are advantages in the long-term.

Recommendation II: **The challenges in engineering design work should be explicitly recognized and communicated (chapter 4's lesson).**

Engineers have a professional responsibility to complete work of high quality and to promote this responsibility. The completion of "work of high quality" implies being clear to the client about

the limitations of designs, the difficulty of defining design loads, potential problems which may arise, and troubleshooting guidelines. Engineers do not have all the answers, yet this point is often obscured by engineers who have too much faith in their own ability and by non-engineers who are willing to accept anything provided by an expert. By recognizing and debating the limits of engineering and technology, non-technological solutions can complement technological solutions when needed.

Recommendation III: The objective of managing society's vulnerability to natural disasters should be preventing vulnerability (chapter 5's lesson).

As mentioned at the end of section 7.1, there might be other objectives with a wider scope which would supersede preventing vulnerability. Sustainability is one such objective which would benefit society. Sustainability and preventing vulnerability, though, are often complementary as discussed towards the end of sections 5.3.3 and 5.4.

Recommendation IV: Engineers should examine the influences of boundaries and scales on the effectiveness of their designs (chapter 6's lesson).

The most prominent aspects to be accounted for are spatiotemporal boundaries and scales, psychological boundaries, and technological boundaries. Boundaries and scales, however, are a model for describing observations, and thus should be examined in context for each situation. Models have limitations, and although boundaries and scales are fairly general concepts which are readily applied to managing vulnerability to natural disasters, different responses or interpretations may be appropriate for different situations.

Recommendation V: Effective communication of problems and limitations is needed (Part I's lesson).

Effective communication helps to anticipate problems before they develop. Consequently, there will be more time for attempts at mitigating the problems, through solutions such as preventing the problem from occurring and preparing to cope with the problem. Effective communication also ensures that stakeholders are aware of potential difficulties and have an opportunity to voice their personal preferences and to propose solutions. The exchange of ideas and viewpoints also assists in developing and preserving innovative approaches and builds trust for responding effectively to a crisis.

Recommendation VI: Intensive, interdisciplinary research should be continued and promoted in order to develop creative and flexible solutions (Part I's lesson).

Engineers have the technical expertise and analytical skills which are necessary for research into using technology for managing vulnerability to natural disasters. Non-engineers bring their own expertise and skill sets to natural disaster research which are as important. Working together and sharing ideas facilitates the development of innovative and flexible solutions. Interdisciplinary research also assists in identifying and coping with the diverse factors which can account for the failure of technology, and helps in producing solutions with components outside the realm of traditional engineering. Solutions based on non-technological influences are integral to making technology function properly in disparate situations, and often have an adaptability not available with technology.

7.3 Conclusions

Engineers and technology have the potential to contribute immensely to the management of society's vulnerability to natural disasters. There are challenges at all stages of technology's development and implementation and these challenges must be dealt with by both engineers and other sectors of society. Many of the difficulties encountered in using technology come from neither technical problems nor the specific natural disaster event, but manifest because society errs in applying technology. Not all the challenges are entirely solvable, but there are methods of anticipating and reducing potential detrimental impacts. These methods require acknowledgement and communication of the challenges along with adaptable and innovative solutions. Through cooperative and interdisciplinary research and application, engineers can ensure that technology helps solve, rather than contribute to, the difficulties in the role of technology in managing vulnerability to natural disasters.

Part I, concepts and models for technology in managing vulnerability to natural disasters, is now concluded. Theory, where feasible, should normally be validated by empirical evidence, which, for this thesis, implies examining the role of technology during specific case studies of natural disasters. These case studies, as explained in Part II, are volcanic disasters on non-industrialized islands and will be used to apply the ideas from Part I. Before leaping directly into the mouth of the volcano (so to speak) a brief pause is taken in the form of an interlude (Chapter 8) which reevaluates the achievements of Part I and foreshadows the exploration of Part II.

8. Interlude

Part I explores the role of technology in managing vulnerability to natural disasters in a framework of concepts and models. The importance of natural disasters and technology to society is established briefly (Chapter 1) followed by operational definitions of terminology (Chapter 2). The traits of vulnerability are further explored during an examination of non-technological influences on vulnerability (Chapter 3). The traits of technology, particularly when used as a tool for managing vulnerability to natural disasters, and the framework used by engineers in such situations are explored, revealing the engineer's main challenge as understanding and defining the design load (Chapter 4). The prevention of vulnerability to natural disasters is deemed more appropriate than risk prevention or natural hazard prevention, and the challenges of using technology to prevent vulnerability are discussed (Chapter 5). Spatiotemporal boundaries and scales, psychological boundaries, and technological boundaries are investigated to establish their influence on using technology for managing vulnerability to natural disasters (Chapter 6).

In the conclusions to Part I (Chapter 7), a common theme which emerges is the need for engineering creativity and innovation in order to produce solutions which are flexible and adaptable. As well, cooperation and communication between engineers and other sectors of society are emphasized as necessary for ensuring that engineering solutions function and have the desired diversity to respond well in numerous situations. These results can be captured under the umbrella of interdisciplinary research: engineers must step beyond their traditional and expected roles while bringing non-engineers into closer contact with engineering design processes. Of course, such actions must still maintain the professional responsibility and integrity encoded in laws by many jurisdictions, since engineers do have the technical expertise and the licence requirements for conducting engineering work.

Nonetheless, the engineer's legal and moral professional responsibility and integrity does not preclude close interaction with non-engineers. Engineers should be working on a diverse team as a member with technical expertise, and can indicate what is and what is not possible technologically. Another important role for the engineer is to listen to the viewpoints and analyses of the other team members and to determine how non-technological factors could impact the technology. For example, a local community leader could indicate the locals' priorities and the amount of acceptance for technology which could upset those priorities while a planner or geographer could indicate potential logistical difficulties in transporting and setting up technology. The engineer would then work with the others to ensure that such concerns were factored into designs; design criteria would include

avoiding or minimizing any such concerns. The inherent characteristics of the technology and the manner of using the technology would both help to solve these problems.

Such an approach is not straightforward. Engineers do not always have the resources or the mandate to work closely with an interdisciplinary team. As well, many aspects of a design or a technology have often been developed previously and are used as pieces or subcomponents for the current project. The interdisciplinary approach might be used for the current project, but it may not be practical to rectify any problems in the previously developed components. Nevertheless, the engineer can minimize these constraints. If the engineer is inhibited in using the interdisciplinary approach, the opportunity to state the limitations of designs and to educate society about the merits of the interdisciplinary approach should be taken. Hopefully, engineers and the rest of society will communicate with each other so that the manner of engineering work and technology development will slowly change.

These comments about the interdisciplinary approach are fairly generic and could be reasonably applied to many areas of engineering. Such behaviour, though, is particularly important for technology used for managing vulnerability to natural disasters because of the diversity and depth of challenges put forward by natural disasters, another theme which emerged from Part I. Natural disasters directly impact most sectors of society and numerous sectors are involved professionally in managing vulnerability to natural disasters. Despite this wide range, the challenges posed by natural disasters and their potential scope of damage threaten to overwhelm society's efforts at managing its vulnerability.

In recognition of the natural disaster challenge, the IDNDR (section 1.1) was implemented. Prior to the IDNDR, society had accomplished much in managing vulnerability to natural disasters, using both technological and non-technological solutions such as insurance, building codes, land zoning, disaster planning, public education, and emergency response systems. There is, however, still an enormous amount to be accomplished in these areas as well as in previously less successful areas such as enforcing regulations, reducing the impact of poverty on vulnerability, and predicting occurrences and magnitudes of natural disasters. The IDNDR, through research and education, has attempted to compel society and society's experts to reevaluate society's relationship with the environment, with respect to natural hazards. Assumptions and paradigms, such as the preventing natural hazards and preventing all damage from natural hazards all the time, are questioned and past activities are examined to determine the actual accomplishments of previously assumed successes. Similar discussions are scattered throughout Part I and suggestions are proposed for activities which

should be continued, changed, commenced, and halted. Neither the IDNDR nor Part I of this thesis raises all the pertinent questions or resolves all the outstanding issues, but each provides a worthwhile contribution to the role of technology in managing vulnerability to natural disasters¹.

The exploration in Part I, as its title states, involved concepts and models (i.e., ideas) which need to be considered in managing vulnerability to natural disasters. Theory is a necessity, but should be complemented by its equally necessary partner, which is practice. Although Part I uses both real and hypothetical examples, it remains essentially an intellectual framework for analyzing and discussing the issues. In order to fully explore the role of technology, the intellectual framework should be used in a practical setting: case studies to which the concepts and models can be applied.

Part II accomplishes this goal by examining one natural hazard, volcanoes, in one particular type of location, non-industrialized islands. Two case studies are scrutinized to permit a critical analysis and comparison. An explanation of volcanic hazards and volcanic disasters introduces the role of technology in managing vulnerability to volcanic disasters (Chapter 9). The major significance of volcanoes and volcanic disasters to non-industrialized islands and the subsequent selection of the case studies is discussed (Chapter 10). The case studies are the eruption of Mount Pinatubo in the Philippines which started in 1991 (Chapter 11) and the eruption of Soufrière Hills in Montserrat which started in 1995 (Chapter 12). The role of technology during each eruption is compared in order to make recommendations and to draw conclusions about using technology to manage vulnerability to natural disasters (Chapter 13). Following Part II, there remains room for a further synthesis of Part I and Part II (Chapter 14).

Part II thus examines technology and engineering in action, for one specific natural disaster category. Like the illustrative examples interspersed throughout Part I, however, the use of specific examples reflects the issues, ideas, and challenges relevant to other examples and other natural disasters. The lessons learned from the mistakes and successes during volcanic disasters on non-industrialized nations can be applied for improving the role of technology in managing vulnerability to all natural disasters.

¹ Although the IDNDR's contribution is significantly more substantial than the contribution of this thesis.

PART II
Case Studies: Volcanic Disasters on Non-Industrialized Islands

9. Volcanic Disasters

9.1 Introduction

This chapter describes the risk from volcanoes and the volcanic disasters which have ensued. Section 9.2 categorizes and provides a brief overview of volcanic hazards, and is thus representative of the natural hazard component of risk depicted in Figure 2-1. An indication of how volcanic hazards can lead to volcanic disasters is also given, although section 9.3 details the vulnerability component of risk and discusses previous and potential disasters in more depth.

9.2 Volcanic Hazards

The information in this section is summarized and adapted predominantly from Chester (1993), van Rose & Mercer (1991), and Blong (1996). For further reading, Chester (1993) provides the most detail while Blong (1996) provides the most straightforward discussion. Other significant sources are referenced within the text. Figure 9-1 displays a schematic diagram for this section. Table 9-1 lists major volcanic disasters in history and the most significant hazards during those events.

9.2.1 Gas Hazards

Land volcanoes are estimated to emit 7.13×10^{11} kg/year of water (H₂O), 6.5×10^{10} kg/year of carbon dioxide (CO₂), 1.9×10^{10} kg/year of sulphur dioxide (SO₂), 3×10^9 kg/year of hydrogen chloride (HCl), and 1×10^8 kg/year of hydrogen fluoride (HF) (Decker and Decker, 1998). Minor emissions include hydrogen (H₂), carbon monoxide (CO), carbonyl sulphide (COS), hydrogen sulphide (H₂S), sulphur (commonly denoted S), oxygen (O₂), nitrogen (N₂), hydrogen bromide (HBr), hydrogen iodide (HI), metal halogens (M_pX_q, with elements such as sodium and aluminum (M) bonded with chlorine, fluorine, iodine, or bromine (X)), and noble gases (helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and radon (Rn)).

If large amounts of these gases are emitted without oxygen, there is the danger of suffocation as occurred beside Lake Monoun, Cameroon in 1984 with 37 deaths and beside Lake Nyos, Cameroon in 1986 with 1,746 deaths. Even with the presence of oxygen, volcanic gases are poisonous, which is one of the reasons that there is relatively little growth adjacent to volcanic vents, termed fumaroles. The temperature of vented gases, usually at least several hundred degrees celsius, is another discouraging factor to life near fumaroles. Blasts of steam and other hot gases can occur unexpectedly and can be lethal.

Figure 9-1: Schematic of Volcanic Hazards

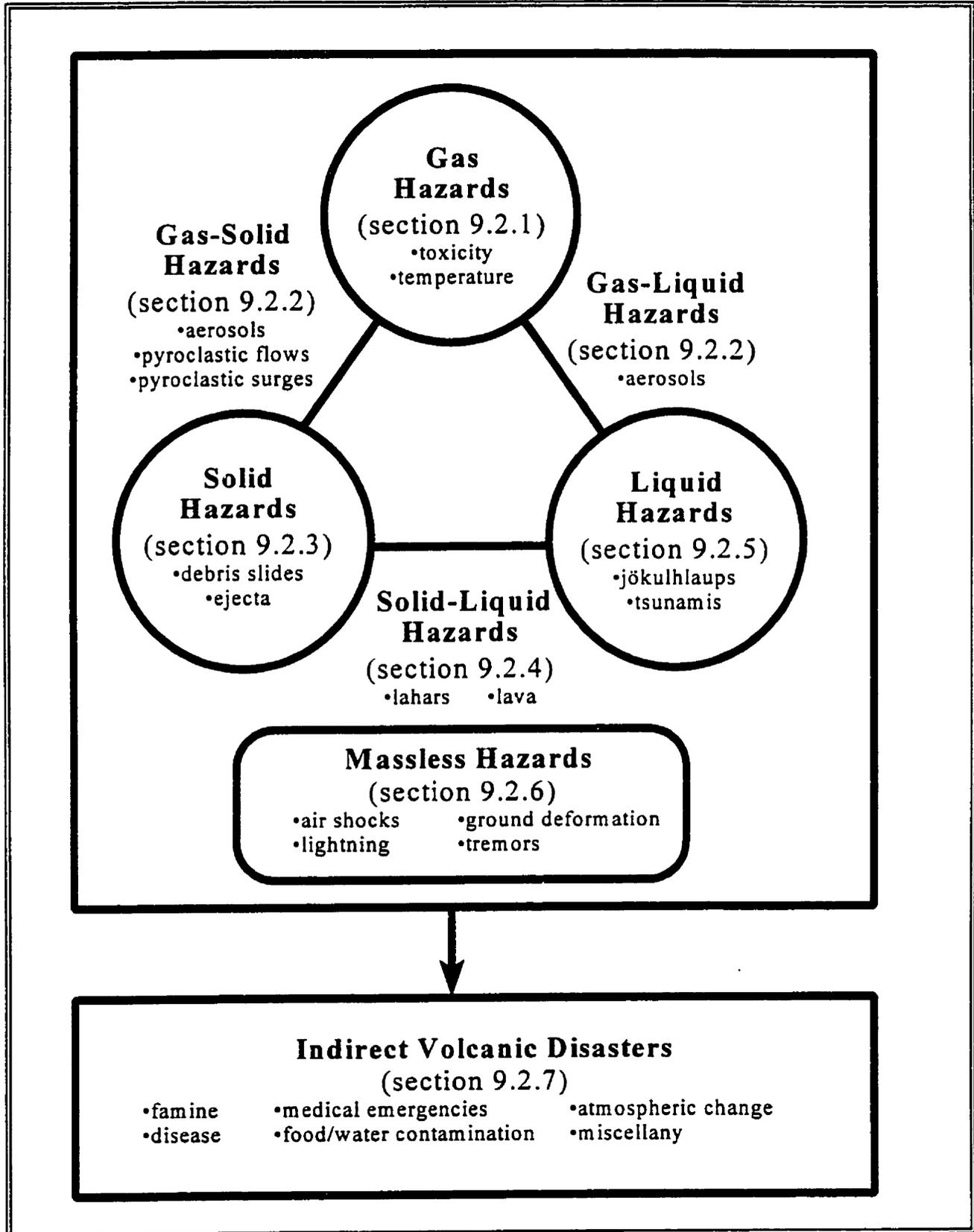


Table 9-1: Selected Volcanic Eruptions

(Because the number of fatalities varied amongst sources, the most popular value or range is listed for each eruption without providing a specific reference)

Date	Location	Fatalities and Main Causes
c. 3500 years before present	Santorini, Greece	unknown (likely tsunamis, solid ejecta, and the blast force)
August 24, 79	Mount Vesuvius, Italy	2,000 (ash falls and pyroclastic flows)
February 4, 1169	Mount Etna, Italy	15,000 (ash falls and pyroclastic flows)
1586	Kelud, Indonesia	10,000 (lahars)
December 16, 1631	Mount Vesuvius, Italy	6,000 (ash falls and pyroclastic flows)
1638	Raung, Indonesia	several thousand (lahars and pyroclastic flows)
March 11, 1669	Mount Etna, Sicily, Italy	20,000 (ash falls and pyroclastic flows)
August 4, 1672	Merapi, Indonesia	3,000 (pyroclastic flows)
December 10, 1711	Awu, Indonesia	3,177 (lahars)
September 22, 1760	Makian, Indonesia	2,000 (lahars)
August 11, 1772	Papandajan, Indonesia	2,957 (avalanche and lahars)
July 26, 1783	Asama, Japan	1,200 (lahars and pyroclastic flows)
June 8, 1783	Laki, Iceland	10,521 (famine)
May 21, 1792	Mount Unzen, Japan	14,524 (avalanche and tsunamis)
February 1, 1814	Mayon, the Philippines	more than 2,200 (falling rocks and fires)
April 10, 1815	Tambora, Indonesia	92,000 (10,000 from pyroclastic flows, and 82,000 from famine and disease)
March 2, 1856	Awu, Indonesia	2,806 (lahars)
October 8, 1882	Galunggung, Indonesia	4,011 (pyroclastic flows)
August 27, 1883	Krakatoa, Indonesia	36,000 (tsunamis)
June 7, 1892	Awu, Indonesia	1,532 (lahars)
May 7, 1902	La Soufrière, St. Vincent	1,600 (pyroclastic flows)
May 8, 1902	Mount Pelée, Martinique	28,000 (pyroclastic flows).
October 24, 1902	Santa Maria, Guatemala	several thousand (pyroclastic flows)
May 19, 1919	Kelud, Indonesia	5,110 (lahars)
1931	Merapi, Indonesia	1,369 (pyroclastic flows)

January 21, 1951	Mount Lamington, Papua New Guinea	2,942 (pyroclastic flows)
March 17, 1963	Mount Agung, Indonesia	1,184 (lahars and pyroclastic flows)
March 29, 1982	El Chichón, Chiapas, Mexico	5,000 (ash falls and pyroclastic flows)
November 13, 1985	Nevado del Ruiz, Colombia	approximately 25,000 (lahars: see section 5.3.3 for details).
August 21, 1986	Lake Nyos, Cameroon	1,746 (toxic gases).
June 10-15, 1991	Mount Pinatubo, the Philippines	500-1000 (see Chapter 14 for details).
July 18, 1995 to the present	Soufrière Hills, Monserrat	19-30 (see Chapter 15 for details).

The build-up of gases which cannot vent properly is one of the main causes, along with magma motion, of volcanic explosions. The gases released by volcanoes also play important roles in atmospheric chemistry thereby contributing to atmospheric variability and change such as global warming (e.g., CO_2), acid rain (e.g., SO_2), and stratospheric ozone depletion (e.g., HCl), which have their own subsequent environmental hazards (section 9.3 provides more discussion of volcanic climate variability and change).

9.2.2 Gas-Solid and Gas-Liquid Hazards

Pyroclastics are fragments of magma, ash, and rock often emitted by volcanoes in a gas-solid dispersion. Although the terminology and categorization of pyroclastic hazards is inexact, the three main categories are pyroclastic falls, pyroclastic flows, and pyroclastic surges. Pyroclastic falls are essentially solid hazards and thus are discussed in section 9.2.3. Pyroclastic flows are a concentrated (dense) gas-solid dispersion travelling at hundreds of kilometers per hour with temperatures in excess of 100°C . The peak velocities and temperatures rarely occur for longer than several minutes. Steam is the most common gas in pyroclastic flows. Pyroclastic surges are a low-concentrated (dilute) gas-solid dispersion with wide-ranging temperatures and velocities. Because of the low concentration of solids, pyroclastic surges can move rapidly across complex terrain and can mount obstacles up to 1 km high.

Aerosols are gaseous suspensions of fine solid or liquid particles¹. When gases dissolve in water aerosols, acid aerosols--such as sulphuric acid (H_2SO_4), hydrochloric acid ($\text{HCl}_{(aq)}$), and hydrofluoric acid ($\text{HF}_{(aq)}$)--are formed, which are corrosive to vegetation, lungs, and property. Solid aerosols close to the Earth's surface can also damage lungs or settle to the surface, impacting vegetation and property. Solid and liquid aerosols in the troposphere and stratosphere cause significant backscattering of solar radiation, cooling the Earth (section 9.3 provides more discussion of volcanic climate variability and change).

9.2.3 Solid Hazards

A large amount of material falling or sliding down a mountainside is termed a rock avalanche (rockslide) or a debris avalanche (landslide). Volcanic eruptions or tremors can trigger such avalanches by shaking loose material. The reverse can also occur, as was observed at Mount Saint

¹Confusions with this definition of aerosols, which comes from physical chemistry, can arise because atmospheric physicists tend to refer to only solid suspensions in gas as aerosols, with respect to solar radiation scattering. Liquid aerosols are referred to as liquid dispersions in the atmosphere.

Helens in Washington, U.S.A. A volcanic earthquake triggered a landslide on the north side which removed material. The slope was weakened sufficiently to permit the trapped gases and magma to blast through on May 18, 1980 killing 57 people including a volcanologist who was camped on the north slope.

Ejected material from volcanoes ranges in size from dust (see also the discussion about pyroclastics and solid aerosols in section 9.2.2) to boulders. Finely pulverized rock and lava particles are termed ash. Larger ejecta are termed tephra or pyroclastics (both words are of Greek origin) and are pieces of lava, crystals, or frothed glass (pumice). Lapilli are approximately pea-sized to walnut-sized, while blocks or bombs refer to larger chunks. Pyroclastic or tephra falls involve material injected into the atmosphere or hydrosphere with a high velocity which then falls back to the Earth's surface or the body of water's floor. Volcanoes can eject material up to 55 km into the atmosphere, although columns between 3 km and 10 km high are more regularly observed. Fallout can cover thousands of square kilometers with layers several meters thick.

9.2.4 Solid-Liquid Hazards

Lava (an Italian word from the Neapolitan dialect) is molten rock which has egressed from the volcano (compared to magma, which is molten rock underground) and is a hazard both as a liquid and in its cooled solid form, due to its high temperature. Upon ejection, lava is usually between 750°C and 1100°C, although temperatures of up to 1400°C may occur. Due to its low thermal conductivity and high heat capacity, lava can remain hot enough to start fires and cause serious burns for years after an eruption. Lava viscosity, and hence velocity and final cooled thickness, varies with its composition, but velocities rarely exceed 65 km/hr and are usually much slower, permitting most mobile creatures to evade flows much of the time. Vegetation and property are not so fortunate and fires started by lava can range much farther than the lava itself.

A lahar (a Javanese word) is any collection of volcanic fragments transported by water regardless of origin or sedimentological properties, but particularly referring to quick flows of mud of volcanic origin. There are more than a dozen methods of lahar formation, but all result in a mixture of solid volcanic material and water. The water could be from the volcano, a river, melted ice or snow, or rain which often mobilizes ash or tephra deposits. Lahars can be of various temperatures, can travel in excess of 100 km at speeds reaching 100 km/hr (especially down slopes), and can inundate thousands of square kilometers, often breaking dams and topping riverbanks. Even after

coming to rest, the solid material can be remobilized by subsequent floods or precipitation, generating a lahar hazard for years following an eruption.

9.2.5 Liquid Hazards

A jökulhlaup (an Icelandic word) is an explosive flood of glacial origin, also described as a glacial outburst, which is often caused by subglacial volcanic activity melting ice. Non-volcanic jökulhlaups occur, but are not characteristically different from those of volcanic origin. The challenge of the jökulhlaup hazard is their sudden appearance and large volumes of water moving swiftly, sometimes with a discharge rate more than 100,000 m³/s.

A tsunami (a Japanese word) consists of a series of waves separated by several minutes or more than an hour which are usually turbulent, onrushing surges with the largest one generally being the second or third wave. The misnomer "tidal wave" is often applied, but a tsunami is never of tidal origin and is not a single wave that breaks onto the shore. Volcanic tsunamis are caused by the force of an eruption or by an eruption-generated or tremor-generated landslide. The volcano can be underneath, adjacent to, or partially in the ocean. Tsunamis can devastate coastlines and islands thousands of kilometers from the originating event, taking several hours to cross the ocean.

9.2.6 Massless Hazards²

The force of a volcanic explosion causes air shocks which can upset nearby aircraft and sound waves which shatter windows and ear drums. Some eruptions have been heard thousands of kilometers away and have felled nearby forests. The force of the volcanic explosion also exacerbates other hazards: solids, liquids, and gases ejected at faster velocities do more damage than those ejected at slower velocities. Furthermore, the angle of the blast impacts the hazard experienced. Larger objects fall farther from a volcano during a lateral blast than during a vertical blast, and thus larger regions are exposed to these hazards during lateral blasts. Lighter objects, such as dust, which are ejected vertically often reach the high troposphere or stratosphere and are then transported by winds around the globe.

Volcanoes can create their own microclimate during eruptions, which often includes lightning. Ash and tephra clouds move turbulently while erupting and friction amongst particles

²This section discusses hazards from force and energy, terms which are normally related as $\mathbf{F} \cdot \mathbf{r} = E$; i.e., the dot product of the net force vector and the distance vector yields the energy scalar. To avoid being sidetracked by the issue of whether the force or the energy is the fundamental hazard, a straightforward term for hazards without mass is used.

builds up enough static electricity to result in spectacular lightning flashes from one part of the cloud to another part (Kemp, 1988). The lightning may continue in clouds more than 200 km from the volcano. Cloud-to-ground lightning also can occur in the vicinity of the volcano.

Ground deformation is a dominant hazard, particularly preceding an eruption. Rising magma can fissure, change the elevation of, and tilt ground. Elevation changes involve the growth of dome structures above the magma or ground collapses, usually immediately preceding or during an eruption. Calderas are large, basin-like depressions formed when the centre of a volcano collapses inwards due to an eruption. Subsidence following an eruption can impact hundreds of square kilometers surrounding the volcano if a large amount of material is released, thereby undermining support for the land. Volcanic earthquakes are also precursors and consequences of ground deformation and eruptions, and can have magnitudes equivalent to the most powerful fault earthquakes.

9.2.7 Indirect Volcanic Disasters

Many consequences of volcanic events tend to be referred to as indirect hazards in the literature, pushing the limits of the description of "natural hazard" presented in section 2.5, since the resulting situations tend to be better classified as natural disasters (section 2.9). These events, though, are suitable for section 9.2 which discusses the dangers from volcanoes, and so they are presented here, but are classified as disasters.

Volcanic material--such as gases, ash, tephra, and lahars--severely impact agriculture by killing livestock and crops. Deposits and flows also contaminate water supplies and inhibit treatment and disposal of wastewater. Transportation³, energy, and/or communication networks are often damaged too, along with other infrastructure such as houses and hospitals, making day-to-day survival challenging. Famine and disease are thus regular aftermaths of volcanic events. Even with the sophisticated relief responses and operations witnessed currently, evacuation camps often

³Bridges, roads, and railways are wrecked by lahars, jökulhlaups, the force of an eruption, and the weight of settled ejecta, leading to disasters such as the express train derailment which killed 157 people on December 24, 1953 in New Zealand after a lahar from Ruapehu volcano swept away a bridge. In aviation, Tilling & Lipman (1993) write "more than 60 planes, mostly jumbo jets, have been damaged by [volcanoes, by flying through their ash clouds], and several planes experienced total power loss, necessitating emergency landings" (p. 277). These incidents fall in the realm of disasters of ambiguous origin which are not considered to be completely natural, as discussed in section 2.9.

facilitate the spread of disease due to the large number of people living in close proximity and the difficulty of maintaining supplies of food, water, and medicine.

In addition to disease and malnutrition, medical emergencies resulting from volcanic events include emotional and physical shock, asphyxiation from volcanic gas emissions, lung damage from inhalation of particulates and corrosive substances, and the usual plethora of injuries present during emergency situations such as burns, blood loss, broken bones, cardiac arrest, and concussions. A breakdown in civil authority leading to riot, looting, insurrection, and crime can also occur.

As mentioned in sections 9.2.1 and 9.2.2 and expanded upon in section 9.3, volcanoes contribute to local and global atmospheric variability and change with far-reaching consequences. Section 5.2.5 discussed volcanoes' impact on global biogeochemical cycles which can lead to further hazards and disasters. As well, there are event combinations which yield bizarre situations; for example, tephra can absorb much water, becoming a superb electricity conductor, so if it rains or floods onto a tephra deposit which rests amongst downed but live power lines, the possibility of electrocution exists for the unwary who venture into the area.

9.2.8 Relative Dangers from Volcanic Hazards

Blong (1996) points out that the relative dangers from the different volcanic hazards are specific to each volcano and to each eruption. Forming general conclusions or ranking the hazards by an overall danger or risk index is misguided and detrimental to educating society about volcanic hazards. Developing a relative danger index for a specific volcano and for a specific eruption or anticipated eruption, however, assists in identifying and communicating the main hazards of concern to the surrounding population.

9.3 Society's Vulnerability to Volcanic Disasters

Worldwide, more than 1,300 volcanoes have had at least one eruption in the last 10,000 years, and approximately 50 volcanoes erupt in an average year, with only a few of these causing fatalities (Smith, 1996; Tilling, 1990). Nearly 400,000 people are reported to have been killed throughout history by volcanic eruptions, though some authors (e.g., Decker and Decker, 1991) claim more than 1 million deaths. As seen in Table 9-1, the five most fatal eruptions in history caused slightly more than 200,000 of these deaths and the four most fatal eruptions in history occurred recently--two in the 19th century and two in the 20th century.

Casualties from volcanic disasters appear to be dramatically increasing over time, yet one or two devastating disasters skew the data spectacularly (after Tilling, 1991). Any real increase in deaths is likely attributable to population increases rather than to changes in the frequency of volcanic

hazards. Around the world, close to half a billion people are at risk from volcanoes--a population equivalent to the global population 400 years ago (Tilling and Lipman, 1993). Furthermore, Boggs (1991) argues that population increases have far outpaced the increase in deaths from volcanoes, so the probability of dying during a volcanic disaster has actually decreased in the 20th century compared to previous centuries.

Compared to other severe natural disasters, major volcanic disasters occur infrequently and do not cause many human casualties (Chester, 1993; Tilling, 1990). Table 9-2 lists some natural disaster events with death tolls in excess of the total fatalities caused by volcanic eruptions throughout history. Single-event droughts, floods, and storms causing more deaths than the worst single volcanic event (92,000 deaths from Tambora, Indonesia in 1815) have occurred several times throughout history (Nash, 1976), hence the historical total of fatalities for these disasters far exceeds the volcanic toll. Earthquakes have killed more than 3 million people in the past five hundred years (Bolt, 1993)--an order of magnitude greater than volcanoes.

Volcanic events, however, cause widespread damage to property and to the environment as demonstrated by the following two examples (National Geographic, 1997):

- On January 23, 1973, a new volcano started erupting near Vestmannaeyjar on the island of Heimaey, Iceland. At the end of the eruption four months later, 300 houses had been destroyed by fire, 1.18×10^9 kg of ash covered the town burying 65 houses in a layer up to 6 m thick, and the town's harbour was nearly closed in by lava; and
- On May 18, 1981, Mount Saint Helens in Washington, U.S.A. erupted devastating 368 km² of forest, filling a valley to a maximum depth of 183 m, and raising the bottom of Spirit Lake by 60 m.

The eruption of Mount Pinatubo in the Philippines and the destruction of two American military bases (Chapter 11) also illustrates the amount of property devastation, and the influence on international politics, which volcanoes can have.

Volcanic eruptions often affect global climate as well, at least in the short-term. Volcanic gases and particulates ejected high into the stratosphere disperse around the world and backscatter incoming solar radiation in the visible and ultraviolet regions of the spectrum, while permitting reradiation from the Earth in the infrared region of the spectrum, to escape. The 1815 eruption of Tambora in Indonesia likely resulted in "The Year Without a Summer" in 1816 with New England experiencing a snowstorm in June and frost in every month. Handler and Andsager (1994) associate injection of aerosols into the atmosphere by volcanic eruptions with subsequent ENSO (El Niño-Southern Oscillation) events, and the affiliated extreme weather and storms. Their case studies focus

Table 9-2: Selected Natural Disasters With Death Tolls in Excess of the Total Fatalities Caused by Volcanic Eruptions
 (Volcanic eruptions have killed nearly 400,000 people throughout history)

Date	Disaster	Location	Fatalities	Source
1347-1351	Bubonic Plague (Black Death)	Europe, Russia, and North Africa	approximately 50 million	Maloney (1976)
1851 to 1866	Floods	Beijing-Shanghai-Hankow triangle, China	40 to 50 million	Nash (1976)
1917-1919	Influenza	World	25 million	Maloney (1976) Nash (1976)
1936	Drought	western China	5 million	Nash (1976)
August 1931	Flood	Huang He River, China	approximately 3.7 million	Lawford <i>et al.</i> (1995)
January 23, 1556	Earthquake	Shensi, China	over 830,000	Bolt (1993) Smith (1996)
July 28, 1976	Earthquake	Tangshan, China	up to 750,000	Smith (1996)
November 12, 1970	Cyclone and Tsunami	Bangladesh	300,000 to 500,000	Nash (1976)
November 1, 1530	Flood	Netherlands	400,000	Nash (1976)

on Mount Pinatubo, the Philippines in June 1991; Nevado del Ruiz, Colombia in November 1985; and the combination of Nyamuragira in the Democratic Republic of Congo (formerly Zaïre) in November 1981 and El Chichón in Mexico in March 1982. Another global impact on the atmosphere of volcanic ejecta is the potential of chlorine gases to destroy stratospheric ozone, in a manner similar to chlorofluorocarbons (CFC's).

Climate variability and change caused by volcanic eruptions has caused many more fatalities than have been recorded. Some famine deaths are reported in Table 9-1, but they occurred in the immediate vicinity of the volcano because pyroclastic flows, lahars, or ash falls ruined communities and crops. Determining the toll from famine induced by climate variability and change, along with deaths due to cold temperatures and storms, would be extremely challenging and is rarely completed, but such deaths would likely account for the vast majority of volcano fatalities. For example, the most probable explanation for a famine in northern China which killed millions of people from 207 B.C.E. to about 204 B.C.E.⁴ was a volcanic eruption in Iceland in about 210 B.C.E. which severely reduced solar energy input to the Earth for three years (Anderson, 1987). Another Icelandic eruption in 1773-1774 produced fluorine-rich gas, ash, and rain which decimated crops and starved 24% of Iceland's population (Simkin, 1994).

These examples typify the diversity of ways in which volcanoes can kill, and the wide range of hazards described in section 9.2 along with the main causes of volcanic deaths listed in Table 9-1, add support. Lahars, pyroclastic flows, and ash flows dominate the fatalities in Table 9-1, but avalanches, tsunamis, fire, and poison gas are represented. Steam blasts, lateral blasts, rock falls, lightning, and lava burns are implicated in eruptions with smaller death tolls, not listed in Table 9-1. Displacement of populations due to volcanic eruptions can exact a heavy toll too. For example, between February 5, 1943 and February 17, 1952 Paricutin in Mexico killed three people from lightning and approximately 100 due to resettlement (Krafft, 1993; Luhr and Simkin, 1993). As well, the immediate toll from the 1991 Mount Pinatubo eruption in the Philippines was dominated by later deaths due to resettlement (Chapter 11).

⁴While the B.C.E. system of dating events which occurred more than two thousand years ago demonstrates ethnocentricity, it is readily understood by this thesis' audience and avoids awkward phrasing and clarifications needed with other systems. The A.D. system for dating events which occurred less than two thousand years ago is as ethnocentric as the B.C.E. system, but no substitute could be easily conveyed to and understood by this thesis' audience.

The toll on human life from volcanic eruptions is therefore much larger than reported, and data on the numbers of people injured, affected, or displaced suffer similarly. As well, the potential for a terrible disaster exists. Recalling the discussion in section 6.3, society has not existed long enough to have experienced an extreme volcanic event on Earth's temporal scale--an event which would be cataclysmic to society. The 20th century has twice witnessed the annihilation of a city of more than 20,000 inhabitants by a volcanic event (St. Pierre, Martinique by Mount Pelée in 1902 and Armero, Colombia by Nevado del Ruiz in 1985), both of which were considered major, international tragedies yet resulted from relatively minor volcanic eruptions. The 1815 eruption of Tambora, the largest recorded eruption in human history, produced 150 km^3 of tephra as a maximum estimate (Decker and Decker, 1991) compared to the 2500 km^3 produced by an eruption in Yellowstone National Park, U.S.A. two million years ago (Simkin, 1994). Another Yellowstone eruption 630,000 years ago yielded $1,000 \text{ km}^3$ of magma compared to about 40 km^3 from Tambora (Decker and Decker, 1991). Society has not yet experienced volcanism at its full potential.

Society's lack of experience with volcanism is further illustrated by the relatively high death toll of volcanologists on the job (Table 9-3). At least thirteen volcanologists were killed by volcanoes during the first third of the IDNDR, with three of the most renowned volcanologists in history--Geoffrey Brown, Maurice Krafft, and Katia Krafft--amongst the casualties. One of the top American volcanologists, Stanley Williams, was with Brown at Galeras, Colombia and required several months to recover from his injuries. The Kraffts had just completed a video on the dangers of pyroclastic flows when they were engulfed by a pyroclastic flow at Mount Unzen, Japan on June 3, 1991. At the time of their death, their video was being widely shown around Mount Pinatubo in the Philippines, which turned out to be a significant factor in the ease of communicating the dangers of pyroclastic flows, saving many lives during the eruption (section 11.3.5). Each incidence of volcanologist casualties indicates to the scientific community how dangerous volcanic events are and how little are understood about them, even by those who study them.

Drawing conclusions about casualty trends in volcanic disasters is tenuous, due to discrepancies and contradictions between sources and large gaps in the data. Systematic recording of volcanic eruptions and casualties did not occur until the 20th century, prompted by two devastating disasters in the Caribbean in 1902 (see Table 9-1). Many eruptions in previous years were unknown until decades after, and even in the 20th century "the two largest drops in apparent volcanism coincided with the two World Wars, when observers (and editors) were preoccupied with other things" (Simkin, 1994). Simkin (1994) also points out that observed volcanism has steadily increased

Table 9-3: Examples of Volcanologists Killed by Volcanoes
(from Kerr, 1993; Rowland, 1998)

Year	Volcano	Total Killed	Volcanologists Killed
1947	Hekla, Iceland	no information	1
1951	Kelut, Indonesia	7	3
1952	Myojin-sho, Japan	31	9
1979	Karkar, New Guinea	2	2
1980	Mount Saint Helens, U.S.A.	57	1
1982	El Chichón, Mexico	5,000	1
1983	Klyuchevskaya, Russia	no information	1
1991	Mount Unzen, Japan	43	3
1991	Lokon-Umpung, Indonesia	1	1
1991	Mutnovskaya, Russia	no information	1
1993	Galeras, Colombia	9	6
1993	Guagua Pichincha, Ecuador	2	2
			TOTAL: 31

since the 18th century at about the same rate as global population increase, yet the frequency of large eruptions--which are the least likely to go unobserved irrespective of population--has been constant.

The number of people highly vulnerable to volcanoes, though, is increasing and the potential for an unprecedented catastrophe exists. Some of the largest cities in the world, including Mexico City and Tokyo, sit beside active volcanoes. Possible volcanic disasters not yet encountered by society could be an eruption in Antarctica precipitating widespread melting of the ice cap and subsequent sea-level rise (Monastersky, 1993), and volcanic ash causing an airplane crash, as alluded to in footnote 2 in section 9.2.7. As well, if global climate warming occurs, there might be a corresponding increase in volcanic activity, as has occurred in Iceland over the past 300,000 years (Hardarson and Fitton, 1991; Monastersky, 1988). Society is highly vulnerable to volcanic disasters and future experiences could bring volcanoes to the forefront of natural hazard concerns.

9.4 Volcanoes and IDNDR

In support of the IDNDR, IAVCEI (the International Association of Volcanology and Chemistry of the Earth's Interior)--in cooperation with the International Lithosphere Commission (ICL [sic]), the International Union of Geological Sciences (IUGS), and the International Union of Geodesy and Geophysics (IUGG)--developed a list of projects for preventing volcanic disasters. IAVCEI produced a working document (IAVCEI, 1990) which detailed these plans (summarized later in this section) in order to stimulate discussion amongst the volcanological community. Feedback was sought about which projects scientists would be interested in working on and for further proposals for similar activities. Funding requirements for these projects were estimated at US\$10.2 million/year (1990 dollars) exclusive of infrastructure, with organizations, institutions, agencies, and governments at all political levels assisting (IAVCEI, 1990).

The identified needs for managing vulnerability to volcanic disasters are (IAVCEI, 1990)⁵:

- political mandates backed up by financial support;
- sustainable volcano-related programs at various spatial scales;
- quantitative and qualitative hazard assessments for volcanoes for a range of temporal scales, particularly volcanoes which pose the greatest, unaddressed threats;
- monitoring programs to detect and track volcanic unrest and for short-term warnings of impending eruptions;

⁵The terminology used by IAVCEI (1990) has been altered in places to more fully reflect the meanings defined in Chapter 2 and used in this thesis.

- actions by civil officials to reduce vulnerability;
- development of crisis response capability; and
- follow-up activities after volcanic crises in order to put the volcanological and sociological lessons into practice during future situations.

The two main tasks espoused by IAVCEI (1990) for meeting these needs are data collection by scientists and vulnerability management by civil authorities.

Twelve projects for managing vulnerability to volcanic disasters are proposed in detail by IAVCEI (1990) and, in summary, are:

- hazard and risk mapping of volcanoes which threaten people and for which no adequate maps exist;
- basic surveillance of background volcanic activity at volcanoes which are not monitored but which threaten people;
- increased public education and awareness of volcanic hazards;
- communication amongst scientists, civil defence officials, and community leaders;
- Decade Volcano demonstration projects for volcanoes which are representative of the volcanic threat and appropriate for intensive, international research (Table 9-4);
- IAVNET, an email and voice network for rapid communication amongst volcanologists around the world;
- development of national archives of volcano data and volcano reference materials, updates of reference materials, and information-sharing agreements;
- training of scientists, technicians, planners, and civil defence officials;
- development of new, more reliable, and less expensive instrumentation and experiments;
- application of satellites for research, monitoring, and warning;
- co-ordination of national and international teams for assisting volcanic crises; and
- seed money and matching grants for volcano-related projects.

These projects are expected to expand knowledge of, awareness of, and resources for activities related to volcanic hazards and disasters while attempting to prevent hazards from becoming disasters in the future.

9.5 Summary and Conclusions

Volcanic hazards are diverse and remarkably dangerous, and society is highly vulnerable to volcanic disasters. As well, there is a strong potential for a volcanic disaster with a magnitude greater than volcanic disasters already witnessed by society. Therefore, activities related to managing vulnerability to volcanic disasters are desirable. The IDNDR's activities have indicated that society accepts the threats from and challenges posed by volcanic hazards and is willing to tackle them

Table 9-4: Decade Volcanoes
(information from IAVCEI, 1994)

The volcanoes in this table were nominated by their host countries and endorsed by IAVCEI for the combination of population at risk, volcanic unrest, scientific infrastructure, and national commitment.

Volcano	Country
Colima	Mexico
Etna	Italy
Galeras ⁶	Colombia
Mauna Loa	U.S.A.
Merapi	Indonesia
Mount Rainier	U.S.A.
Nyiragongo	Democratic Republic of Congo (formerly Zaire)
Sakurajima	Japan
Santa Maria/Santiaguito	Guatemala
Santorini	Greece
Taal	The Philippines
Teide	Spain
Ulawun	Papua New Guinea
Unzen	Japan
Vesuvius	Italy

⁶The 1993 eruption of Galeras which killed six volcanologists (Table 9-3) occurred during a field trip to the volcano at a workshop for planning Decade Volcano activities there.

through diverse and innovative programs and solutions, including the development and implementation of technology. As with other natural disasters, technology has a prominent role to play in managing vulnerability to natural disasters, but there are many difficulties to overcome. Specific difficulties and solutions are examined in the following chapters for volcanic disasters on non-industrialized islands.

10. Volcanic Disasters and Islands

10.1 Island Geography

There is no set definition for a small island in a geographical context. Many authors (e.g., Briguglio *et al.*, 1996; King, 1993; Pantin, 1998; Streeten, 1993) have discussed definitions of "island", "small", and "small island" using such criteria as population size; land area; economic criteria such as arable land area or gross national product; environmental influence, such as defining an island to be a landmass which does not create its own climate or ecology due to its volume; and characteristics of social geography, such as the presence of an island people or culture.

Although there are similarities between island and non-island small states, this author views the presence or absence of land borders as an important distinguishing characteristic between island small states and non-island small states (such as Andorra, Guyana, and Lesotho). Due to their economic, demographic, and physical size, small nations are self-sufficient in few resources--including natural resources, manufactured goods, labour, food, and water--so the presence of land borders enables the cheapest lifelines to be employed for importing. Land transportation networks for products and people tend to be cheaper than air and quicker than water transportation networks while wire-based communication and energy lifelines are easier to construct and maintain across land borders than in the absence of land borders. These difficulties present unique challenges, such as developing local, small-scale, renewable energy sources and balancing tradeoffs between the cost of wireless communications and the construction/maintenance challenges and environmental impact of wire-based communications.

Therefore the lack of land borders is a distinguishing characteristic of islands compared to other small states, with two provisos. First, the addition of a land transportation route, normally a bridge or tunnel, is effectively the creation of a land border. A land transportation route is not as established or as reliable as a natural land border, and so islands with such links tend to be "pseudo-islands", with characteristics lying in the transition zone between those of islands and non-islands. Canada's Prince Edward Island, connected to the mainland by a road bridge, and Singapore, connected to Malaysia by rail and road links, are examples. Second, some islands belong to more than one sovereign nation, such as Haiti and the Dominican Republic forming Hispaniola and New Guinea split between the country of Papua New Guinea and the Indonesian region (for the moment) of Irian Jaya. Irrespective of the land borders, they are islands; the term "land border" implies "land border with a continental land mass".

The intuitive concept of an island as a comparatively small (to other landmasses on the planet) landmass without land borders can be adopted for this thesis. Despite potential ambivalence over examples such as Greenland, Sri Lanka, and Madagascar, this concept serves this thesis well because borderline examples do not influence the selection of case studies or the results. Regions with many islands include the Caribbean Sea (e.g., Dominica, Grenada, Montserrat, and St. Lucia) and the south and western Pacific Ocean (e.g., Japan, Kiribati, the Philippines, and Vanuatu). Other examples of islands around the world are Chatham Island (New Zealand), Comoros, Lakshadweep (India), Sardinia (Italy), and Tristan da Cunha (U.K.).

These islands are shaped by their remoteness (at times referred to as insularity, somewhat tautologically) from continental landmasses, which develops ecologies and cultures that are usually unique to their island(s). Islands tend to have few natural resources, fragile environments, fragile economies, and are highly vulnerable to some of the most devastating hydrometeorological and geological natural disasters. The hydrometeorological hazards of concern are mainly hurricanes/cyclones/typhoons, but rarely tornadoes. As well, maintaining a constant supply of fresh water is often challenging, but the falling cost for more efficient desalination techniques should be able to eliminate drought as a concern if implemented properly. Geological hazards of particular concern are volcanoes (section 10.3), and earthquakes are also frequent in many locales, along with subsequent tsunamis. Due to their remoteness, islands are relatively free from biological hazards. These characteristics of island geography yield challenges which have common themes throughout all islands yet produce an incredible diversity of environments and societies.

10.2 Non-industrialized Islands

The dwindling number of overseas territories controlled by colonial powers has led to numerous new nations comprising islands, most of them non-industrialized. Section 1.1 noted that the IDNDR emphasizes developing countries in its natural disaster reduction plans while section 10.1 noted that islands are often subjected to some of the most devastating natural disasters. Developing, or non-industrialized, islands thus have an immense challenge in managing their vulnerability to natural disasters. Furthermore, the characteristics of island geography discussed in section 10.1 indicate the difficulty of technology transfer. Technology must be transported to areas without efficient transportation lifelines, transferred to an isolated culture, and implemented in a fragile environment and economy. The problems with using technology for managing vulnerability to natural disasters discussed in Part I are likely to be amplified on non-industrialized islands, where there are usually fewer resources for their resolution.

10.3 Volcanic Disasters on Non-Industrialized Islands

Most non-industrialized islands have formed due to volcanic activity and many are currently active volcanically¹. Thus, the non-industrialized islands which are vulnerable to volcanic disasters tend to be volcanoes. This situation contrasts continental volcanoes which are generally just part of a mountain range. Island volcanoes thus produce a dichotomy of creation and destruction alluded to in section 2.6 during the discussion of the benefits of natural hazards. The creative force which permitted society to exist on the island often threatens the island society with destruction. Living on and with an active volcano becomes a continual life experience which impacts attitude and belief systems (section 3.3) and psychological boundaries (section 6.4). There is no easy escape route from the volcano during threatening times or for implementing less vulnerable lifestyles; the volcano is part of the culture's day-to-day life--and could potentially be its death any day.

Although entire languages and cultures on islands are threatened by volcanoes, the number of people affected tends to be relatively small because islands tend to have small populations. Notable exceptions amongst non-industrialized islands are Indonesia and the Philippines (Japan is an example of an industrialized island group with a high population which is threatened by volcanoes). The combination of a large population and a high frequency of volcanic events has guided Indonesia and the Philippines to the most sophisticated response to volcanic eruptions amongst non-industrialized islands (Chester, 1993). Tables 9-1 and 11-1 list the many high-fatality eruptions in Indonesia and the Philippines respectively, but most such eruptions occurred several decades ago indicating an improvement in managing vulnerability to natural disasters despite increases in population.

Therefore non-industrialized nations can manage their vulnerability to volcanic disasters at least reasonably effectively, although they do not always do so. The reasons echo the difficulties with using technology to manage vulnerability to natural disasters, discussed in Part I. Specific case studies (Chapters 11 and 12, described in section 10.4) illustrate these difficulties and demonstrate how the role of technology varies widely between location and incident and how the role of technology in managing vulnerability to volcanic disasters can be improved.

¹Chester (1993) provides a detailed but readable discussion of how plate tectonic theory explains island volcanoes, at both the boundaries and the interiors of tectonic plates.

10.4 Selection of Case Studies

The previous sections in this chapter have noted the interesting and challenging features of using technology to manage vulnerability to volcanic disasters on non-industrialized islands. Sections 1.1 and 1.3 discussed the desire to examine natural disasters which occurred during the IDNDR. A further constraint for the selection of the case studies is logistical: information on the disaster as well as on the role of technology had to be available in a form obtainable under the resource constraints imposed on this thesis. An examination of the literature yielded two events which not only met the necessary criteria, but which also raised numerous, relevant issues which are not as evident in other examples, volcanic and non-volcanic, examined during the work for this thesis. These issues portray technology in a variety of roles indicating its versatility along with the numerous manners in which it can succeed and fail. The two case studies are Mount Pinatubo in the Philippines, which started erupting in 1991 (Chapter 11) and Soufrière Hills in Montserrat, which started erupting in 1995 (Chapter 12).

11. Mount Pinatubo, The Philippines (Initial Eruption 1991)

Abbreviations used in this chapter:

Clark	Clark Air Base
PHIVOLCS	Philippine Institute of Volcanology and Seismology (Filipino volcanologists)
PVOT	Pinatubo Volcano Observatory Team (Filipino and American volcanologists, mainly from the PHIVOLCS-USGS team)
Subic Bay	Subic Bay Naval Station
USGS	United States Geological Survey (American volcanologists)
VDAP	Volcano Disaster Assistance Program (an USGS international aid initiative)

11.1 The Philippines

The Philippines is 300,000 km² in land area and comprises 7,000 islands on the Pacific edge of Asia. The nation's history chronicles successive invasions by various cultures, with the most influential being the Spanish, from the late 16th century until the end of the Spanish-American War on December 10, 1898, and the Americans, from December 10, 1898 until independence on July 4, 1946. The current Filipinos are predominantly descendants of Spanish Caucasians, with minorities of arab muslims, mestizos, and Chinese (Steinberg, 1994).

There is also an indigenous (aboriginal) race, the Negritos, who were the nation's first human settlers and who inhabited the Philippines for thousands of years before invasions by other cultures began. One group, the Aeta tribe (also termed Ayta or Agta), had a population of between 10,000 (England, 1993b) and 50,000 (Goertzen, 1991) living on the slopes of Mount Pinatubo before its eruption. The term "Filipinos" does not refer to the Aetas in this thesis.

The Philippines is ranked as lower-middle income by the World Bank (1995). The average annual rate of inflation from 1960-1970 was 5.8%. and since then, it has fluctuated wildly, but averaged 13.5%. The economy is quite diversified with manufacturing, natural resource, and agricultural industries and numerous exports. Thus, the economy is overall in reasonable shape compared to many developing countries and non-industrialized island nations, but is definitely not at the level of a developed country.

The economic problems are influenced by the moderately large (for the nation's area) population of 64.8 million (1993) which is becoming progressively urban, but the demographic situation is promising. The average annual population growth rate has declined from 3.0% between 1960 and 1970 (World Bank, 1978) to the 1993 to 2000 projection of 2.0% (World Bank, 1995). Despite the Catholic influence against birth control (Brands, 1992; Steinberg, 1994), at least 40% of

married couples use contraception (World Bank, 1995). Since 1960, the infant mortality rate has halved to 42 per 1,000 live births and adult illiteracy has dropped by $\frac{2}{3}$ to 10%, with 11% of women illiterate (World Bank, 1978 and 1995).

Most demographic and economic indicators put the Philippines in a better situation than most developing countries and non-industrialized island nations, but without the impetus or strength to make the transition to developed status. Political problems have also debilitated attempts to improve the Philippines' situation, especially incompetence and corruption which remain as part of the legacy of the brutal dictatorship of Ferdinand Marcos (and his wife Imelda). Marcos' reign began with his election as president in 1965 and ended with a violent revolution in the capital Manila on February 25, 1986. Since the exile of Marcos, the Philippines has experienced two relatively fair presidential elections, in June 1992 and May 1998, settling down to a reasonably stable and coup-free government with only minor constitutional hiccups and two fading guerilla wars. The conflict between economic dependence on the U.S.A. and the nationalistic desire to shed all colonial influences continues to impinge on the political scene with bitter debates. The main Filipino-American issue related to Mount Pinatubo was the September 1991 expiry of the Americans' lease on Subic Bay Naval Station and Clark Air Base (see Figure 11-1).

The Philippines has 48 land volcanoes and 5 sea volcanoes which have erupted in the past 10,000 years (Smithsonian Institute, 1997). Except for exceptionally brief mentions of the Mount Pinatubo eruption in 1991, neither Brands (1992) nor Steinberg (1994) mention volcanoes, indicating that volcanology is not a particularly important political priority or historical influence for the Philippines. Table 11-1 lists some examples of volcanism in the Philippines. The devastation from the 1951 eruption of Hibok-Hibok volcano was exacerbated by the complete lack of preparation in the Philippines for a volcanic eruption and was the impetus towards creating the Commission on Volcanology (COMVOL), the forerunner of PHIVOLCS, which was founded in 1952 to prevent a similar situation from occurring (Tayag and Punongbayan, 1994). PHIVOLCS has ensured that the Philippines is reasonably prepared for responding to volcanic events, but they have been strengthened by a close, lengthy relationship with the USGS which arose from the historical links between the two countries and continues due to contemporary bonds.

11.2 Mount Pinatubo

Mount Pinatubo (see Figures 11-1 and 11-2) is located at 15.13°N and 120.35°E, 100 km northwest of Manila, with a current summit elevation of 1,600 m above sea level. Before 1991,

Table 11-1: Selected Volcanic Eruptions in The Philippines

Date	Volcano	Casualties
1616	Mayon, Luzon	Many dead.
October 23-27, 1766	Mayon, Luzon	more than 2,000 dead
February 1, 1814	Mayon, Luzon	more than 2,200 dead
1825	Mayon, Luzon	1,500 dead
1835, 1886, 1888	Mayon, Luzon	no information
June 23-30, 1897	Mayon, Luzon	more than 400 dead
January 27-30, 1911	Taal, Luzon	1,335 dead and 199 severely injured
1951	Hibok-Hibok, Camiguin	500 dead
1965	Taal, Luzon	200 dead
September 1984	Mayon, Luzon	no deaths, 73,000 evacuated
June 10-15, 1991	Mount Pinatubo, Luzon	500-1000 dead, at least 200,000 evacuated (see text in this chapter)
February 2, 1993	Mayon, Luzon	70 dead, 60,000 evacuated

Figure 11-1: Mount Pinatubo's Location Within The Philippines
(modified from http://volcan.wr.usgs.gov/Images/Gif/Pinatubo/pina_ybk_fig1.gif, accessed on May 10, 1998)

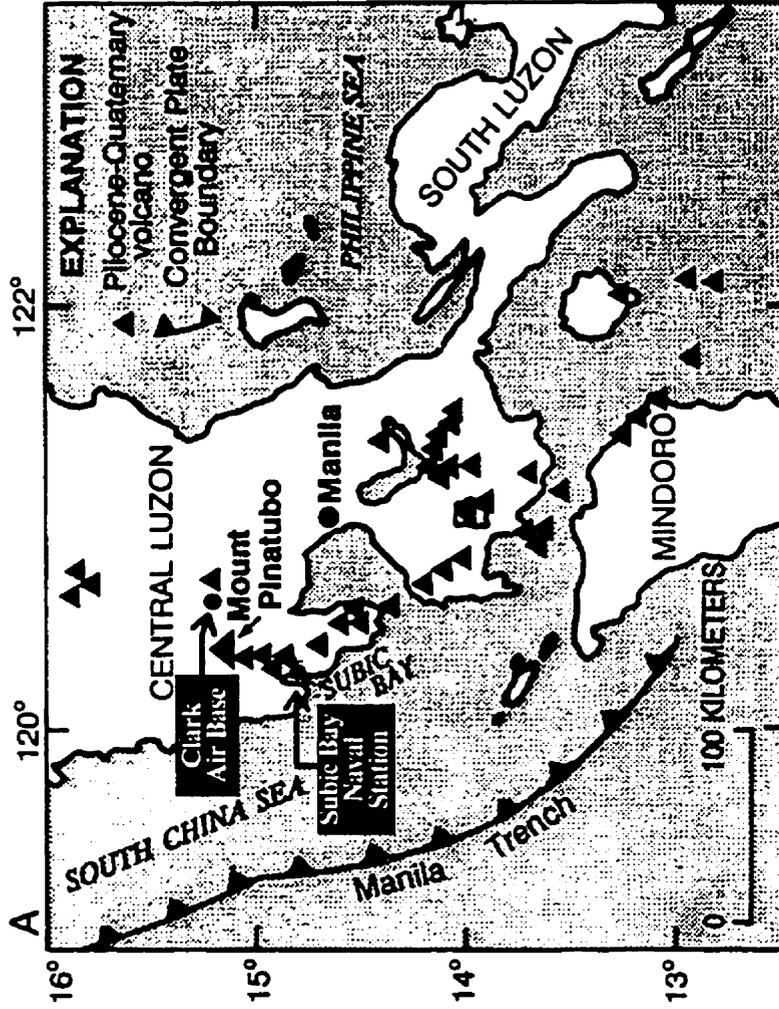
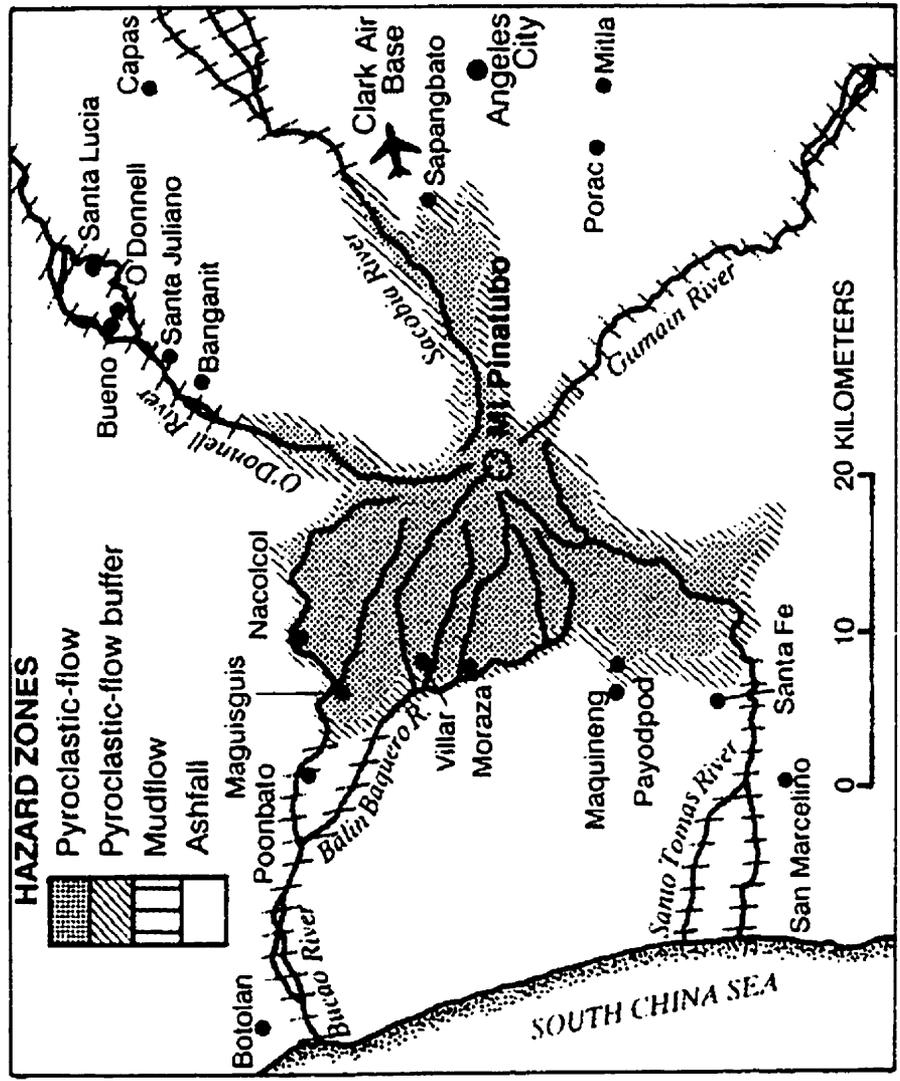


Figure 11-2: Region Around Mount Pinatubo with Volcanic Hazard Zones
(from http://vulcan.wr.usgs.gov/Images/Cif/Pinatubo/pina_ybk_fig2.gif, accessed on May 10, 1998)



Mount Pinatubo was classified as a dormant volcano. Widespread damage occurred during its last eruption in 1380, well before permanent settlement of the area (Davis, 1992) and thus outside the temporal scope of Filipino and indigenous societies. Although the area was known for its geothermal energy potential, there had been minimal volcanic activity between the late 14th century and 1991. Mount Pinatubo had been studied superficially, but there was no indication that it might be a concern.

Because it was not perceived that Mount Pinatubo would ever pose a threat, neither planning nor preparation were completed for an eruption there.

The temporal sequence of events of the eruption of Mount Pinatubo which started in 1991 is well-documented (e.g., Ewert and Newhall, 1992; PVOT, 1991; WGBH, 1992; Wolfe, 1992) and summarized in Table 11-2. Although these references were "factual" accounts of events, there were often discrepancies amongst them. Table 11-2 attempts to collate the information in the references and provides the most popular dates and data for the listed events. If a table entry seems ambiguous, it emulates the references.

Estimates of deaths from the eruption range from "approximately 200" (Davis, 1992, p. 303) to "nearly 500" (Kerr, 1991, p. 514) and exact numbers quoted include 320 (PVOT, 1991, p. 545) and 435 (Krafft, 1993, p. 194). Most of the victims were crushed when the volcanic ash and tephra layers covering roofs absorbed water from Typhoon Yunya (which had been downgraded to a tropical storm early on June 15th)¹ and the extra weight collapsed the roofs. One American soldier died when his vehicle skidded on rain-slicked and ash-covered roads. Many deaths were thus a result of the combination of two simultaneous natural disasters rather than a consequence of either the volcano or the typhoon (Ewert and Newhall, 1992; PVOT, 1991; Wolfe, 1992).

The most devastating effects of Mount Pinatubo occurred far beyond June 1991, though there are no consistent compilations of casualties. These effects involved lahars and the evacuated population. The threat from lahars (see also section 11.3.4) will continue for several more years—at least 100,000 people were left homeless by lahars from Mount Pinatubo in 1995 ("Like Pompeii", 1996)—and has exacerbated the deleterious effects of temporary camps set up for evacuees from the eruption. By late October 1991, more than 100,000 Filipinos still resided in temporary camps and plans to permanently resettle them were just commencing (PVOT, 1991). There were also several

¹Yunya was identified as a tropical depression on the evening of June 11th, reached Typhoon Category 3 (with 5 as the strongest) on June 14th, and dissipated as a tropical depression early on June 17th. The storm will be referred to as Typhoon Yunya in this thesis.

Table 11-2: Chronology of the 1991 Eruption of Mount Pinatubo
(summarized from Ewert and Newhall, 1992; PVOT, 1991; WGBH, 1992; Wolfe, 1992)

Date in 1991	Events
April 2	Multitudinous, small steam and mud explosions from Mount Pinatubo end the volcano's 611-year dormancy. 5,000 residents within 10 km of the summit are soon evacuated.
April 22	USGS scientists travel to the Philippines in response to requests from PHIVOLCS and concerns about possible damage to Clark. The USGS-PHIVOLCS team becomes PVOT.
June 3	A small explosion leads to almost continuous, increasing seismic and volcanic unrest.
June 7-9	The evacuation zone is raised to within 15 km and then 20 km of the summit. 20,000 residents are evacuated. Most aircraft at Clark are evacuated.
June 10	14,500 Americans and all remaining aircraft, except for three helicopters, are evacuated from Clark. 1,500 personnel remain. PVOT moves to the side of Clark farthest from Mount Pinatubo, about 25 km from the summit (Clark is approximately 8 km wide).
June 12	The first large explosion from Mount Pinatubo creates an enormous ash cloud. The evacuation zone is raised to within 30 km of the summit and more than 33,000 Filipinos are evacuated along with 600 Americans from Clark. Eruptions continue throughout the night.
June 13	A large explosion occurs in the morning.
June 14	At 1309h, the climactic eruptive phase begins.
June 15	The climactic eruption of Mount Pinatubo starts at 0555h followed by almost continuous eruptions throughout the day. Typhoon Yunya makes landfall at 1400h as a tropical storm and passes 50 km north of Mount Pinatubo. All remaining personnel leave Clark at 1430h. Most of PVOT's remote monitoring equipment on and around Mount Pinatubo has ceased functioning.
June 16	At least 200,000 people are displaced from the Mount Pinatubo area. Basic military personnel and PVOT return to Clark and new instruments are set up on the volcano by June 18th.
To the present	Lahars and small eruptions continue to devastate the surrounding area, destroying crops and houses and killing livestock and people.

instances of lahar warnings and evacuation orders being ignored by Filipinos who had spent time in these camps and who preferred to risk the lahars rather than return to camps where there were continuing casualties from disease, malnutrition, and exposure (Tayag and Punongbayan, 1994). The Aetas suffered similarly (section 11.3.2).

PHIVOLCS states (Tayag and Punongbayan, 1994) that "The management of the Pinatubo Volcano eruption crisis of 1991-92 represents the highest point in the development of volcanic disaster mitigation in the Philippines" (p. 2). Despite their feeling of readiness, PHIVOLCS continues (Tayag and Punongbayan, 1994) that "The hazards unleashed by Pinatubo, however, have certain characteristics for which the country has been poorly equipped by its four decades of volcanic disaster mitigation experience" (p. 2), but that they are learning from the problems they had in order to be better prepared next time. As well, many Filipinos panned the government's response to the crisis ("Volcano preparations lacking...", 1991) and the lack of long-term planning for evacuees could and should have been ameliorated long before Mount Pinatubo's activities began. Considering that 2 million people were highly vulnerable to Mount Pinatubo, there were comparatively few casualties and PHIVOLCS and other participants should be commended for their efforts and successes; however, irrespective of the apparent success, there were numerous problems during Mount Pinatubo's eruptions. Many of these problems relate to the role of technology and the role of the engineer, as discussed in section 11.3.

11.3 Role of Technology

11.3.1 American Influence

Clark Air Base and Subic Bay Naval Station contributed US\$1 billion per year and 68,000 direct jobs to the economy of the Mount Pinatubo region (Steinberg, 1994) but were a continuing source of damage to the Philippines' pride as a reminder of dependency on colonial powers (Brands, 1992; Steinberg, 1994). The presence of the military bases contributed to the American interest in the eruption and the military provided housing, communications, helicopter support, and some money to PVOT which assisted enormously in monitoring and predicting the volcano's behaviour. Without the involvement of the American military, many of these resources—including accommodations at Clark, which was a relatively secure location with electricity in close proximity to the volcano—would have been unavailable and the PVOT's activities would have been much more challenging.

The Mount Pinatubo eruption wrecked most of Clark and severely damaged Subic Bay in the midst of difficult negotiations to extend the Americans' lease on the bases beyond September 16, 1991. The Americans decided to abandon Clark but to negotiate for Subic Bay. A deal was reached

between the Americans and Filipinos which was rejected by the Filipino Senate. The Americans then announced that they would leave Subic Bay. The specific reasons are difficult to discern--for example, Brands (1992) and Steinberg (1994) assign widely disparate levels of importance to Subic Bay during the 1991 Gulf War to eject Iraqi troops from Kuwait--but the failure of the August 1991 communist coup in Moscow and the apparently impending breakup of the Soviet Union was as important as uncertainty about Mount Pinatubo's future activity. In any case, Mount Pinatubo was one of many factors which contributed to the final outcome.

Irrespective of the American interest in the military bases, USGS' mandate was clearly to assist the Filipino government (through PHIVOLCS) as part of VDAP, rather than to focus on the threat to the military bases. Since its inception in 1986, which was in direct response to the tragedy at Nevado del Ruiz, Colombia in 1985 (see section 5.3.3), VDAP has assisted eleven countries on four continents in responding to volcanic hazards. The 1991 Mount Pinatubo eruption was VDAP's "most extraordinary contribution to volcano-hazard mitigation" (USGS, 1997a). Given the extensive interest of the Americans in maintaining a military presence in the Philippines (Brands, 1992; Steinberg, 1994), it would seem that the military bases provided an overriding impetus for USGS to become heavily involved in investigating Mount Pinatubo without being the sole cause.

As part of VDAP, USGS brought with them new software and hardware which were applied to monitoring, modelling, and predicting Mount Pinatubo's behaviour, and which made the tasks much easier and more accurate. PHIVOLCS relied on USGS to create, bring, apply, operate, maintain, and interpret results from the needed technology (Bowler and Joyce, 1991; Kerr, 1991; WGBH, 1992). USGS and VDAP incorporate the fundamental goals of training others to use imported technology and promoting self-sufficiency (USGS, 1997a) but these goals were not always achieved.

The main constraining factor was the temporal scale of the natural hazard (section 6.3). There appear to have been ardent intentions to train PHIVOLCS in using USGS' technology, but the first priority had to be appropriate decision-making and advice for evacuations. The volcano could have erupted on any day following the initial activity, and even if the exact timeframe for eruptions had been predicted with confidence in advance, only the short time period between April 22 and the beginning of June (see Table 11-2) could have been used for training--amongst all the other required tasks. The long-standing relationship between USGS and PHIVOLCS mentioned in section 11.1 also provided an ideal atmosphere for technology transfer, but the temporal scale of Mount Pinatubo's activities did not always permit such principles to be put into practice.

The best practical situation under the circumstances was for USGS, who knew their technology well, to control operations, with PHIVOLCS learning as much as possible through observation and imitation. This point refers to the involvement of the American military too, discussed earlier, since the Filipinos had neither the expertise nor the resources to supply the necessary logistical support. The American influence on technology used during the Mount Pinatubo events might seem colonial and domineering (which it was) but the alternative was to avoid the use of such technology, likely resulting in tens of thousands of deaths.

11.3.2 Aetas

(This section collates and analyzes material from England (1993a and 1993b), Goertzen (1991), and Shimizu (1989))

The Aetas were devastated by the eruption and relief efforts seemed unprepared for, and uninterested in, responding to their cultural needs and values. Mount Pinatubo was a divine protector to the Aetas and the volcano's activity was an enormous psychological blow to them, indicating that they (or perhaps non-Aeta loggers and miners) had terribly angered the volcano. The complete destruction of their land and villages added despondency because the Aetas are proud of their self-reliance and believe that the slopes of Mount Pinatubo are the only place for them to live. Government plans to build new settlements and to permanently relocate them were initiated without the Aetas' consent and were eventually thwarted by the lack of cooperation from the Aetas.

Instead, the Aetas were left in temporary camps where they were forced into the horrendous indignity (to them) of accepting charitable support of food and clothing. As well, more than 600 Aeta children died of malnutrition and diseases such as measles in the camps in 1991 (PVOT, 1991), which is significantly more than the death toll during the actual eruption. The Aetas refused some of the food aid and much of the proffered medical services due to unfamiliarity; Western-style medicine and food are unnatural for them whereas death is normal and acceptable. The relief efforts neither anticipated nor responded to these cultural values. Two years after the eruption, the Aetas became tired of waiting in camps and commenced the return to their homes on the volcano's slopes against the instructions of the Filipino authorities. The Aetas prefer being self-reliant and in danger rather than being safe but dependent, yet this factor was never considered by others.

There is not much which an engineer could have done to alleviate the situation. Without a long history of engineers and other professionals cooperating with the Aetas to demonstrate that Western food and medicine are acceptable and to assist them in designing safer communities with more bountiful crops, the Aetas will be mistrustful about outside help. They have a society with a

low level of technology but a strong feeling of the need for self-reliance, so irrespective of how sensitive an engineer is to the Aeta culture or how much the technology is moulded for the Aetas' needs, the Aetas will refuse the assistance due to mistrustfulness and pride. This situation exemplifies the impact on technology's success and vulnerability to natural hazards of ingrained cultural/philosophical boundaries (sections 3.3 and 6.4.1).

11.3.3 Land-Use Planning

An extremely successful pre-disaster action for minimizing casualties from a volcanic eruption is to forbid the populace from settling in areas which are deemed to be highly vulnerable. Prohibiting human habitation within 10 km of Mount Pinatubo was only proposed three years after the eruption, by Tayag and Punongbayan (1994), when lahars (section 11.3.4) were causing damage. Enforcing such a directive, however, is challenging. The Aetas (section 11.3.2) refuse to live away from Mount Pinatubo's slopes. Meanwhile, rural Filipinos trying to eke out a subsistence living would oppose orders to avoid good land because of potential volcanic threats, particularly when they do not understand, and do not care to understand, the full implications of a volcanic eruption (PVOT, 1991). Present hunger and pride easily overwhelm potential, future dangers.

Preventing encroachment into volcanic areas is an effective long-term preventive solution which is often inappropriate, untenable, and unjust. Nonetheless, more investigation into and discussion of this issue would have been helpful as part of PHIVOLCS' mandate since its inception. For example, enlisting the cooperation of engineers for community design could assist in creating communities with reduced vulnerability to volcanic hazards--even on the slopes of a volcano. Warning systems and emergency response plans could be developed along with structures which are designed to be less vulnerable to volcanic hazards. Structures identified as important--such as schools, hospitals, and emergency services--could be designed with a higher level of safety than other structures. Hydrological engineering and surveying would also permit the least vulnerable locations for communities to be identified and would indicate how engineering works might be integrated into the environment to reduce vulnerability and environmental impact. Such concepts are not new or innovative; in fact, they have been applied to earthquake, tornado, and hurricane engineering, and to less dramatic natural hazards, for years. Applying similar engineering techniques to volcano engineering--coupled with education about hazards and individual and community response measures--would reach a compromise where land-use around a volcano was neither forbidden nor highly vulnerable.

11.3.4 Design Loads

The main damage to engineered structures from Mount Pinatubo came from ash and tephra falls and lahars. Section 11.2 described how the majority of deaths during the eruption occurred as a result of the combination of Mount Pinatubo's ash and tephra falls and Typhoon Yunya. Volcanic material accumulated on roofs and readily absorbed water from the typhoon's rain. The weight of wet ash and tephra collapsed the roofs and crushed victims. This situation epitomizes the concerns espoused about how past experience influences vulnerability (section 3.3) and creates challenges for engineering design (section 4.4.2) along with the design challenge presented by conjunctive events (section 4.4.3).

Designing roofs for this case would have entailed anticipating a conjunctive event which had never before been experienced in the Philippines and which is not mentioned in the literature of other volcanic eruptions or potential volcanic hazards. Furthermore, anticipating the conjunctive events of one the worst volcanic eruptions in the twentieth century along with a severe (category 3 out of 5) typhoon would have been stretching the boundaries of plausibility. Even if such a prediction had been accepted, the cost of designing for such a load could well have been beyond the means of rural Filipino communities. This situation illustrates the economic influences on vulnerability discussed in section 3.4.

In this situation, the engineer would be responsible for ensuring that the limits of the design load were known and understood at the time of construction. Then, in the few days leading up to June 15, 1991 when it became apparent that Typhoon Yunya might strike Mount Pinatubo, the engineer should have been able to work with volcanologists to anticipate the threat of water-soaked ash and tephra and to communicate the hazard and appropriate safety measures to the population. Unfortunately, there appeared to be no engineers on PVOT nor on the local emergency committees. Additionally, as seen in Table 11-2, Mount Pinatubo's activity was intense from approximately June 10th--before Typhoon Yunya's formation (see footnote 1 in section 11.2). The lack of engineers present during the crisis could have been rectified, and should be altered for future events. The complete dominance of the volcanic threat during Typhoon Yunya could not have been altered, since it is nature's contribution. While engineers and additional resources might have provided the opportunity for identifying the wet ash and tephra hazard, there would have been no guarantee of success. In any case, an important lesson in volcanic hazards has been learned for future instances.

In contrast to the difficulty of anticipating the wet ash and tephra hazard, lahars are a well-known volcanic hazard (section 9.2.4), and received international publicity and much academic

interest after the disaster at Nevado del Ruiz, Colombia in 1985 (details are in section 5.3.3). Lahars have occurred each year following the 1991 eruption of Mount Pinatubo, with material being remobilized during the rainy season by typhoons as well as by regular showers (information in the remainder of this section is from "Like Pompeii" (1996), Tayag and Punongbayan (1994), and Tiglao (1996)). Estimates of casualties vary widely, but lahars have buried several towns, clogged rivers in the area, devastated hundreds of square kilometers of land in layers several meters thick, killed a few hundred people, and displaced tens of thousands of people, with some locations undergoing several evacuations over the years.

Despite the knowledge of and continuing threat from lahars, the response to Mount Pinatubo lahars has been abysmal. Theory and planning for engineering countermeasures have been exhaustively explored (see Table 11-3) but translation to practical results has failed miserably. For example, concrete dams are recommended for intermediate and long-term measures, yet no attempt has been made to construct any. Instead, dikes made from lahar material are used because of the low cost and the abundance of lahar material. By 1994, 9 of 22 check dams had collapsed and they had all been filled by lahars--although inundation of downstream communities was prevented temporarily. In 1996, a US\$40 million lahar dike was breached for 67 m. Repair work and further construction have been delayed by disagreements, corruption and incompetence.

The Public Works Department complains that PHIVOLCS, particularly the director Dr. Raymundo S. Punongbayan, failed to predict lahar behaviour. Dr. Punongbayan not only denies the charges but also has publications (e.g., Tayag and Punongbayan, 1994) which clearly spell out the threat long before the catastrophic lahars of 1996--although whether Dr. Punongbayan communicated this information to the Department is not clear. Dr. Punongbayan retaliates to the accusations by complaining of poor design and construction of the dikes by the Department. The Public Works Department also takes issue with criticisms from American-Filipino geologist Kelvin Rodolfo, a professor at the University of Illinois. Rodolfo offers criticisms of, and proposes improvements to, the Department's dike plans, but the Department downplays the identified problems and blames both nature's power and the lack of funds.

The lack of funds, however, stems from mismanagement. In 1995, less than one quarter of expected lahar infrastructure funds were released, of which less than half were actually used. In 1996, President Fidel Ramos pledged substantial money for dike projects but did not appropriate any in the national budget. As well, dike and catchment basin projects have rarely been built according to

Table 11-3: Summary of Engineering Intervention Measures for Mount Pinatubo Rehabilitation Program
(Table and title are from Tayag and Punongbayan (1994); spelling errors have been corrected)

Strategy	Immediate	Intermediate	Long-term
Stop the sediment at its source.	Emergency low sabo/check dams ² (gabions ³ , sand-cement bags).	Series of permanent low sabo/check dams (gabions, concrete).	Series of permanent high sabo/check dams (concrete).
Convey the materials directly to the sea.	Emergency desilting/channelling of river channels and mouths through pilot channels.	More extensive desilting and dredging to restore original channels.	Continuous dredging and channelization and creation of new channels based on long-term river system plans.
Control the sediment as it moves from the mountain to the alluvial fans.	Emergency rehabilitation of breached dikes; emergency desilting/channelling of rivers; construction of emergency spur dikes, hurdles, and other river training works; provision of emergency protective dikes and sand pockets.	Raising and strengthening of dikes; construction of new/secondary dikes; construction of permanent spur dikes, hurdles, and other river training works; provision of sand pockets and protective dikes; construction of transverse sills and consolidation dams.	Expansion of intermediate measures; construction of diversion channels; development of catch basins; construction of new/extension of diking systems.

²Sabos and check dams are synonyms.

³Gabions are boulders covered in galvanized wire cage.

plan, are usually opposed by locals with firearms and machetes who vent their frustrations on the site engineers and workers, and are often delayed by continued disputes amongst decision-makers.

The lahar situation at Mount Pinatubo illustrates how political influences on vulnerability can supersede technological solutions (section 3.5) and also how economic influences can inhibit technological solutions (section 3.4). Technological boundaries (section 6.5) also affect the engineering countermeasures: solutions are focussed on redirecting and containing lahars because prevention of the natural hazard does not seem to be feasible and could be dangerous (section 5.2.5) since the mobilized lahar material must flow somewhere, under the influences of topography and gravity. Challenges of preventing vulnerability (section 5.3.3 along with the attitude and belief system influences on vulnerability in sections 3.3 and 6.4.1) are demonstrated too. Locals would rather face lahars, the threat which they do not necessarily understand fully, than have their land expropriated for dams and catchment basins, which is a straightforward threat. In summary, designing a system for the lahar load is fraught with complex difficulties beyond the traditional tasks of the engineer. The engineer must therefore examine issues outside the regular realm and work with others in the community to develop appropriate solutions.

11.3.5 Technology Transfer and Cross-Cultural Communication

A prevalent theme during the eruption was difficulties in cross-cultural communication. Section 11.3.1 described problems of technology transfer from USGS to PHIVOLCS. Section 11.3.2 described a lack of understanding of the Aetas' needs and values. Similarly, the Catholic influence on the Filipino culture introduces an element of fatalism (as discussed in section 3.3)--i.e., if a volcano threatens one's life, then it is God's will and should not be interfered with--which was not acknowledged by PVOT.

The Americans also had difficulties in explaining the nature of a volcanic threat to a populace that they considered to be scientifically illiterate, but said that the problems were overcome by talking to Filipino civil defence leaders who in turn communicated with the population. This approach illustrates a learning experience by the Americans for cross-cultural communication. The Americans did not anticipate that different cultures would have different values, but when problems manifested, some were identified and resolved. Unfortunately, USGS apparently expected all cultures to accept scientific explanations as paramount, which did not occur with the Aetas (England, 1993a and 1993b) or with many Catholic Filipinos who interpreted the eruption of Mount Pinatubo as a message from God stating that ("The voice of God", 1991) (a) the Americans should be ejected from their military bases, (b) increasing pornography in Filipino art should cease, or (c) (care of Imelda Marcos) the rule

of Ferdinand Marcos (who died in 1989) has now been exonerated. PVOT (1991) also mentions the challenge of explaining volcanic hazards to a rural population which has never before experienced them, but suggests only that videos be used.

PVOT (1991) are highly complimentary about using videos to convey information about volcanic hazards--particularly the video on pyroclastic flows produced by Maurice and Katia Krafft shortly before their death in a pyroclastic flow from Mount Unzen, Japan (section 9.3)--but do not acknowledge that VCR's might not be common items in rural Filipino households or local governments. Furthermore, the Philippines has been in a protracted energy crisis for more than a decade which makes electricity supplies extremely unreliable at short notice (Steinberg, 1994). Similarly, cellular and satellite phones are justifiably espoused by PVOT (1991) as essential communication tools during a volcanic emergency situation, yet their cost, availability, and logistics (such as recharging batteries and having cellular phone networks in place) are ignored. Videos and cellular phones might be adequate for PVOT, but are appropriate for neither many rural Filipinos nor the Aetas.

11.3.6 Conclusions

Technology played a significant role in the eruption of Mount Pinatubo, but the few successes were eclipsed by other problems and influences. As well, there was little indication of attempts at using preventive engineering approaches. PHIVOLCS does state (Tayag and Punongbayan, 1994, p. 2):

We have reached the point at which we are already willing to go beyond disaster relief and recovery, and even beyond disaster preparedness planning and consider long-term mitigation. We are also at a point where the temptation is great to swing to the other extreme and adopt technological measures for interfering with natural processes.

The recognition of these issues and the implicit restraint on embracing technological measures without question indicates a mature view of the role of technology which complements PHIVOLCS' partial self-recrimination with respect to their actions at Mount Pinatubo, mentioned at the end of section 11.2.

There is, however, much room for improvement. The limitations of the technology which was used were rarely noted. Meanwhile, explicit recognition of both cultural conflicts with technology and technology transfer issues was almost absent. The role of the engineer could also have been much more prominent, particularly as part of the decision-making and volcano monitoring teams. Instead, engineers were relegated to constructing and repairing infrastructure, lifelines, and

post-eruption mitigative structures. Such tasks are obviously needed, but the engineer could not have completed much under the political circumstances which existed and, in any case, engineers also have the ability to contribute much more to the prevention of volcanic disasters.

12. Soufrière Hills, Montserrat (Initial Eruption 1995)

Abbreviations used in this chapter:

MVOT	Montserrat Volcano Observatory Team (see section 12.3.1)
USGS	United States Geological Survey (American volcanologists)
VDAP	Volcano Disaster Assistance Program (an USGS international aid initiative)

12.1 Montserrat

Montserrat is a single island centred on 16.75°N and 62.22°W between the Caribbean Sea and the Atlantic Ocean amongst the Leeward Islands in the Lesser Antilles (Figures 12-1 and 12-2). The immediate neighbours of Montserrat are Antigua to the northeast, Guadeloupe to the southeast, and Nevis to the northwest (with the tiny island of Redonda, belonging to Antigua and Barbuda) lying in between. At maximum, Montserrat is 18 km north-south and 11 km east-west yielding a 102 km² of area, most of which is land as there are no significant bodies of water.

Montserrat's history (summarized from Akenson, 1997 and Fergus, 1994) begins vaguely, with small settlements by various aboriginal groups. The Arawak aboriginals were forced out, probably in the 14th or 15th centuries, by the violent Carib group who retained control of the island without establishing a large, permanent settlement. In 1493, Christopher Columbus became the first European to record the island, and although he did not land there, he named it after the monastery of Santa Maria de Monserrate in Catalonia. The first recorded European landings on Montserrat occurred in 1628 and 1631 with no reports of settlers, but Father Andrew White in January 1634 recorded an Irish plantation. Thus, Montserrat was settled by whites, possibly displacing a small Carib colony and probably bringing black slaves, in the early 1630's.

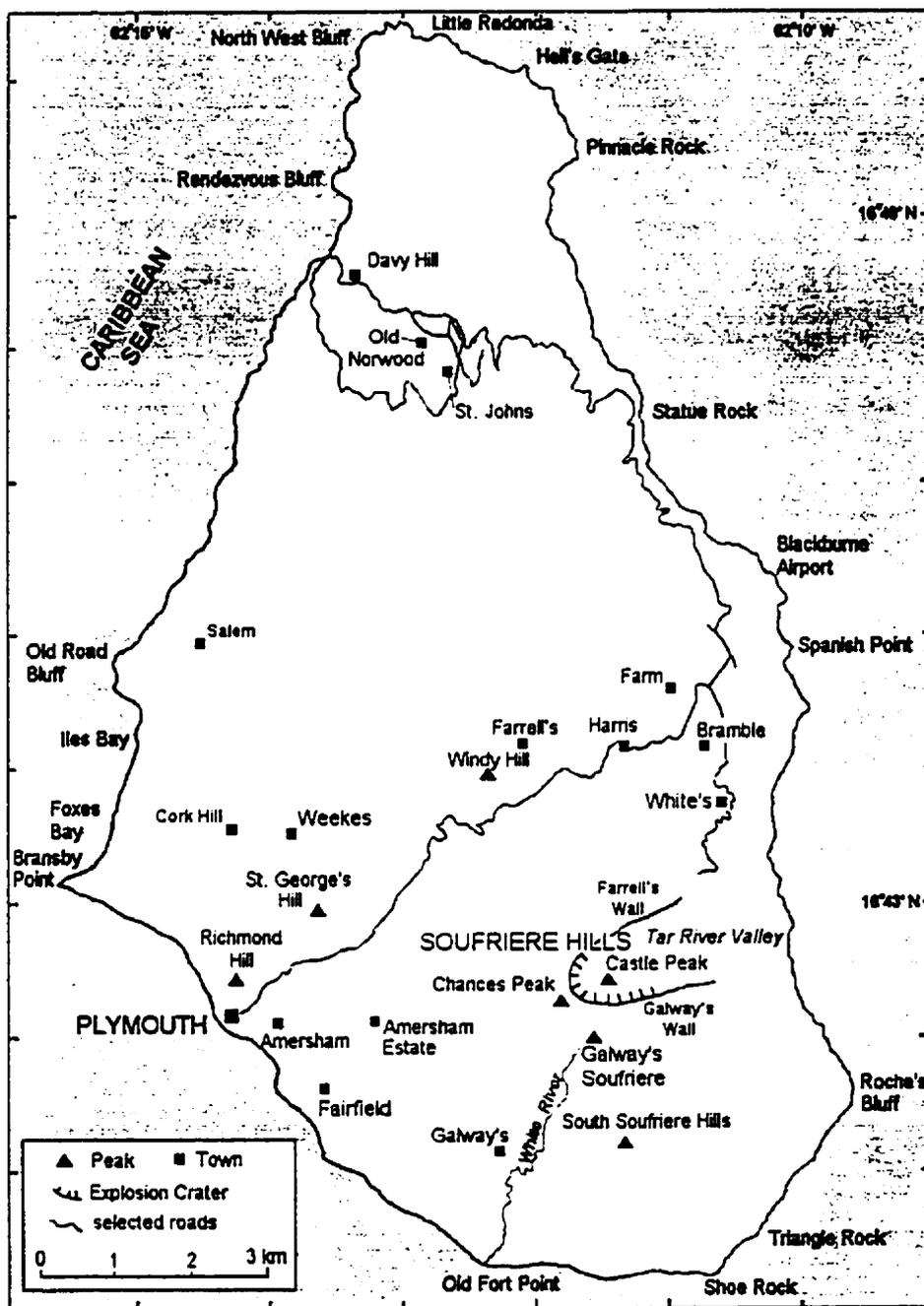
The pursuit of riches through tobacco, indigo, and sugar farming permitted Montserrat to grow into a British colony, settled mainly by Catholics from Ireland, controlled by English Protestants, and using black slaves. The Irish presence, along with the island's physical appearance, accounts for Montserrat's nickname "The Emerald Isle" and for Ireland's current affinity and empathy for the island. Despite brief periods of French occupation in 1667 and 1782-3, attacks by the Dutch and the Carib, and uprisings by Irish farmers and black slaves, Montserrat remained part of the British Empire and is currently one of thirteen British Overseas Territories. External affairs and defence are controlled by the U.K., but other policies are developed domestically with a governor appointed by the British government. This status denies the inhabitants British citizenship, but there are few Montserradians who desire independence.

Figure 12-1: Eastern Caribbean Islands

(from http://www.geo.mtu.edu/volcanoes/west.indies/soufriere/images/carrib_map.gif, accessed on May 10, 1998)



Figure 12-2: Montserrat and Soufrière Hills
 (from <http://www.volcano.si.edu/gvp/volcano/region16/soufhill/2211shml.gif>,
 accessed on May 10, 1998)



The main impetus in eschewing independence is economics, since approximately 20% of Montserrat's budget is British overseas development aid (economic and demographic information in this section is from Fergus (1994) and ODCI (1997)). There are few natural resources, with tourism being the predominant income generator and the service industry accounting for approximately three-quarters of economic production and employing two-fifths of the labour force. Exports are dominated by electronic components and appliances shipped to the U.S.A. although hot peppers, live plants, plastic bags, and cattle are exported as well. Ireland follows the U.S.A. as Montserrat's largest trading partners. The small agricultural industry produces various fruits and vegetables for domestic consumption. Rum, sugar, cotton, and construction are also industries on Montserrat. Imports are worth approximately forty times the value of exports and cover all other necessitates including fuel, most manufactured goods, and most food. Montserrat is considered to be upper-middle income by data from the World Bank (1995).

Domestic industries and imports sustain the population which was reported as 12,771 in 1996, but is more commonly reported as 11,000 or 11,500. The capital, Plymouth, has approximately 4,000 people and the island's only hospital; there are no other settlements of comparable size. Montserrat's population has been approximately steady or slightly declining in recent decades. Other demographic data resemble the developed world with literacy at 97% amongst both men and women, life expectancy at birth at 75.65 years, and the infant mortality rate at 11.78 deaths per 1,000 live births.

Most demographic and economic indicators put Montserrat in a reasonably good position for a non-industrialized island, but there are problems. The main advantage for Montserrat is British economic support. In recent times, but before Soufrière Hills erupted, there have been few political problems and a good relationship with the U.K. The main issue of Montserratian concern has been hurricanes, including four major storms since 1899, but particularly focussed on Hurricane Hugo which devastated the island in 1989 and from which Montserrat never fully recovered (Fergus, 1994; Howe, 1997a; "Too little...", 1997; Williams and Musi, 1997).

According to Akenson (1997), Montserrat "may be considered a footnote to volcanic activity" (p. 38). Volcanic activity has built the island, producing sea cliffs which preclude a natural deep harbour, three mountain ranges reaching up to 915 m above sea level, and continuous sulphur emissions from volcanic vents. In between the peaks lie plateaus and deep, broad valleys. The mountains prevent salty winds from infiltrating Montserrat and keep the north and east relatively dry while yielding unevenly distributed rainfall throughout the rest of the island. A major factor in making

Montserrat livable is the more than one hundred waterways which are fed only by this rain, as Montserrat has no significant groundwater.

12.2 Soufrière Hills

Montserrat's volcano, Soufrière Hills¹ is located at 16.72°N and 62.18°W and, as the highest point on Montserrat, has a summit elevation of 915 m at Chances Peak. Soufrière Hills is one of fifteen volcanoes in the Caribbean islands which has erupted in the last 10,000 years (Smithsonian Institute, 1997; see Table 12-1 for selected volcanic eruptions in the Caribbean) but prior to 1995, it would not have made this list.

Baker (1985) and Wadge and Isaacs (1988) studied the volcanic history of Soufrière Hills. The last major eruptive period started approximately 24,000 years ago and went until approximately 16,000 years ago with a widespread layer of pyroclastics dating from approximately 19,000 years ago. A sample dating from 1646 A.D. \pm 54 years possibly represents an eruption generating small pyroclastic flows, but attempts at refinding the site and collecting new samples were unsuccessful. The absence of historical and anecdotal evidence for an eruption from both the aboriginals and the Europeans also reduces credence for an eruption around this date. On the other hand, USGS (1997b) report that magma movement generated pyroclastic flows and created a structure known as a lava dome "less than about 500 years ago". There have also been three notable periods of seismic and fumarolic activity, in 1897-98, 1933-37, and 1966-67. The 1966-67 period was marked by inflation and then deflation of an area near Soufrière Hills, which is usually indicative of magma upwelling and then settling down. Newhall and Dzurisin (1988) suggest that the activity starting in 1897 actually ran until the end of 1900 with heavy damage to buildings occurring during an October 1900 earthquake.

In January 1992, another period of seismic activity began with intense earthquakes occurring in June 1994 (MVO, 1998). On July 18, 1995 the first recorded eruption of Soufrière Hills occurred. The temporal sequence of events of the eruption is summarized in Table 12-2 which attempts to collate the information in the references and provides the most popular dates and data for the listed events. If a table entry seems ambiguous, it emulates the references. The only confirmed fatalities to date occurred on June 25, 1997 when pyroclastic flows swept through several villages. The reported toll ranges from 19 (Smithsonian Institute, 1998; Svitil, 1998) to "more than 30" (Howe, 1997a, p.

¹"Soufrière" is French for "sulphur mine".

Table 12-1: Selected Volcanic Eruptions on Caribbean Islands

Date	Volcano	Casualties and Evacuations
March 27, 1718	La Soufrière, St. Vincent	no information
April 27-30, 1812	La Soufrière, St. Vincent	56 dead
January, 1880	Valley of Desolation, Dominica	no information
May 7, 1902	La Soufrière, St. Vincent	1,600 dead
May 8, 1902	Mount Pelée, Martinique	28,000 dead
1929	Mount Pelée, Martinique	no information
October 17, 1971	La Soufrière, St. Vincent	no information
1976	Soufrière, Guadeloupe	no deaths, 70,000 evacuated
April 13-26, 1979	La Soufrière, St. Vincent	no deaths, 15,000 evacuated
July 18, 1995 to the present	Soufrière Hills, Montserrat	19-30 dead and approximately 7,000 evacuated (see the text in this chapter)

Table 12-2: Chronology of the Eruption of Soufrière Hills
(summarized from MVO, 1998; Smithsonian Institute, 1998; Volcano World, 1998)

Date	Events
July 18, 1995	Initial explosion of steam and ash.
August 21, 1995	First large steam and ash explosion. Plymouth becomes covered with ash and the first evacuation of southern Montserrat is initiated soon after.
October 17, 1995	First lahar.
October 30, 1995	A large steam and ash explosion.
November 30, 1995	Lava is observed for the first time and magma upwelling is confirmed.
December 1-2, 1995	The second evacuation of southern Montserrat is started.
January 1, 1996	Residents are permitted to return to evacuated areas.
April 3, 1996	First pyroclastic flow. The third evacuation of southern Montserrat is started.
May 12, 1996	Pyroclastic flows reach the sea for the first time.
July 25 to August 11, 1996	A major period of volcanic and seismic activity.
August 21, 1996	The largest eruption so far.
September 17, 1996	The first magma explosion destroys houses and covers southern Montserrat with 600,000 tonnes of ash.
March 30 to June 1997	Major pyroclastic flows.
June 25, 1997	Several villages are engulfed by pyroclastic flows causing the first fatalities of the eruption. The first bodies are recovered two days later. The final toll is 7-9 confirmed dead, 13-21 missing and presumed dead, 5 injured, 45 people airlifted to safety, and 100-150 houses destroyed in 8 villages. The island's airport is evacuated.
June to September 1997	Pyroclastic flows and small explosions continue. Plymouth is virtually destroyed.
September 7, 1997	MVOT moves its base farther north.
September 9, 1997	The southern $\frac{2}{3}$ of Montserrat is closed to the public.
September 21, 1997	Montserrat's abandoned airport is destroyed: the runway is buried and the terminal burns down.
September 22 to October 21, 1997	76 explosions.
November 11, 1997	Explosions and pyroclastic flows.
December 26, 1997	A major explosion followed by large pyroclastic flows.
1998	Continuing volcanic activity.

19), all of whom were illegally in the area which the pyroclastic flows hit, but only between seven (MVO, 1998) and nine (Volcano World, 1998) bodies were recovered.

The most devastating effect of Soufrière Hills is the impact on the inhabitants' lifestyle and the evacuations. Three zones have been defined (Figure 12-3):

- Exclusion Zone: Entry is forbidden except for scientific monitoring and national security matters.
- Central Zone: A residential area only; commercial activity is forbidden. All residents must be on a heightened state of alert with a rapid means of departure ready 24 hours a day and must have hard hats and dust masks.
- Northern Zone: Residential occupation and commercial activity are permitted.

Thus, approximately two-thirds of the island is uninhabitable, and since this zone includes Plymouth and most of the other larger settlements, the majority of the population remaining on the island is displaced with thousands living in makeshift, temporary shelters. At least half of the original population has left, ostensibly permanently, mainly to Antigua, Guadeloupe, and Great Britain with some going to relatives in the U.S.A. The departure of many of the residents, though, was marred by poor political actions (section 12.3.2).

The crisis on Montserrat is ongoing. No long-term plans for, or decisions with respect to, complete evacuation, building up the north for settlement, or resettling of the south have been made. The main factor delaying decisions on Montserrat's future is Soufrière Hills. There is no certainty how much longer the volcano will continue to erupt or the final impacts of the eruptions, but the likelihood is that several more years of activity will continue to devastate the southern portion of Montserrat.

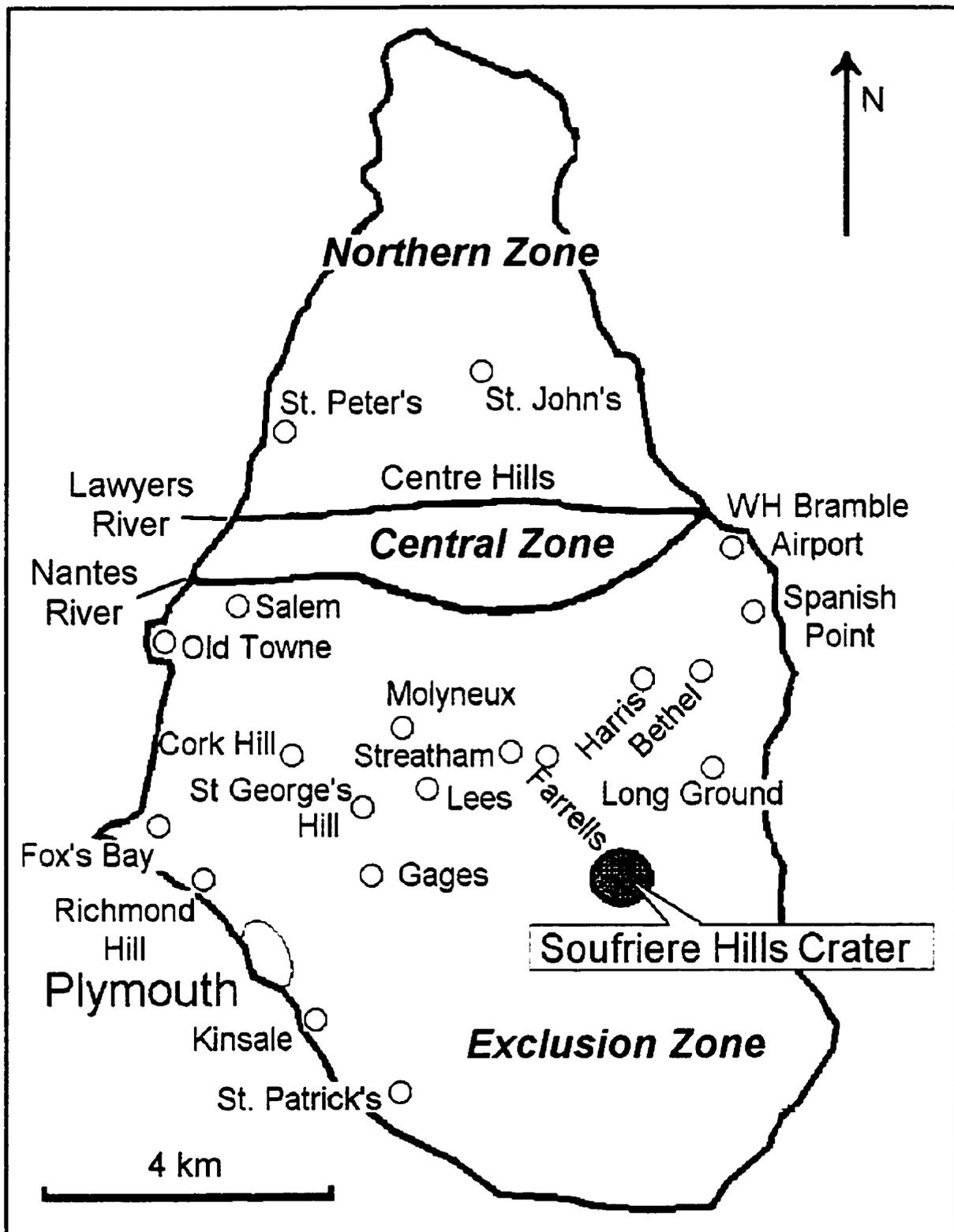
12.3 Role of Technology

12.3.1 MVOT

Immediately following the July 18, 1995 activity of Soufrière Hills, a scientific team was established as MVOT, the Montserrat Volcano Observatory Team. MVOT comprises participants from the U.K., the U.S.A. (including Puerto Rico), and Trinidad and Tobago who are drawn from a group numbering more than three dozen. Approximately one dozen members of the group are normally on Montserrat at any time, with a turnover timespan of one to three months (Norton, 1998).

The Americans include USGS volcanologists who are present under the auspices of VDAP (see details of VDAP in section 11.3.1), with some funding from contracts with the British Geological Survey, and they brought with them software and hardware for monitoring, modelling, and predicting

Figure 12-3: Volcanic Hazard Zones for Soufrière Hills
 (from <http://www.volcano.si.edu/gvp/volcano/region16/southill/2209shml.gif>,
 accessed on May 10, 1998)



volcanoes. MVOT applied, operated, maintained, and interpreted results obtained from the technology (Schneider, 1997).

Additionally, MVOT includes six local technical staff from Montserrat who are either Montserratian or long-term Montserrat residents from other Caribbean islands (Norton, 1998). Some of these staff had worked as volunteers since the 1992 seismic events which preceded the volcanic eruption. As soon as the volcano erupted and MVOT was created, they were hired. MVOT's Montserratian staff have been given extensive training and the intention is that "they will form MVO[T] once the volcano has gone to sleep" (Norton, 1998). MVOT also meets daily with local leaders. Thus, Montserratians have a definite presence in MVOT, although their decision-making influence is hard to gauge. Including Montserratians in MVOT and informing their leaders of the daily situation demonstrates explicit recognition that the Montserratians are most affected by the volcano and that they should have input to scientific activities.

Training locals in monitoring, data acquisition, and observation interpretation is advantageous by:

- integrating MVOT with the Montserratian community;
- providing potential employment and direct participation for a despondent population;
- making use of local knowledge and experience;
- directly illustrating the challenges of volcanology; and
- transferring technical skills to a community which needs to enact long-term volcano observation and response measures;

These advantages facilitate communication and augment trust amongst the various groups dealing with the Montserrat crisis, thereby helping to ensure appropriate attitudes and belief systems (section 3.3) and helping to overcome psychological boundaries (section 6.4).

The presence of the Trinidadians and Puerto Ricans on MVOT, in addition to the Montserratians, is important, not only to transfer technology and technical skills to more Caribbeans, but also to provide more Caribbean input and perspectives to MVOT. The dominance of Americans and Brits on the team coupled with the dominance of American technology undoubtedly inhibited the participation of less-experienced members because MVOT's priority had to be analysis and prediction of Soufrière Hills' behaviour. The work of MVOT (e.g., Aspinall *et al.* 1998; Baxter *et al.*, 1998; MVO, 1998) does seem to reflect the geographic and disciplinary diversity of the team members implying that all scientific members participated and learned from their colleagues at a significant level.

These same publications, while seemingly representing the scientists quite well, did not acknowledge the technicians, who were mainly Montserratian, particularly well. In fact, before Gill Norton of MVOT was contacted directly (the reference to Norton (1998)), it was not apparent that there were any Montserratians on MVOT. Although technicians in a scientific team are rarely given credit in the academic world, the importance of integrating Montserratians into MVOT--and of being seen to integrate Montserratians into MVOT--merits brief but evident mentions of the technicians, and standard scientific protocol would not be sacrificed.

There is one clearly identified engineer affiliated with MVOT: Professor B. Voight from the Department of Geosciences at Pennsylvania State University in the U.S.A. with an adjunct appointment at USGS. Professor Voight, an engineering geologist, has made a career of studying volcanic phenomena and has been recognized by the Institution of Civil Engineers (London) for his work. Discerning the specific contributions from and influences of Professor Voight is not feasible, but it is important to note that the contributions of engineers to natural disaster management have been acknowledged to some degree during the Soufrière Hills events.

12.3.2 Political Situation with the U.K.

When Soufrière Hills erupted in 1995, the U.K. government under Conservative Prime Minister John Major attempted to ignore Montserratian appeals for assistance, apart from an increase in monetary aid to the island. For example, Montserratians were provided with work permits for the U.K. only after the third evacuation of southern Montserrat in April 1996, although no funds were allocated to assist travelling and resettlement costs ("Too little...", 1997). In the May 1, 1997 election in the U.K., Tony Blair and the Labour Party (known as New Labour) won a landslide victory promising, and then enacting, reform in many areas. One governmental reform was to separate the Foreign Office--under the Foreign Secretary (one of the most senior ministers) Robin Cook--from the Department for International Development--under the secretary (one of the most junior ministers) Clare Short.

The division of responsibility between the two ministries is still unclear, but the responsibility for Montserrat's situation was firmly placed on Ms. Short. Ms. Short has set out to eradicate world poverty by 2010 and considers her budget to exist for helping "the poorest people of the world" which does place Montserrat high on her list of priorities (Lloyd, 1997, p. 9). In August 1997, Ms.

Short's offer to Montserrat was UK£41 million² along with UK£2,500 to each person who wishes to leave, plus the right to live and work in the U.K. for up to two years. Montserratians would also be provided with help to move to Antigua³ or Guadeloupe, with no promises of assistance after arrival. Negotiations were underway with other Caribbean islands to accept Montserratian settlers.

Montserratians viewed this offer as inadequate and there was particular mistrust over the lack of consultation and flexibility in developing the offer. Frustrated by the Montserratian reaction, Ms. Short--who is known for neither her diplomacy nor her ability to restrain her temper--publicly lambasted the Montserratian officials for irresponsibility and greed. Mr. Blair and Mr. Cook sought to disregard Ms. Short's comments and announced a review of the U.K.'s relationship with its dependent territories to be run by Mr. Cook's department--a deliberate snub to Ms. Short. The suggestion of resettlement on Antigua is further complicated by the existence of the most corrupt government in the Caribbean running Antigua and Barbuda, leading to concerns that any aid money from the U.K. could end up with the Russian mafia, in the prime minister's personal financial accounts, or assisting the prime minister's brother to purchase cocaine rather than going towards resettling Montserratians (after Howe, 1997b).

The Economist ("Caribbean follies", 1997; "The Montserrat muddle", 1997; "Too little...", 1997) states that the problem stems from the U.K.'s poor attitude towards Montserrat. The U.K.'s response should be viewed as disaster relief to a needy region of the U.K. rather than as overseas assistance to a developing nation. The inhabitants are thus entitled to generous funds and full British passports. Howe (1997a, 1997b) suggests that Montserrat is unlivable and the Montserratians are greedy; Mr. Cook and Ms. Short should "exercise some leadership" (Howe, 1997b, p. 34) and channel all funds for evacuating Montserrat permanently. On May 21, 1998, the British government's Home Office (one of the most senior ministries) granted permission for any Montserratian, past or future evacuee, to settle in the U.K. permanently.

The political gaffes, posturing, and ambiguities have impacted appropriate decision-making techniques. Important issues such as the practicality of engineering plans, primarily land-use planning

²The British pound (UK£) was worth just over CAN\$2 towards the end of the summer of 1997, but has risen steadily since then to approximately CAN\$2.50 in June 1998.

³Prior to 1995 there was a strong Montserratian connection with Antigua due to previous emigration from Montserrat, and Antiguan would not be averse to the remaining Montserratians settling there (Howe, 1997b).

and appropriate design loads (section 12.3.3), are not debated publically enough or in appropriate detail. Political and economic influences on vulnerability (sections 3.4 and 3.5) have created many more problems on Montserrat than are necessary.

12.3.3 Land-Use Planning and Design Loads

Montserrat's settlement since the 17th century has been rather haphazard without extensive land-use planning or examination of design loads required to withstand natural hazards, particularly with respect to volcanic hazards. Hazard mapping for Soufrière Hills had been examined and completed prior to the initial eruption (e.g., Baker, 1985; Wadge and Isaacs, 1988) but there was no incentive to act on potential problems because the volcano was not expected to erupt. This situation illustrates how engineering design decisions with respect to natural hazards are often based on past experiences (section 4.4.2). As well, most of Montserrat's population and industry were located in the south, near the volcano. For example, Plymouth is at the bottom of Soufrière Hills' slopes, 4 km away from the peak. Attempting to uproot the settlements based on the small probability of an eruption would have been difficult, an example of other factors superseding concerns about vulnerability to natural disasters (section 3.3).

The experience from Hurricane Hugo in 1989 illustrates the Montserratian attitude towards natural disasters. The hurricane devastated the island, damaging or destroying almost all structures. The response was to rebuild an almost exact imitation of what had been destroyed ("The Rumbling Caribbean", 1997) without any evidence of attempts at analyzing the damage patterns and failure causes in order to try and be better prepared for the next hurricane. Montserrat's governor estimated that the cost of rebuilding completely would be US\$300 million in 1989 dollars (Howe, 1997a), which not only seems excessive on either a per capita or per km² basis (approximately US\$25,000 per person or nearly US\$3 million per km²), but which is also nineteen times Montserrat's annual budget (ODCI, 1997). When a single event causes such an enormous scale of damage, and considering that hurricane and volcano threats are well-known to Montserrat, the wisdom of permanent settlement on the island is in doubt without extensive social and technical preparation. There seems to have been negligible activity with respect to such preparation.

After the volcanic eruption commenced, hazard maps were updated and used to develop the three zones discussed in section 11.2 (MVOT, 1997). The population, however, was not convinced of the necessity of the three zones. Roads into the Exclusion Zone had to be barricaded to prevent Montserratians entering. As soon as gates were installed, two new roads into the Exclusion Zone were born along former cow paths. The only fatalities due to Soufrière Hills up until June 1998

(which occurred on June 25, 1997; see Table 12-2 and section 12.2) occurred in a forbidden zone. The deaths made a strong impression on Montserratians who afterwards heeded the volcanic threat much more seriously and paid much more attention to the zone definitions (Monastersky, 1997; Williams and Musi, 1997)--an example of a psychological boundary (section 6.4) which changes rapidly.

The UK£41 million promised by Ms. Short in August 1997 (section 12.3.2) was marked mainly for rebuilding infrastructure, but fails to examine whether or not infrastructure and communities could actually be rebuilt with an appropriate level of safety. The likelihood of an eruption severely affecting the Northern Zone is low (Aspinall *et al.*, 1998) but ash has been blanketing the entire island, the surrounding ocean, and, on occasion, Guadeloupe. An ashfall followed by a hurricane or heavy rainfall could cause roof collapses and deaths (a conjunctive natural disaster event, as discussed in section 4.4.3), similar to those witnessed during the 1991 eruption of Mount Pinatubo in the Philippines (section 11.3.4), unless stringent design guidelines were implemented. As well, the north's land area and resources would be unlikely to sustain a viable settlement. Although engineers have drawn up plans for a jetty in a sheltered bay on the northeast side (Williams and Musi, 1997), constructing a harbour sufficient for Montserrat's long-term needs would be more expensive and would have severe environmental impacts.

As of June 1998, there is no possibility of cleaning up and rebuilding the south, since the volcano is continually active. As noted in section 5.2.3, preventing volcanic hazards is currently not feasible, and the descriptions of volcanic hazards in Chapter 9 indicate that design loads would have to be excessively high to ensure safety from volcanic hazards emanating from only a few kilometers away (recall also section 4.4 and the challenges of selecting appropriate design loads). The best approach for now to maintaining a safe population on Montserrat is the updating and enforcement of the three zones described in section 11.2. Ash and occasionally larger volcanic ejecta have fallen on the north, but the probability of a large-magnitude volcanic event affecting the north is quite low, and is less than the probability of a major earthquake in the region (Aspinall *et al.*, 1998).

12.3.4 Internet

The internet has immensely facilitated communication during Soufrière Hills' eruption. There are several WWW (World Wide Web) sites dedicated to updated information on the situation (Table 12-3). Email has enabled MVOT scientists to maintain rapid and inexpensive communication with each other, with governments, and with the public. FTP (File Transfer Protocol) sites open only to MVOT staff have permitted large amounts of data to be disseminated rapidly. Young (1998)

Table 12-3: WWW Sites Related to Montserrat's Volcanic Crisis
 (These sites were accessed in May and June 1998)

Organization	URL
Government of Montserrat and the Montserrat Volcano Observatory	http://www.geo.mtu.edu/volcanoes/west.indies/soufriere/govt
Michigan Technical University	http://www.geo.mtu.edu/volcanoes/west.indies/soufriere
Montserrat Information Access Centre	http://members.aol.com/MontsIAC/monthome.htm
Montserrat Information Archives	http://209.150.130.238
	http://www.montserrat.org
Smithsonian Institute's Global Volcanism Network	http://www.ninuh.si.edu/gvp/volcano/region16/soufhill/gvnb.htm
The Emer@ld Network	http://www.members.aol.com/emnetwork/tenhome.htm
USGS	http://volcan.wr.usgs.gov/Volcanoes/Montserrat/framework.html
Volcano World	http://volcano.und.nodak.edu/vwdocs/vw_news/montserrat.html

summarizes the lessons learned from the events on Montserrat about using the internet during a disaster crisis:

- *The Internet has provided a cheap and effective way of disseminating a wide variety of information very rapidly in an ongoing volcanic crisis...*
- *Good links to the net and server support are vital for effective Internet usage. In a disaster situation, lack of communication can be interpreted as bad news...*
- *We have found that having a good Web site can generate a great deal of unwanted attention from an interested public, which can be very time-consuming. We have abundant conventional correspondence from school children and college students, job seekers and cranks...*
- *Finally, the Internet should not replace human interaction, especially in crisis situations.*

One proviso which Dr. Young should have added to his list of observations is that due to the lack of regulation of the Internet, a user should be aware of the potential abuses which could occur.

Young's (1998) observation about the "great deal of unwanted attention" is unfortunate since these enquiries from non-scientists provide a superb opportunity for public relations and for publicizing the work of volcanologists. Response to a volcanic eruption is an example of scientific analysis which is high-profile and which is clearly relevant to many people outside of the scientific world, hence it provides a chance for pedagogy, for demystifying scientific operations, and for publicizing the role of specialists, such as engineers. Dr. Young and MVOT are presumably under severe pressure and constraints with too few resources and therefore would prefer to eliminate all unessential activities, but by dismissing this opportunity as Young (1998) does, the image of the aloof, incomprehensible scientist is perpetuated. Interestingly, when this author emailed queries to MVOT, Gill Norton of MVOT replied swiftly in a friendly and detailed fashion (the reference to Norton (1998)). Ms. Norton did not know the answer to one of the questions and forwarded it to Dr. Young who responded briefly after nearly two weeks.

The Internet, particularly the WWW, has also provided means for Montserratians to inform the world of their views directly, without mollification from MVOT or distortion from the media--as has occurred during this crisis. The Montserrat Information Archives (<http://209.150.130.238> or <http://www.montserrat.org>) contains a wealth of personal essays, open letters, and anecdotes from Montserratians about life during the crisis. Frustrations about incompetence in importing fuel and rebuttals to media and scientific reports yield a fascinating, first-hand picture about life on an island during a crisis without the need for expensive and labour-intensive field research, letters, faxes, or telephone calls. Public services are also provided through "Making Connections" (<http://www.montserrat.org/connections>) for notices about missing Montserratians and through

compilations of local and international media reports on the crisis (<http://www.montserrat.org/archives.html>) for the interested observer.

12.3.5 Vulnerability of Caribbean Islands

The volcanic crisis has proved to be a lucid demonstration to the Caribbean islands of their vulnerability to natural disasters. Caribbeans are used to, though not inured to, hurricanes and volcanoes, but they are rarely confronted with a situation which might entail permanently abandoning one of their islands. Howe (1997c) states that "The demise of Montserrat reflects the fragility of all these tiny islands" (p. 25) and believes that Caribbeans prefer to ignore their potential doom rather than to confront it and attempt rectification: "In Tobago the locals' fatalism is born of a sense of permanently impending calamity" (Howe, 1997c, p. 25), a clear cultural/philosophical boundary (section 6.4.1) which would have to be overcome in order to manage vulnerability properly.

This situation is representative of psychological boundaries and influences which impact vulnerability to natural disasters and the role of technology (sections 3.3 and 6.4). Without recognition by a society of their vulnerability and a willingness to manage it, solutions--both technological and non-technological--will likely fail. Technology and engineers can contribute to preserving the Caribbean way of life in the face of volcanic (and other natural) hazards, particularly through monitoring and risk analyses before and during events. If those results are not communicated or are not listened to, then inappropriate reactions to the information will inevitably occur.

The absence of interest in applying technology to managing vulnerability to natural disasters on Caribbean islands may arise somewhat from the comfort of non-technological solutions used previously for managing vulnerability. The predominant non-technological solution witnessed during the Soufrière Hills eruption has been emigration. Although there are some Montserratians who have refused to leave or who expect to return after the crisis, the majority seem have little compunction about making a new life elsewhere (Williams and Musi, 1997). The main objection to emigration from Montserrat has been the lack of financial and political support from the U.K. government for permanent resettlement (section 12.3.2). Howe (1997b) states (p. 34):

Caribbean peoples have also long been known for their migratory instincts. Sentiment has habitually been transcended by economic necessity. Montserratians are no exception. I can only imagine that staying on the island is a tactic to strengthen their bargaining hand for a full and final settlement.

Howe (1997c) also writes (p. 25):

My adopted daughter, whose birthfarther is a Montserratian, asked me: "Can anyone describe themselves as a Montserratian any more?"

"Could they ever?" I replied sternly.

She shrugged and walked away into the Tobago sunset.

The migration solution, boosted by the apparent lack of feeling for Montserrat as a homeland (which is possibly influenced by the island's colonial status), is a valid approach to reducing vulnerability to natural hazards through land-use strategies (compare to section 12.3.3).

12.4 Conclusions

Technology and engineering did play and continue to play useful roles during the eruption of Soufrière Hills, but there were other influences which overwhelmed technology's usefulness and applicability. Political and economic influences (sections 3.4 and 3.5) inhibited technology's effectiveness which, coupled with psychological boundaries and influences (sections 3.3 and 6.4), reduced the prominence and consideration of technological solutions. Issues of selecting appropriate design loads (Chapter 4) and proper land-use with respect to volcanic hazards have been somewhat buried. The lack of preventive approaches discussed in Chapter 5 stems from the perceived lack of need for preventive approaches, because preventive technological solutions have previously not been a high priority for Montserrat (compare to section 5.3.3). The fatalistic attitude, reminiscent of attitude and belief system influences on vulnerability (section 3.3) and cultural/philosophical boundaries (section 6.4.1), is prevalent amongst Montserratians--"Faith is the islanders' bedrock" (Williams and Musi, 1997, p. 70)--and creeps into many of the issues discussed in section 12.3.

Scales are also important for the situation on Montserrat. The temporal scale of the volcano's eruptive history is far greater than the temporal scale of Montserratian society (section 12.2; compare to section 6.3). Before 1995, society had not directly experienced a volcanic eruption from Soufrière Hills, and this past experience downplayed concerns of a volcanic eruption's consequences. Views of temporal scales are even influencing contemporary decision-making: Frank Savage, Britain's governor of Montserrat at the start of the volcanic crisis, stated (Williams and Musi, 1997) that "The north of the island has not been affected by a volcano in two million years [except for falling ash from Soufrière Hills since 1995], so we've based all our contingency plans on that" (p. 68). The wisdom of this attitude relates to the understanding of return periods and temporal characteristics discussed in Part I (sections 4.4.2, 4.4.3, and 6.3), but also introduces the spatial scale of the eruption (section 6.2). The spatial scale of Soufrière Hills' effects encompasses clearly defined and coincident political and physical boundaries: the island of Montserrat. Decisions must therefore be made regarding the

safety of using technology and other tools to maintain settlements within these boundaries versus the appropriateness of vacating a political and cultural region just because a natural hazard threatens.

13. Technology and Volcanic Disasters on Non-Industrialized Islands

13.1 Comparison of Case Studies

Volcanic eruptions yield diverse hazards with wide-ranging impacts to which society is highly vulnerable (Chapter 9). Volcanic hazards and society's vulnerability lead to volcanic disasters, which are particularly prominent for non-industrialized islands (Chapter 10) as illustrated by the eruption of Mount Pinatubo in the Philippines (Chapter 11) and Soufrière Hills in Montserrat (Chapter 12). This chapter compares and contrasts these two case studies in order to extract themes related to the role of technology in managing vulnerability to volcanic disasters on non-industrialized islands. Volcanic eruptions rarely resemble each other in fine detail but there are nonetheless similarities in the issues which arose and in how these issues are dealt with in the case studies (section 13.1.1). There are also some differences between the case studies for these issues (section 13.1.2). Section 13.1.3 discusses the IDNDR (section 1.1) with respect to these case studies.

13.1.1 Similarities

The influences on vulnerability discussed in Chapter 3 were evident during both case studies. The main demographic influence (section 3.2) for both eruptions was that populations had settled in areas vulnerable to the respective volcanoes because concerns other than vulnerability to natural disasters superseded concerns about a volcanic eruption. This decision to settle these areas was not necessarily flawed since neither Mount Pinatubo nor Soufrière Hills had previously posed dangers during society's settlements in those locations--a contrast in temporal scales between society and the environment (section 6.3). Population increases coupled with the desire to explore new land for political and economic reasons led to encroachment onto and near Mount Pinatubo (the Aetas were actually forced further up the slopes by Filipino settlements) and to settlement on Montserrat. One contrast within this similarity is that the settlement of Mount Pinatubo was predominantly a local desire of subsistence farmers for better land while the settlement of Montserrat was predominantly an international, empire-building, profit-driven desire of politicians and entrepreneurs for better land.

Further similarities are observed in the influence of attitudes and belief systems (section 3.3) and psychological boundaries (section 6.4) which often inhibited appropriate vulnerability prevention measures. Cross-cultural communication difficulties exacerbated problems. Individuals and communities would not accept, or were not properly informed about, the vulnerability prevention measures and the reasons for the measures. Detrimental political and economic influences (sections 3.4 and 3.5) added to the confusion, in instances such as the corruption and incompetence during the construction of protective works against Mount Pinatubo lahars (section 11.3.4) and Westminster's

indifference to Montserrat (section 12.3.2). Technology's effectiveness was blocked in key areas during both eruptions due to these factors.

Another similarity is that prior to the eruptions, there was minimal implementation of preventive measures related to volcanic disasters on both islands. Some land-use planning existed, but it was based on criteria other than vulnerability to a volcanic disaster. Designs and design loads rarely factored in potential volcanic loads. There were also few attempts at educating the population about volcanic hazards and disasters until the eruptions. As mentioned earlier, these decisions are not easy to criticize since there was little reason to fear severe volcanic activity in these locations. Following each eruption, reasonable land-use measures were implemented--though not particularly promptly with respect to lahars from Mount Pinatubo--and although design load issues were raised, they could have been examined more closely on each island.

Despite the problems, both eruptions demonstrated some similar successes. The response to each eruption was swift, was relatively competent logistically, and resulted in minimal death tolls considering the size of the vulnerable populations. A combination of technological and non-technological solutions helped achieve the successes. Both islands, which were non-industrialized, also had an industrialized nation overseeing the efforts, making an immense difference in the availability of resources, which is further evidence of the political and economic influences on vulnerability (sections 3.3. and 3.4). The Philippines relied on the U.S.A., their former colonial power, while Montserrat relied on the U.K., their current colonial power, although American technology and technical expertise was prominent. The challenges in exercising colonial power in a post-colonial world were evident during both eruptions, in the debate with respect to the American military bases in the Philippines (section 11.3.1) and the ambivalence in the U.K.'s attitude about foreign aid for Montserrat (section 12.3.2).

Irrespective of the political difficulties, each eruption illustrated the benefits and positive potential of international scientific cooperation. In both instances, a reasonable amount of technology transfer was completed, given that the scientists were in the midst of a volcanic crisis and thus had other concerns, which will be invaluable for future volcanic problems in the Philippines and the Caribbean. The two volcano observatory teams, particularly for Mount Pinatubo, did have problems explaining concerns to the local populations, but they were generally able to overcome the difficulties through creativity and cooperation with non-scientific personnel. Both eruptions demonstrated some similarities in the positive and negative roles of technology in managing vulnerability to volcanic

disasters, but overall, the case studies demonstrated how effective technology could be, if implemented appropriately and in combination with non-technological solutions.

13.1.2 Differences

Aside from the detailed characteristics of the particular volcanic hazards from each volcano, there were also marked differences in their spatiotemporal scales. There was just 75 days between Mount Pinatubo's initial activity and its climactic eruption, although minor volcanic activity has continued since then. Soufrière Hills has been erupting for almost three years without reaching its peak activity, and there is no guarantee that a definitive, climactic eruption will occur, although frequent activity is expected for several more years. For society, these temporal scales are quite different and numerically they are a different order of magnitude (0.2 years for Mount Pinatubo compared to 3+ years for Soufrière Hills), but it is questionable whether the temporal scale is indeed different since both eruptions are effectively instantaneous on the geologic temporal scale.

Mount Pinatubo has had global climatic impacts, hence its spatial scale is the planet, whereas Soufrière Hills has had little environmental impact outside Montserrat and virtually none outside the Eastern Caribbean. Both eruptions have had international political impacts, but the issue of the American military bases in the Philippines affects more widespread and wide-ranging geopolitical issues in the late twentieth century than the U.K.'s troubles with its overseas territories.

Interestingly, the national impact of each eruption is reversed in relation to the international impact. Mount Pinatubo affected a global spatial scale, but the Philippines and the Filipino people have nicely survived the eruption, with American assistance. Soufrière Hills, however, affects a local spatial scale yet has effectively destroyed the viability of Montserrat as political entity and has scattered the Montserratian people, possibly irrevocably. These case studies exemplify the clash which can occur between spatial scales of the environment and society (section 6.2) and also emphasize the challenge of maintaining a viable community in the face of adversity on a small island such as Montserrat rather than a larger island nation such as the Philippines.

Differences between the two eruptions also manifests in some technology transfer issues. In the Philippines, there were four groups of cultures with different levels of technology, which were, from the most technological to the least technological: the American volcanologists, the Filipino volcanologists, the Filipino locals, and the Aetas. In Montserrat there were two such levels: the (non-Montserratian) volcanologists and the Montserratians. Caribbean volcanologists potentially form a middle level, but are not listed separately because they appeared to be much more integrated into their volcanological team than the Filipino volcanologists. Whereas the Filipino volcanologists

requested American help because they could not handle the situation on their own, the Caribbean volcanologists were invited to be part of the team on Montserrat.

As an aside, appearances from the literature about the extent of cooperation between the volcanologists could be deceptive. The Caribbean and the Filipino volcanologists could have been equally included in or excluded from their respective volcano teams without the situation being properly noted in the literature. The published literature on the two eruptions is written primarily by the most technologically advanced cultural groups: the volcanologists. The other dominant authors in the literature were journalists, observing and reporting events. Both the volcanologists and the journalists tended to have a modern Western bias, although the journalists discussed the less technologically advanced cultural groups (e.g., England, 1993a and 1993b; Goertzen, 1991; Howe, 1997a, 1997b, and 1997c; "The Voice of God", 1991; Williams and Musi, 1997) far more often than the volcanologists. Since the lesser technologically advanced cultural groups do not have as much opportunity to publish their views as the more technologically advanced cultural groups, the literature is likely overly biased towards the views of the more technologically advanced cultural groups. Therefore, although the literature does indicate a certain level of cooperation amongst the different groups, these appearances could be deceptive.

Technology transfer and cross-cultural communication seemed to become more challenging as more of the aforementioned cultural groups with different levels of technology were traversed. Therefore, technology transfer was perhaps easier in Montserrat than around Mount Pinatubo. The Filipino volcanologists and civil authorities had severe difficulties in using technology with and for the Aetas and the results were severe consequences--many deaths amongst the Aetas--which could have been anticipated and prevented. Similar troubles arose with the Filipino locals, especially in countering lahars (section 11.3.4). In contrast, the problems with obtaining Montserratian cooperation arose primarily from political gaffes and political decisions rather than from engineering gaffes and decisions on technology (section 12.3.2). The two cultural groups present in Montserrat were also easier to integrate for joint decision-making than the four groups present in the Philippines, due to Montserrat's smaller population, smaller geographical size, and narrower technological gaps between groups.

The final major difference between the two eruptions is the application of specific technologies and engineers. Montserrat included at least one identifiable engineer in the volcano observatory whereas in the Philippines, the volcano observatory seemed to be comprised of only scientists who, at times, ended up in conflict with engineers, such as the dispute between Dr.

Raymundo S. Punongbayan and the Public Works Department (section 11.3.4). As well, the rapid development of the internet between 1991 and 1995 provided Montserrat with an advantage over the Philippines, by reducing the island's psychological isolation—an opportunity not previously available. The internet is currently used widely to disseminate information about Mount Pinatubo, similarly to the manner of use for Montserrat (section 12.3.4), but there is no evidence to suggest that this availability, capability, and interest were present in 1991 during Mount Pinatubo's main period of activity. Moreover, the use of the internet during Soufrière Hills' eruption permits a broader spectrum of people to disseminate their views internationally. The previously discussed analysis of communication between cultural groups at different levels of technology thus had more material for Montserrat than for the Philippines and there can be more confidence in the results for Montserrat. Of course, only a select group of Montserratians have the opportunity to make use of the internet, so the results may still overly reflect the views of the more technologically advanced cultural group in Montserrat.

These differences between the two eruptions indicate that the cultural and political context of using technology impacts the effectiveness of that technology. The same technology may also be required to perform different types of roles depending on the specific natural disaster event.

13.1.3 IDNDR

Four years of the IDNDR (sections 1.1 and 9.4) elapsed between the initial eruption of Mount Pinatubo and the initial eruption of Soufrière Hills. Investigating for any improvements in international volcano crisis response as a result of the IDNDR is important for determining the effectiveness of the IDNDR. Unfortunately, since the literature for the two eruptions rarely mentions the IDNDR, and does not discuss the activities of the IDNDR in relation to the activities at the two volcano observatories, it appears that the IDNDR has had little direct impact. Neither Soufrière Hills nor Mount Pinatubo were selected as Decade Volcanoes (Table 9-4 in section 9.4) further reducing the potential of a significant influence from the IDNDR.

The indirect impact, however, is liable to be more consequential but less obvious. For example, some of the twelve projects for managing vulnerability to volcanic disasters proposed by IAVCEI (1990; see section 9.4) involve electronic communication networks amongst volcanologists, training many sectors of society to deal with volcanic crises, and development and application of new technologies to volcanic disaster management. These projects would have a gradual impact on volcanology and it would be challenging to differentiate these projects' results from the normal rate of progress expected in science and engineering. For example, establishing whether the prominence of

the internet during Soufrière Hills' eruption, as compared to Mount Pinatubo's eruption (section 13.1.2), resulted from the influence of the IDNDR or the increased popularity of the internet (or, more likely, both) is subjective. Similarly, the improved integration of locals into volcanology work seen in Montserrat, as compared to the Philippines, could be a result of IDNDR initiatives, different and fewer cultural groups (section 13.1.2), prior experience and research, good project management, or a combination of these factors.

The IDNDR's influence is not obvious but might be present either significantly or to a lesser degree. The fact that the IDNDR's influence is not obvious may be indicative of the IDNDR's lack of success, yet the Soufrière Hills eruption occurred in 1995, only half-way through the IDNDR. As well, much of the IDNDR's volcanic work is related to developing and establishing long-term projects which could require much of the IDNDR for setting up, but which will reap significant effects long after the IDNDR finishes. Criticizing the IDNDR for apparently not changing volcanic crisis response methods between the Mount Pinatubo and Soufrière Hills eruptions may be premature or completely unjustified.

13.2 Recommendations

Recommendation I: **Technology should play a prominent, positive role in managing vulnerability to volcanic disasters.**

The case studies have demonstrated that technology can play a prominent, positive role in managing vulnerability to volcanic disasters, even though it does not always occur. Engineers, along with other sectors of society, should ensure that this potential is maximized. Volcanic disasters present fascinating, unique, and challenging problems, and technology has many, but not all, of the characteristics needed in a tool for coping with these disasters.

Recommendation II: **Non-technological influences on vulnerability to volcanic disasters should be analyzed when designing technology in order to avoid incompatibility between society and technology.**

Non-technological influences on vulnerability to volcanic disasters have a significant impact on the development and implementation of technology. When technological failures occur, the blame is often directed at the engineer, which erodes faith in the profession and in technology. As well, blaming the engineer distracts from the more relevant problem which is some form of incompatibility between society and technology. Resolving this incompatibility is complicated because the appropriate solution could involve modifying technology, modifying society, or both. Deciding which solution is appropriate and how to implement that solution is rarely the responsibility of only engineers. Nonetheless, engineers must always accept some responsibility for their work and for

failures which arise from their work. By communicating and cooperating with their clients and with other sectors of society to understand and predict incompatibility between society and technology, the most appropriate solution can be implemented during the design phase, before a technological failure occurs.

Recommendation III: The impact of boundaries and scales should be considered in using technology to manage vulnerability to volcanic disasters.

The case studies have shown some of the potential impacts of the boundaries and scales discussed in Chapter 6 on the role of technology in managing vulnerability to volcanic disasters. The situation in Montserrat has also shown that a smaller spatial scale for a disaster does not necessarily imply a less severe local impact. Correlating impact with temporal scale is similarly challenging. A quick eruption such as Mount Pinatubo enables Filipinos to put the incident behind them immediately and to start the recovery quickly, yet a slower eruption such as Soufrière Hills provides time to adequately research the volcano, prepare scenarios, and judge and select alternatives. Boundaries, particularly the psychological ones, were prominent in both eruptions. Without considering boundaries and scales in the design of technology, there will be fewer successes in using the technology for managing vulnerability to volcanic disasters.

Recommendation IV: Cooperation amongst sectors of society is advantageous for managing vulnerability to volcanic disasters and should be used, but there are problems which should be identified and overcome.

International, cross-disciplinary, and cross-cultural teams are necessary for properly implementing technology to manage vulnerability to volcanic disasters. The variety of perspectives, especially ideas and thoughts from those who will be depending on the technology, is an important aspect in inducing the technology to function properly. Unfortunately, involving more sectors of society in decision-making and policy implementation permits more opportunities for conflict and misunderstandings. Being wary of and aware of problem issues such as technology transfer and communication difficulties enables anticipation of, and development of procedures for resolving, any difficulties. Therefore, the advantages of cooperation amongst sectors of society are present while the disadvantages are minimized.

Recommendation V: Society should maintain an awareness of its vulnerability to volcanic disasters.

Society often does not realize or wish to admit its vulnerability to natural disasters, and the case studies illustrate this problem for volcanoes. Neither Montserrat nor the Philippines investigated

their vulnerability to their respective volcanoes. Section 12.3.5 alluded to the Caribbean attitude that "ignorance is bliss" with respect to natural disasters. Without confronting vulnerability, society cannot properly prevent vulnerability. Any technological or non-technological solutions to vulnerability must first ensure that the affected sectors of society understand and accept their own vulnerability.

13.3 Conclusions

The comparison between the two volcanic eruptions indicates the extent to which technology needs to be designed and applied while considering the context of its use; i.e., while considering the characteristics of the technology's users, and situations or potential situations of use. Designing for one exact context is usually inappropriate for natural disasters, since precisely predicting all the characteristics of a natural disaster is not possible. Designing for all possible contexts is neither feasible nor necessary. Instead, a set of likely contexts and a set of unlikely contexts should be developed to determine the response of the design (the system) for a wide range of common and rare scenarios (loads).

Flexibility and adaptability will be necessary components of design solutions to ensure that differences in a natural disaster, such as the differences between the eruptions of Mount Pinatubo and Soufrière Hills, do not translate into markedly different performances of the technology. Creativity and innovation are necessary, along with extensive cooperation and communication throughout different sectors of society. The case studies of volcanic disasters on non-industrialized island nations demonstrate these needs, and also illustrate that success is not always forthcoming, with problems emanating from engineers, from other sectors of society, and from the interaction between them. Engineers and the other sectors of society, however, have the ability and the responsibility to accept and resolve these challenges.

Part II, the case studies of volcanic hazards on non-industrialized nations is now concluded. This thesis must still examine jointly the issues in Part I and Part II in order to synthesize the application of concepts and models (Part I) with the case studies (Part II). Chapter 8, the Interlude between the two parts, described the direction which the thesis would be taking in Part II, after having looked at the accomplishments in Part I. Chapter 14, the Finalé, describes the path along which this thesis meandered and the discoveries made, in order to fully explore and understand the role of technology in managing vulnerability to natural disasters.

14. Finalé

14.1 Review and Discussion

An introduction to the role of technology in managing vulnerability to natural disasters (Chapter 1) and a discussion of the terminology used and the relevant contexts (Chapter 2) scopes this thesis and indicates the tasks which it sets out to accomplish. A natural disaster is established as arising from the combination of a natural hazard, a characteristic of the environment, and vulnerability, a characteristic of society. Part I examines concepts and models which clarify the challenges in, advantages of, and disadvantages of using technology for managing vulnerability to natural disasters.

Since either natural hazards or vulnerability, or their combination in a natural disaster, can cause technology to fail, they both induce loads on technology and engineers must design technology while considering these types of loads. One of the most troublesome steps for an engineer is defining the design criteria which should be used to anticipate a system's response to such loads (Chapter 4). Because both natural hazards and vulnerability are often difficult to understand and to predict, the design load input is difficult to predict and to select properly. Anticipating every potential design scenario is also challenging. The definitions for current design criteria are often based on past experiences, which is a form of reactive engineering rather than preventive engineering.

Although preventive engineering tends to be the best approach to engineering problems, natural hazard prevention cannot usually be completely effective and in many cases can have unexpected and deleterious consequences (Chapter 5). Therefore, the prevention of vulnerability is a more appropriate focus. An examination of non-technological influences on vulnerability (Chapter 3) and of spatiotemporal boundaries and scales, psychological boundaries, and technological boundaries (Chapter 6) illustrates important ideas which assist in preventing vulnerability to natural disasters. There are challenges in using technology to manage vulnerability to natural disasters, but with appropriate research and application techniques, these challenges can be overcome (Chapter 7).

An interlude (Chapter 8) evaluates the accomplishments of Part I and foreshadows Part II by espousing the need to put theory into practice through the examination of case studies. The case studies are volcanic disasters on non-industrialized islands and are first presented with an explanation of volcanic disasters (Chapter 9) and the importance of volcanic disasters to non-industrialized islands (Chapter 10). Analyses of the eruption of Mount Pinatubo in the Philippines which started in 1991 (Chapter 11) and the eruption of Soufrière Hills in Montserrat which started in 1995 (Chapter 12)

focus on the role of technology during these volcanic disasters. The case studies were completed with a comparison of the role of technology during both eruptions followed by recommendations and conclusions based on experience from the case studies (Chapter 13).

Parts I and II indicate that managing vulnerability to natural disasters is not simple. Even though technology advances and the appropriate use of technology is being promoted more frequently, the task is unlikely to become simpler. The world's human population, and encroachment of that population into more vulnerable areas, are both increasing. Therefore, more people and a greater percentage of the population are becoming vulnerable to natural disasters. Furthermore, industrialization is increasing worldwide, often using techniques which permit infrastructure in areas where natural disasters had previously discouraged construction. Therefore, more property is becoming vulnerable to natural disasters. Additionally, some natural hazards, particularly hydrometeorological and microbiological hazards, appear to be becoming more severe and more frequent. Meanwhile, the potential magnitude of some of the rare geological, astronomical, and microbiological hazards could threaten the existence of society. While global calamities have a low probability of occurring, attempting to prepare for them has merits, not only because society might actually have to cope with a calamity, but also because the ideas and techniques can be applied to understanding and managing natural disasters of lesser magnitude which are more certain to occur soon.

The future of natural disasters, society, and technology has many uncertainties, most of which are unlikely to be resolved rapidly. As well, it is not possible to resolve all uncertainties. Society must therefore manage vulnerability to natural disasters, and engineers must develop and implement their technology, in the shadow of these uncertainties. Simultaneously, resolving the uncertainties--or, at least, defining their extent--are high priorities for natural disaster research. Some of the IDNDR's activities are related to this aspect through expanding knowledge and generating awareness and interest in natural disaster issues.

The IDNDR is somewhat representative of the general tactics needed for society in order to properly manage vulnerability to natural disasters. As mentioned in section 1.1, "The objective of the Decade is to reduce, through concerted international action, especially in developing countries, the loss of life, property damage, and social and economic disruption caused by natural disasters". The potential for increasing human casualties and property damage caused by natural disasters is

discussed two paragraphs previously to this one, but including "social and economic disruption" in the IDNDR statement is an intriguing point which surfaces subtly throughout this thesis.

Natural hazards, which contribute extensively to society, are nevertheless often accused of disrupting and interfering with society. This viewpoint places the natural hazard as external to society--an approach accepted by this thesis, with qualifications. These qualifications function well for most of the thesis, but it is time to reevaluate them. If society were to embrace natural hazards and the environment as intimate components of day-to-day life, then technology could be used to develop society within the environment rather than to entirely exclude the environment from society, as usually occurs. Engineers would be involved in ensuring the safety of the public from natural hazards, but would also ensure that the benefits from natural hazards are maximized and their detrimental impacts are minimized.

This approach to natural hazards would be different from the attitude witnessed today which is more inclined towards assuming that natural hazards are external to society and are of concern only when a natural disaster occurs. Many of the examples in Part I and the case studies in Part II demonstrate the extent to which this attitude influences natural disasters and the role of technology. An incomplete understanding and acceptance of natural hazards leads to natural disasters through misguided actions such as reliance on and subsequent misapplication of technology. A change from this attitude to a view of natural hazards as part of society would result in reduced vulnerability, improved reactions to natural hazards, and therefore less detrimental impacts of natural disasters.

The inherent diversity and scope of natural disasters requires society to interact closely with the environment while being flexible and adaptable. By accepting this attitude, rather than the standard, deliberate exclusion of the environment and its variations from society, there will be few natural disaster situations to which society cannot effectively respond with confidence. Even when a natural hazard manifests which has not previously been experienced locally, as occurred during the case studies of volcanic disasters on non-industrialized islands, society would be better equipped because many of the management principles and actions apply readily to diverse situations. The case studies in Part II were one specific type of natural disaster, yet the analysis (Chapter 13) extracted themes and ideas (section 13.2) which are applicable beyond volcanic disasters on non-industrialized nations, to other natural disasters in other locations (section 14.2).

The overall themes which have emerged from this thesis are summarized as recommendations in section 14.2, illustrating that engineers can contribute through appropriate development and

application of technology, as discussed in this thesis. Technology has definite contributions to make, but also has the capability of worsening society's vulnerability to natural disasters if developed or applied poorly. Engineers and society should cooperate to ensure that the role of technology in managing vulnerability to natural disasters is vulnerability reduction.

14.2 Overall Recommendations

Recommendation I: **A flexible, holistic, and creative approach should be used for research and application of the role of technology in managing vulnerability to natural disasters.**

This approach implies examining and considering non-technological influences on technology and on vulnerability along with the various boundaries and scales which impact the development and application of technology. As well, the main problem in engineering, which is identifying and selecting the design load, can be confronted and the inherent challenges can be overcome. Through innovative and adaptable solutions with a holistic viewpoint, engineers and the rest of society can develop and implement technological solutions which contribute beneficially to the management of vulnerability to natural disasters.

Recommendation II: **The importance of understanding and living with natural hazards, rather than controlling them, should be emphasized. Vulnerability to natural disasters should be understood and controlled.**

Society, through technological and non-technological measures, should seek to control society's characteristics, such as vulnerability, rather than the environment's activities, such as natural hazards. Part I establishes the difficulties and potential detrimental consequences of preventing natural hazards as well as the effectiveness of preventing vulnerability. The case studies in Part II illustrates the wisdom of this focus: even if society had desired to prevent these volcanic events, their magnitude was so great and their influence so widespread that it would not have been possible with currently available technology. The objective of preventing vulnerability to natural disasters should be paramount in natural disaster research and applications, and technology can play a definite role in assisting the fulfillment of this objective.

Recommendation III: **The solutions for using technology for managing vulnerability to natural disasters should be as long-term, as global, and as interdisciplinary as feasible.**

Preventive approaches, as discussed in Recommendation II, are important and sustainability should also be considered as a prominent criterion for accomplishing this recommendation. Since global repercussions can often result from local activity, and since local activity is often more effective

and efficient than global activity, actions at all spatial scales should be implemented. The interdisciplinary component of this recommendation implies continual and effective communication amongst, and understanding the needs of, various sectors of society with respect to the use of technology. Such cooperation is not always the swiftest of operational mechanisms, but the long-term advantages tend to outweigh the short-term costs in the absence of a crisis. Realizing the significance of such tradeoffs will assist in producing worthwhile technological solutions for managing vulnerability to natural disasters.

Recommendation IV: Technology should be used to fulfill society's objectives with respect to vulnerability and natural disasters without interfering with these objectives.

Engineers have the responsibility for and capability of developing and implementing technology. Technology has the ability to enormously assist society in managing its vulnerability to natural disasters. Since technology can be used positively while minimizing its negative impacts, engineers and society should ensure that this strategy is employed.

14.3 Conclusions

Technology, society, and the environment continually interact in a dynamic relationship which presents new challenges and opportunities. When difficulties for society--particularly damage--ensue, society responds by applying various tools, one of the most prominent of which is technology. Natural disasters are notable in their significant effect on society and the variety of approaches which are implemented for managing those effects. Despite the accomplishments of society in managing vulnerability to natural disasters and the many beneficial applications of technology, there are still many difficulties to overcome and many problems to admit and resolve. Society has travelled far, but a longer journey yet lies ahead.

Technology and engineers can help smooth the path for this journey. Nonetheless, technology is not a panacea for managing vulnerability to natural disasters. Despite the continually improving ability of engineers, technology on its own will never alleviate all of society's concerns about vulnerability to natural disasters.

Society plays an essential role in the success of technology. The environment, through natural hazards, is neither an opponent nor an enemy with respect to natural disasters. Society, partly with technology, creates the natural disasters. Society, partly with technology, can also prevent many of these natural disasters. By acknowledging this responsibility and by undertaking to resolve

difficulties, society will be taking a tentative, yet imperative, step forward in examining the role of technology in managing vulnerability to natural disasters.

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