Natural Disasters and Human Activity

A Contribution to the North American Commission on Environmental Cooperation State of the Environment Report

by

David Etkin, Environmental Adaptation Research Group, Environment Canada

María Teresa Vázquez, National Disaster Prevention Centre, Mexico City

Ilan Kelman, Dep't. of Civil Engineering, University of Toronto

March 18, 1998

Acknowledgements: We gratefully acknowledge the useful reviews and advice provided by Claudio Alatorre, J.M. Aylsworth, Greg Brooks, Ian Burton, Ramon Dominguez, M.I. Roberto Duran, Roberto Duran Hernandez, Andrew Hamilton, Mike Hewson, Grant Kelly, Howard Kunreuther, Alfonso Medina, Mary Fran Myers, Roger Pielke Jr., Jarmilla Pitterman, Alberto Pizaña, Edgar Segura and Chris Tucker.

Natural Disasters and Human Activity
TABLE OF CONTENTS

List of Figures:

(1) Introduction

Disasters happen when extreme events overwhelm our ability to cope, and we need to seek assistance from beyond our own community. Occasionally 'Great' disasters occur, when the support needed for reconstruction becomes truly national or international. There is nothing new about natural disasters; humankind has been subject to them since antiquity. History and myths are fraught with tales of how nature overwhelms people and societies.

In some societies, such as Canada and the U.S., people have historically tended to view themselves as being well-protected from natural disasters. After all, there are building codes, dams and levees, insurance, and government compensation, which are all designed to buffer society from the harsher acts of nature. In recent years, however, the number and cost of natural disasters have each increased enormously, to the point where some assumptions regarding protection are being challenged (for example, Figures 1 show Canadian federal disaster financial assistance and costs from the Insurance Bureau of Canada; Figure 2 shows the number of US catastrophes exceeding $100 million (Changnon et al., 1997)). Worldwide the insurance industry had never experienced a loss greater than $1 billion prior to 1988. From 1988 to 1996 there were 15, with Hurricane Andrew costing them over $15 billion.

> *Nature, with equal mind,*
> *Sees all her sons at play,*
> *Sees man control the wind,*
> *The wind sweep man away.*
> Matthew Arnold

Nature can always provide an event more extreme than that for which society has prepared. Ironically, at the time of writing this paper, the strongest El Niño on record is being blamed for numerous disasters, including an ice storm that may well turn out to be Canada's worst natural disaster to date. Global change (such as population growth and migration, climate change, and urbanization) is altering the characteristics of natural disasters, making them more frequent, more severe, and more systemic. Some of our current adaptations are probably not really protecting society against natural disasters, but are simply postponing them (Mileti *et al.*, 1998). In Latin American countries such as Mexico, even though adequate construction codes are available, and the nature of disasters is well-understood by scientists and engineers, natural disasters interact with society in such a way that people tend to be at greater risk of injury or death. This situation results from a mix of cultural and financial factors such as less evolved urban planning; fewer resources; a more rapid and chaotic growth; greater poverty; and a relative scarcity of urban services, infrastructure, and financial capacity.

The magnitude of natural disasters depends greatly on social factors. Examining this interaction, in part, can be accomplished by reviewing past situations, current experiences, and speculating on future trends. In order to achieve this goal, this chapter examines:

- the origins of natural disasters;
- the types of natural disasters;
- how human activity mitigates disasters;
- how human activity contributes towards natural disasters, particularly the influence of myths; and
- how a sustainability paradigm might be used to reduce the impacts of disasters.

(2) What is a Natural Disaster?

Offering a precise definition of a disaster is difficult, if not impossible. The term means different things to different people and depends upon the size of community considered. A disaster to a small town is not one to the nation, and one person's disaster may be another person's inconvenience or opportunity. At some point, though, when nature has ravaged residential and work areas, and when many people have been injured and killed, all perceptions merge. The same human conditions that lead to small disasters contribute to large ones, and so for the purposes of this paper, fine distinctions are not important.

A natural disaster has its origins both in nature and in society. This concept is illustrated by the most deadly recorded tornado outbreak in Florida's history to date, which occurred February 22-23, 1998. As the tornadoes ripped through well-built suburbs, relatively few deaths occurred; however, when the tornadoes, with similar intensity, moved through communities with mobile homes and recreational vehicles, a large number of deaths occurred as these dwellings were annihilated and the remnants scattered. At least 37 out of the 42 deaths occurred in these fragile communities.

The difference in fatalities results from the reality that the mobile homes (an ironic term, considering what happens to these homes during tornadoes) are more vulnerable than traditional houses; this difference also accounts for the myth that tornadoes are attracted to mobile homes. The issue of vulnerability to natural hazards lies at the heart of society's natural disaster experience. Society is vulnerable when poverty or a lack of access to resources restricts people's ability to live in safe locations or safe buildings, or to buy insurance (if it is available); when the risks of rare extreme events are not incorporated into cost-benefit analyses; when adaptive behaviours are based on poor assumptions; or when people do not pay sufficient attention to the laws of nature and choose to live in harm's way. Ultimately, society is vulnerable when an extreme event exceeds the design criteria of technological protections (as one eventually must). Though nature provides the hazardous environment, society designs its own disasters through its adaptive decisions.

> That once an eagle, stricken with a dart,
> Said when he saw the fashion of the shaft,
> With our own feathers, not by others' hands
> Are we now smitten.
>
> Aeschylus, 550 B.C.

A conceptual model showing how disasters occur is shown in Figure 3 (modified from Blaike *et al.*, 1994). This figure can be interpreted as the cyclic interaction between our hazardous environment and our adaptive decisions. In the top box (risk) a disaster is shown to occur when a certain hazard (or pressure) coincides with a state of vulnerability–the response is the disaster. The occurrence of a disaster tends to create a burst of overlapping human activities (the bottom box), beginning with the response and recovery, but also including longer term endeavours such as mitigation and preparedness. These activities feed back into the risk box, and can reduce our vulnerability if they are done well, increase it if done badly, or can potentially modify the hazard itself. Subsequent disasters are affected by outcomes resulting from previous ones, in an ongoing cycle of adaptation.

Sometimes difficult to distinguish natural disasters from technological ones. When Hurricane Andrew destroyed Dade County, Florida and the poor enforcement of building codes was largely at fault, was the disaster caused by nature or society? A disaster is generally considered to be a natural disaster when the extreme event triggering the disaster is rooted in nature (e.g. heavy rains causing flooding) and not in humanity (e.g. a chemical explosion resulting from human error or mechanical failure).

(3) Types of Natural Hazards and Disasters

North Americans are subject to many kinds of natural hazards. Generally speaking, they are divided into two major categories [other natural hazards which are not being discussed in this paper are astronomical (e.g. collision of celestial bodies with the Earth, geomagnetic storms, and solar flares); and biological (e.g.

disease, wild animals, and pestilence)]:

- **hydrometeorological** (dealing with the atmosphere and water: drought, fire, floods, fog, hurricanes, icebergs, severe storms (e.g. rain, wind, hail, snow, freezing rain, lightning), storm surges, temperature extremes (heat and cold waves), tornadoes); and
- **geological** (dealing with the earth: avalanches, earthquakes (and associated hazards such as tsunamis), glacial surges, landslides/rockslides, poison gas, tsunamis, volcanoes (and associated hazards such as tsunamis, lahars (mudflows), fumaroles (gas emissions), and jökulhlaups (glacial floods sometimes caused by volcanic activity).).

Natural hazards and the disasters associated with them have widely disparate origins and characteristics. They can be classified by their magnitude, intensity, frequency, duration, extent, speed of onset, and predictability (Burton *et al*, 1993), and are generally more feared when they strike rapidly without warning, are unpredictable, have massive impacts, or are poorly understood. Some rapid-onset events such as earthquakes occur without clear warning. With others, such as volcanoes, flash floods, and tornadoes, some warning is often, but not always, possible. For others, like hurricanes, there are long warning lead times. Some disasters are extremely localized, such as tornadoes or landslides. Others, like hurricanes, sweep across large regions. Drought is an example of a slow-onset disaster, usually combined with a heat wave, which accumulates its impact over several months or years, and tends to be widespread. Though slow to awaken, it can have devastating effects.

Different regions are subject to different hazards, though this spatial variation does not respect political boundaries. For example, parts of the West Coast are at risk from severe earthquakes, unlike many other parts of the continent. Coastal regions are often exposed to storm surges, or hurricanes, unlike inland areas. Canada has not had a major volcanic eruption this century, although there have been several large ones in Mexico and the U.S. In order to understand the geographical distribution of risk, it is necessary to consider the 'hazardousness of a place' (the exposure resulting from all hazards). Unfortunately, most hazard information tends to be hazard-specific, and so it is a challenge to accomplish this task. Figure 4 shows the spatial distribution of tornado risk in North America (EPC, 1998). Note the large variances in risk between different parts of the continent. Figure 5 shows seismic risk (EPC, 1998), which has a very different distribution. High risk areas along fault lines include portions of the West Coast, the Saint Lawrence River Valley, and parts of Mexico. A comparison of these maps reveals some large cities to be at significant risk (e.g. San Francisco, Los Angeles, Oklahoma City, México City, Montréal, and Vancouver) although no city is at risk from both earthquakes and tornadoes. Table 1 shows the risk zones in Mexico due to different types of phenomena (Mansilla, 1993).

> *In Hertford, Hereford, and Hampshire,*
> *Hurricanes hardly happen.*
> *"The Rain in Spain" from My Fair Lady by Alan Jay Lerner*

(A) Historical Natural Disasters: Overview

The costs of disasters we have experienced, both real and perceived, drive the cycle of response, mitigation, and preparedness which mitigate or create our vulnerability. However, the human and economic impact of a disaster is notoriously difficult to assess, especially with respect to indirect costs. The statistics presented in this report represent the best estimates available, but must be regarded as 'soft' data.

> *We make guilty of our disasters the sun, the moon, and the stars*
> Edmund in King Lear (Act I Scene ii), William Shakespeare

A selection of severe natural disasters which have affected Canada, the U.S., and Mexico are listed in Tables 2, 3 and 4 respectively. The economic impact figures represent actual dollar costs at the time of the event and are NOT adjusted for inflation, unless otherwise noted. Similarly, comparing casualty figures amongst different disaster events is suspect since no adjustment has been made for changing populations. The economic toll of floods and droughts in Mexico between 1973 and 1994 are shown in Table 5. Of course, natural disasters occur worldwide as well as in North America. In comparison to other parts of the world, disasters in Canada and the U.S. tend to be expensive but with little loss of life, whereas in Mexico, high-fatality disasters are not unusual. In order to provide context to the North American disaster experience, some noteworthy natural disasters from other parts of the world are listed in Table 6.

According to data collected for the United Nations' International Decade for Natural Disaster Reduction (IDNDR) program, natural disasters kill approximately 1 million people per decade around the world, with recent costs easily surpassing US$100 billion per decade (FEMA, 1997). The cost of natural disasters has been increasing extremely rapidly. The total economic losses worldwide due to natural disasters in the 1980's were approximately US$120 billion (FEMA, 1997), but this total was surpassed on January 17, 1995 when the Hyogo-Ken Nanbu Earthquake struck Kobe, Japan causing approximately US$125 billion in damage (Kuribayashi *et al.,* 1996) and creating the most expensive natural disaster in recent history. Recent years have delivered, on average, about one disaster per month with losses in excess of US$1 billion. Not all disasters may be contributing to these trends. For example, the number of hurricanes varies significantly from year to year, and decades of frequent hurricanes have been interrupted by decades of lesser activity. A study by Pielke Jr. and Landsea (1997) suggests that the long-term damage caused by these storms in the U.S. has not changed over time, when adjusted for inflation and changes in population and wealth.

Comparison of Tables 2 through 6 indicates that currently (with the possible exception of Japan), the U.S. sustains the largest economic losses, but relatively few casualties due to natural disasters. When natural hazards of all levels of severity are included, the costs to the U.S. alone are about US$1 billion per week (FEMA, 1997). Of course, the social impacts of these losses on the U.S. are much less than they would be in other countries with less wealth.

A full comparison of the losses and trends from natural disasters with those from non-natural disasters is beyond the scope of this paper, but the Red Cross' World Disasters Report contains some data worthy of a brief examination. The report provides casualty totals for all disaster events (natural and otherwise) from 1967-1991. During this time period, 7,766 disaster events caused injuries to 2.96 billion people and killed 7.31 million people. Natural disasters (predominantly droughts (48% of all injured people) and floods (36% of all injured people)) accounted for 94% of all injured people, but only 48% of the deaths. The top 5 disasters contributing to deaths were civil strife (41%), droughts (18%), cyclones (12%), earthquakes (9%), and famine (8%). For comparison purposes, Table 7 lists some non-natural disasters. Estimates of economic losses are rarely provided (except for power outages which usually cause few casualties).

During El Niños, which occur every 2 to 7 years, changes in winds over tropical oceans result in a warming of the eastern and central Pacific Ocean. During the alternate phase (La Nina), temperatures are cooler than normal. El Niño episodes result in large changes of the world's atmospheric circulation patterns, with the result that many regions experience rare temperature, precipitation and storm patterns. Though the impacts of El Niño tend to be greatest in tropical regions, they are certainly noteworthy in North America, especially during winter. The 1997-98 El Niño is a major factor in the record global warmth of 1997 and has been blamed for the Feb. tornadoes in Florida (though one researcher found that El Niño events reduce summer tornadic activity in the Great Plains ('Tornado Alley') and Florida, while La Nina events increase tornadic activity in the Ohio and Tennessee river valleys (Bove, 1997)), heavy rain and mudslides in California, the Ice Storm in eastern Canada, and flooding in many parts of North America. El Niños also tend to reduce Atlantic hurricane activity but increase the number of tropical storms in the eastern Pacific. This pattern is reversed during a La Nina.

(B) Natural Disasters Case Studies

(i) Canada and the U.S.: The Red River Flood of 1997 (summarized from IJC, 1997; Pindera, 1997; University of Manitoba, 1997)

This flood is an ideal example of how mitigation and preparedness can reduce vulnerability, and thereby the impact of a disaster (see the bottom box of Human Activity in Figure 3, which feeds into vulnerability reduction, reduces risk and thereby the disaster impacts). The Red River Valley in southern Manitoba was once the site of Lake Agassiz, up until 7,500-9,000 years ago. Under the right conditions, such as occurred in the spring of 1997, massive flooding can occur. In fact, there is a long history of recorded floods in that region dating back to 1776. The flooding appears to be cyclic. Flooding was common in the 19th century (including both spring and summer floods), diminished during the first half of the 20th century, and then increased in frequency again beginning with the 1950 flood. Though the 1997 event has been called 'The Flood of the Century', it is not the largest recorded. Other floods, such as those in 1950 and 1979, were comparable, and the 1776, 1826, and 1852 floods were worse. In Canada during the 1997 flood, 1945 km^2 (750 sq. miles) of land and 2500 homes were flooded, and 28,000 people were evacuated; about 8,000 military personnel were utilized to fight the flood.

The Red River is a major northward flowing river with a shallow slope, and like many other North American rivers, is subject to ice jamming in the spring as a result. The scene was set for a major flood well before the spring, with 300% of normal snowfall in the U.S. and 200% in Manitoba on top of ground saturated from a wet autumn.

In the U.S., flooding occurred in North Dakota and Minnesota at many communities, including Breckenridge, Ada, East Grand Forks, and Grand Forks. In some locations, the recurrence interval of the flow was between 200 and 500 years. The amount of damage was exacerbated by several factors: the inability of existing hydraulic models to cope with the large volumes of overland flow, underestimates of flood levels by the National Weather Service in some locations, data loss from gauges, and the belief that existing protections would be adequate (although 95% of people knew that flood insurance was available, only 20% purchased it).

Canada had the advantage of more advance warning and a better understanding of the magnitude of the risk after seeing the disaster in Grand Forks, and so Canadians planned for a worst-case scenario. Other advantages to Canada were no data loss from gauges and a smaller flood, in the sense that the recurrence interval of the flood was shorter than in the U.S., not exceeding 125 years (bigger floods have longer recurrence intervals). Major damage to Winnipeg was averted by a herculean effort by Manitobans and the military, and because of important mitigative measures begun after the 1950 flood - for example the floodway, which diverts 3690 m^3/s (130,000 ft^3/s) of water around Winnipeg. The floodway has been an even better investment than originally envisaged; its benefit-cost ratio ws originally estimated as 2.73, but more recent estimates put it at over 4. Since its completion in 1968, it has been used 18 times. If the floodway had not been built, the flood in Winnipeg would have been about 1-1.3 m over the 1950 level and the disaster would have been immeasurably worse.

Fighting the flood on both sides of the border involved an immense effort, and the impacts were massive. At least 103,000 people were evacuated–75,000 in the U.S. and 28,000 in Canada. In Canada, very few deaths were attributed to the flooding. Damages in Minnesota will likely exceed US$830 million, far more than in Canada where the estimates are approximately CAN$300 million of damage. In the U.S., flood plain protection is based on the 100-year event. In Manitoba it is based on the flood of record; unfortunately, due to lack of enforcement, only 63% of new homes in the designated flood areas comply with that regulation. Though the costs of this flood were large, they could have been much worse. Efforts devoted to mitigation clearly paid off in both the U.S. and Canada, though much can still be done, as outlined in the International Joint Commission Report 'Red River Flooding, Short–Term Measures' (IJC, 1997).

(ii) Canada and the U.S.: The Drought of 1988

Though droughts are not considered to be severe natural disasters in the North American context, this drought demonstrates that they can be amongst the most expensive and lethal of natural disasters. In the U.S., an estimated 5,000-10,000 people died (due to heat-related stress) and costs are put at US$40 billion in 1988 dollars (NOAA, 1997) with US$13 billion of agricultural production losses in 1988 dollars (Wheaton and Arthur, 1992). In Canada, losses were estimated to be CAN$4 billion in export losses (Phillips, 1990) and CAN$1.8 billion in 1981 dollars in direct production losses (Wheaton and Arthur, 1992). Although agricultural output declined by 4.6% in 1988, subsequent price increases resulted in an 18% increase in cash farm receipts over 1988. The drought mainly affected Canada from southern Alberta across to southern Ontario and the U.S. in the mid-West and central states. The area affected was more widespread than the area affected during the droughts of 1936 and 1937, and the summer of 1988 was one of the hottest and driest this century. The drought exacerbated the frequency and severity of other natural hazards such as dust storms, soil erosion by wind, and forest fires.

(iii) The U.S.: The Northridge Earthquake of 1994

(Compiled and summarized from Arnold (1995), Coch (1995), Klebs and Sylves (1996), Levi and Salvadori (1995), National Geographic (1997), and Tierney (1995))

The Northridge earthquake was caused by a previously unknown thrust fault, described as "hidden" or "blind" because it cannot be seen from the surface. Thrust faults tend to cause intense vertical shaking, rather than the lateral motion assumed for the design of most structures up until the 1980's. The vertical motion caused much of the earthquake's damage, and demonstrated the need for innovative solutions to deal with both types of motion. This earthquake also revealed that a moderate earthquake in an urban area can have severe social consequences, both in taxing emergency response and disaster relief operations and in causing staggering economic damage. This event, and a subsequent one in Kobe, Japan, has substantially increased awareness of the degree to which unsafe conditions exist in earthquake-prone cities, how much there still is to learn about the spatial distribution and physical nature of natural hazards (top right box in Figure 3), and how important mitigation is in order to reduce the potential for disaster.

At 4:31 A.M. on Monday, January 17, 1994–the Martin Luther King Jr. holiday–a "moderate" Moment Magnitude 6.7 earthquake struck Southern California. The event was named the "Northridge Earthquake", after the suburb 34 km (21 miles) from downtown L.A. which was directly over the fault line and which sustained the most damage. The tremors lasted between twenty and thirty seconds and mainly affected areas with a low to moderately high population density. Sixty-one people died, 1,600 people were hospitalized, and 10,177 people were treated for injuries by hospitals and released.

Economic damage from the quake is generally estimated to be approximately US$20 billion in 1994 dollars, putting the Northridge earthquake among the most expensive natural disasters in North America. The most vulnerable buildings appeared to be wood-frame two- to four-storey multi-family dwellings along with strip, mini-, and large-scale commercial malls. Eleven thousand residences were destroyed, 1,300 other structures were deemed irreparable, and 250 gas lines ruptured causing numerous explosions and fires. Nine highway overpasses collapsed, although bridge columns which had been retrofitted following the 1971 San Fernando earthquake performed well. There was one hospital in the area which remained fully operational. About 556,000 applications were made for disaster assistance..

(iv) Mexico: Hurricane Pauline in 1997 (after Meli, 1998):
Though Hurricane Pauline had lost most of its strength by the time it reached Acapulco, it still produced over 350 mm of precipitation in 4 hours. This intense rainfall produced flash floods and debris flows in high elevation gullies; the debris flows included rocks of up to 2 m diameter. Unfortunately, some of the poorest settlement has expanded into these high elevation gullies. Seventy-five people died as a result of the debris flow. Sand deposition in lower regions led to further flooding.

Because no recent flood had included such severe debris flows, no planning had been made for such an event. The deaths and damage resulted from a combination of physical hazards combined with the expansion of poor settlements into vulnerable areas. The government of Mexico has responded by a combination of relocation and the planning of protective structures, in order to avert future similar disasters.

(v) Mexico: Hurricane Gilbert in 1988
Like Hurricane Andrew in Florida, Hurricane Gilbert illustrated how vulnerability is enhanced by poor or poorly enforced building codes, or faulty construction practices (top left box in Figure 3). These unsafe conditions are to a large extent the result of social forces such as the lack of government support to building code development and enforcement, and poor public education regarding extreme events and how to mitigate them.

Winds above 300 km/hr, waves more than 5 m high, a tide more than 2 m high, and a 350 mm rainfall over 24 hours affected between 100,000 and 200,000 people and killed more than 250, with a cost of approximately US$766 million (1988 dollars) from September 14-15, 1988. About 80% of these casualties occurred while people tryied to cross Monterrey's river Santa Catarina at some flooded fords. This tragedy was a typical and yet dramatic consequence of the lack of a culture that emphasizes emergency preparation and response (notably hurricanes) among the population and among low-level authorities, who are the main decision-makers in these circumstances. It was aggravated by the fact that hurricanes in Monterrey are unusual, and despite warnings people did not respond appropriately to the risk. The storm wreaked havoc on the fishing industry and leisure infrastructure of both Quintana Roo and Yucatán states, impairing economic activities. Agricultural production, as well as forested areas, were devastated. In the state of Campeche, oil extraction (1.7 million barrels per day) and fishing activities were brought to a halt. Most deaths (200) occurred in Nuevo León and Tamaulipas. Roads, telephone and electricity grids, and water supply systems were all impacted.

Winds caused severe damage to urban zones, billboards, industrial premises, electricity pylons, telecommunication poles, and lamp posts. In rural areas, it ravaged vegetation along the coastal strip. A number of roofs and masonry walls were destroyed, because of deficiencies in structural design, construction processes, and material quality. In the northeastern part of the country, many steel and galvanized sheet silos were damaged.

The coast of Yucatán suffered the greatest damage. Many sea-front buildings were so damaged that they had to be demolished. Others were weakened by undermining of their foundations. Fishing and pleasure boats were carried inland, killing their crew in some cases. Sea level rises up to 5 m flooded many hotels. The masonry breakwater of Yucatán's most important port (Puerto Progreso) was destroyed. Vehicles were thrown, walls knocked down, streets eroded, roads cut off, and road surfaces degraded. It is estimated that 10% of flamingos and 50% of turtles died.

Widespread damage was caused all along the coast of the state of Tamaulipas, notably in the village of Lauro Villar, where 95% of fishermen's houses were ravaged. Here again, the hurricane had a heavy toll on road surfaces, silos, piers and other structures. As well, it caused erosion and deposits in the seashore, settlements, object removal, and breakwater undermining.

Gilbert's total rainfall in Mexico amounted to 90 billion m^3. Damage by the ensuing runoff was greatest in northeast Mexico, where usually dry rivers across the states of Coahuila, Nuevo León, and Tamaulipas were suddenly flooded. In Monterrey, 200 people died as they tried to cross the Santa Catarina River at road fords (some of them were peasants fleeing their villages, thinking that they would be safer in the city). As the riverbeds and the banks of many rivers were flooded (notably Santa Catarina and Rio Grande), houses, warehouses, pipes, road surfaces, sports and leisure facilities, crops, and electricity poles were destroyed.

Most of the damages should not be attributed to the unusual strength of the storm itself, but rather to the fact that strong hurricanes are not taken into account in the design, construction, and operation of human works and activities. Due to a lack of local expertise, most states of Mexico have copied the building regulations of the Federal District (Mexico City), which does not take into account hurricane-force winds.

(C) Natural Disasters That Might Have Been

Historical disasters provide a great deal of insight into society's vulnerability. They can also, at times, induce complacency, if it is commonly believed that they represent the worst that could happen. By considering what might have been, under slightly different circumstances, a valuable insight regarding potential catastrophes can be gained. This insight can impel society towards greater mitigation than might otherwise be initiated.

There have been various studies on the potential impact of future disasters. For example:

- A single, high-magnitude earthquake in Vancouver or lower Québec (hitting Ottawa and/or Montreal) could cost from CAN$14 billion to CAN$32 billion (Canadian National Report - IDNDR, 1994)
- A storm similar to Hurricane Andrew striking Miami would have expected losses of US$48 billion to US$80 billion (Changnon *et al.*, 1997).
- A recurrence of the December 16, 1811 New Madrid, Missouri Earthquake with a Richter Magnitude of 8.6 could cause damages of US$138 billion (Friedman, 1992).
- A major eruption without warning of the Popocatépetl volcano near Mexico City could cause one of the worst volcano disasters in history.

The three scenarios below paint a picture of what could happen during extreme events in different situations. Three events are chosen, one for each country; the Canadian and Mexican scenarios illustrate society's vulnerability whereas the American scenario illustrates how society's vulnerability could be reduced.

(i) Scenario #1: A tornado in Barrie, Ontario, Canada

The May 31, 1985 tornado which struck Barrie, Ontario killing 8 people in the city and 4 others around southern Ontario could have had much more serious consequences. A power outage resulted in many people being at home who would have otherwise been in the tornado's path in industrial buildings or in vehicles; the tornado hit after school hours so that portable classrooms were empty; and a severe weather warning had been broadcast to the public which might have assisted preparation by individuals.

This scenario examines a worst-case event from a "risk-to-life" perspective by assuming that a tornado of similar magnitude to the 1985 tornado strikes on a June Friday at 3:00 p.m. with no prior warning or power outage. As well, the tornado's track is shifted north so that it passes over 70-75 portable school classrooms, 1000 to 1500 homes, a shopping mall, a major highway, and a senior citizens home. The tornado event is assumed to last approximately 5 minutes over a track length of 5 km. Barrie residents would likely notice the tornado only as it approached, leaving very little time for emergency preparations.

Exact quantification of casualties and damage is not feasible, but examining the damage from 1985 permits some inferences regarding potential impacts. Assuming an average class size of 20 students in each of 75 portable classrooms would put 1500 students at significant risk, and if half of the portables in the tornado's track become airborne as occurred in 1985, then 750 students would be at high risk, with possible hundreds of fatalities. In 1985, 1/3 of the homes in the tornado's path were left completely uninhabitable and there was roughly one fatality per 50 damaged homes; similar statistics in this scenario would result in 6 to 10 deaths in houses. Friday afternoon traffic in the summer tends to be quite heavy, so vehicle damage would be significant on the highway and congestion and wreckage would hamper rescue efforts. The shopping mall and senior citizens home would also be expected to suffer severe damage and significant casualties.

This hypothetical scenario, in which all conditions align to create a major disaster, would yield one of the worst known tornadoes in history. The Tri-State Tornado(es) of March 18, 1925 in the American mid-west which killed 689 people (Felknor, 1992) is the only tornado known in North America to have produced the potential number of casualties suggested here (by comparison, tornadoes in Bangladesh have been reported to have killed up to 1,100 people from one event and injured tens of thousands (National Geographic, 1997)).

(ii) Scenario #2: San Francisco Earthquake (modified from Mileti *et al.*, 1998)

In 1906 an 8.25 magnitude earthquake on the San Andreas fault devastated San Francisco. Subsequent fires destroyed 3/5 of the city, with between 500 and 3,000 deaths and 100,000 people left homeless. There is a 2% chance that this quake could occur again between 1990 and 2020, but a 67% chance that a major earthquake could occur before 2020 along one of the faults in the Bay Area.

This scenario speculates on what might happen to the city in the event of another 8.25 earthquake if sustainability had been adopted as the paramount concern for community development since that time. The assumption is that governments at the national, state, and municipal levels collaborate with industry, business, the general population, and special interest groups to develop a San Francisco in which resilience to disasters becomes an integrated component of a sustainable city.

If sustainability were both a process and a goal to the people of San Francisco, then familiar urban problems such as crime, poverty, pollution, transportation congestion, economic inequities, and increasing energy demand would be tackled holistically, yet with focussed and specific ideas. When examined from a disaster prevention perspective, solutions would be evaluated on how much the population's vulnerability to a major earthquake is reduced.

For example, increasing the presence of parks (green spaces) would provide recreational facilities for the community, but, following an earthquake, would serve as firebreaks and as temporary campsites close to people's homes during aftershocks. If the parks were located in particularly vulnerable locations near the fault lines (as they are sometimes located in flood zones), then the potential for damage would be greatly reduced. Vulnerability could also be reduced by retrofitting older buildings, where feasible.

During the 1994 Northridge earthquake, over 3 million residents were without electricity for over 24 hours, as a result of damage to a centralized energy supply system. Decentralizing the energy supply system, shifting towards renewable energy sources, and using energy demand minimization techniques would provide long-term economic and environmental benefits, yet would reduce the potential for widespread power outages following an earthquake.

The challenges to San Francisco in carrying out such tasks would be immense and would cause much debate. Achieving this vision would require continual consultation with all stakeholders, detailed exchanges of knowledge and information, and carefully managed legislation and tax incentives. If implemented, San Francisco would become much more environmentally, economically, and socially sustainable. When the big earthquake does hit, casualties, economic losses, and recovery time would be much less in this scenario than would occur otherwise. Sustainability creates disaster resilience.

(iii)

Scenario #3a: Mexico City Earthquake

On September 19, 1985 at 7:19 a.m. an earthquake of M_s=8.1 with an epicentre 352 km (220 miles) from Mexico City caused the greatest damage recorded in the city's history. According to official data from the Prosecutor's office (Agencia del Ministerio Publico), the casualties were 4,541 dead (though unofficially more than 10,000 died), 4,096 rescued alive, and 15,936 treated in hospitals and clinics. Furthermore, about 100,000 families suffered damage to their homes. The consequences, however, could have been much more severe, and many more casualties could occur during an earthquake of similar magnitude in the future.

In 1985, damages to buildings and infrastructure were mainly to housing (65%) and more than 37,300 persons were rendered homeless. The number of buildings affected was approximately 12,700, with the highest percentage of damaged structures (56%) being located in the Cuauhtémoc Delegation (downtown Mexico City is located within this Delegation). The number of structures completely destroyed was 412 and 30% of hospital capacity was lost.

At the time of the event, the number of residents in the metropolitan area of Mexico City was over 20 million, yet only 3.2% of them were directly affected (Quarantelli, 1989). Thus, a future earthquake with an epicentre slightly closer to Mexico City could produce much more damage (in terms of both human casualties and infrastructure) than occurred in 1985. The time of day of the next earthquake could also augment casualties. In 1985, the economically active population in the Federal District area was around

8.5 million people and the student population was 2.6 million. Because the earthquake struck early in the morning, a large proportion of these people were in transit to their school or work, i.e. they were in the streets or on public transportation. Most of the deaths were caused by building collapse, hence if the next seismic event were to occur during the day (for example, at 11:00 a.m. when most people are at work or at school) the human losses would far eclipse those from 1985.

It is not certain whether or not it is possible to accurately extrapolate the results of an earthquake today from the results of the 1985 earthquake. For example, the demographics are changing so quickly, due to immigration to the Federal District, that it is impossible to continuously update the population data. As well, after the 1985 earthquake, many though not all buildings were retrofitted, but there is no information on exact numbers. Post 1985 buildings were built taking into account the new Mexican Building Code.

Scenario #3b: Popacatepeti Volcanic Eruption

Mexico has experienced two volcano disasters this century, one of which in 1982 killed about 5,000 people. The potential exists, however, for a far worse scenario. There are several localities in Morelos, Puebla and Mexico states within the hazardous zone of the Popocatepetl volcano in which approximately 1,200,000 people live. Two important cities, Mexico City and Puebla are near the volcano; as a result, the slope areas of the volcano have increasingly become areas of human settlement. The Popocatepetl hazardous zone is divided in three zones; high risk (Zone 1), medium risk (Zone 2) and low risk (Zone 3). About 698,937 people live in the high and medium risk zones. The worst death tolls in history from volcanoes were Tambora in 1815 (92,000 dead - 82,000 from famine), Krakatoa in 1883 (36,500 dead from tsunamis) and Mount Pelée in 1902 (28,000 dead). A major explosion of the Popocatepetl volcano without warning could potentially result in a death toll as or more severe than these.

(4) How Human Activity Mitigates Natural Disasters:

Throughout history, humanity has attempted to prevent natural disasters. Mitigation is driven by social forces in order to create safer conditions and reduce vulnerability, or to reduce hazard severity or probability. Current efforts in this regard are carried out in government, in universities, in industry, by volunteer agencies, and by individuals. Examples of organizations are the Federal Emergency Management Agency (FEMA), Emergency Preparedness Canada (EPC), Environment Canada, Centro Nacional de Prevención de Desastres (CENAPRED), National Disaster Prevention Centre (Mexico), National System of Civil Defence (Mexico), the United Nations' International Decade for Natural Disaster Reduction (IDNDR), Canadian Standards Association (CSA), Building Code Committees, the Natural Hazard and Research Center (NHRC at the University of Colorado), the Institute for Home Safety (U.S.), the Institute for Catastrophic Loss Reduction (Canada), the Red Cross, Médecins sans Frontières (Doctors Without Borders), and Registered Engineers for Disaster Relief (RedR).

In general, society reduces the impact of disasters through three basic strategies:

(A) modifying the hazards;
(B) sharing the risk; and
(C) reducing the vulnerability of society (people and their built environment).

These three strategies are applied through the somewhat overlapping activities of response and recovery, mitigation, and preparedness (Figure 3). Hazard mitigation is defined as "sustained action taken to reduce or eliminate long-term risk to people and property from hazards and their effects" (FEMA, c. 1997). Successful mitigation requires a broad range of approaches, and should include federal, provincial/state and local governments, the insurance industry, and public educators, along with many other stakeholders.

(A) Modifying the Hazards

Altering nature is not an easy (and sometimes not a wise) endeavour. The best known and most prominent examples are discussed below.

Rainfall Enhancement

The purpose of rainfall enhancement is to mitigate drought. Research studies designed to evaluate rainfall enhancement have not been encouraging (Cotton and Pielke, 1995). Cloud seeding experiments of supercooled clouds have not confirmed that increased rainfall at the surface results from the seeding process, possibly because the changes are swamped by large natural variability, because the theory is at fault, or because the sample size of the experiments was not large enough. Experiments with warm clouds in tropical and semi-tropical regions have also been inconclusive, though "there appears to be a real opportunity to enhance rainfall through hygroscopic seeding in some clouds" (Cotton and Pielke, 1995). Several cloud seeding operations have been carried out in Mexico during periods of drought, but the results were inconclusive. In 1997, a program was undertaken by the National Water Commission (CNA), the Mexican Water Technology Institute (IMTA), the University of Colorado, and the Coahuila state government, aimed at mitigating the effects of droughts in the north of the country. This project, with a budget of nearly US$1 million for this year, is now in the research stage.

Hail Suppression (adapted from Etkin and Myers, 1999)

There have been a number of operational hail suppression programs around the world, including ones in Bulgaria, China, France, Germany, Greece, Russia, Slovenia, South Africa, Spain, the U.S. (North Dakota, Kansas), and Canada (Alberta) (WMO, 1995). The results of some of these programs were not encouraging (e.g. a 5-year US$25 million National Center for Atmospheric Research project showed no positive results in hail suppression (Haas, 1974) as a consequence of cloud seeding), while others (particularly in Russia and North Dakota) claimed success, though the World Meteorological Organization (WMO) evaluation suggested that these claims must be viewed with caution since they are based upon crop and hail data that can be difficult to interpret (WMO, 1995).

Weather modification is not used widely. Support for cloud seeding in the U.S. peaked in the 1970's and has been waning ever since, partly due to a lack of a coordinated constituency, a lack of strong leadership at the federal government level, and the failure of interested parties to push for a strong national policy during an era of opportunity in the 1970's (Lambright and Changnon, 1989), but also because no rigorous scientific research program has demonstrated that it is effective, in spite of 50 years of research.

Nevertheless, there are some active operational cloud seeding programs in North America today. The insurance industry spends about CAN$1.5 million per year seeding clouds in Alberta, and may extend their operations into other provinces in the future. This program has no research or validation components, and its perceived success is based on unproven hypotheses. North Dakota also has an active cloud seeding program. Some analysis done by the North Dakota Atmospheric Resource Board suggest that the program has been very effective in reducing hail damage to crops.

Hail events in Mexico are not as severe as in Canada and the U.S., but can still cause damage to agriculture and in urban zones. Some hail suppression in Mexico was initiated in 1982 in the sates of Coahuila and Durango, but was abandoned due to financial constraints. Some hail suppression actions are currently being carried out in apple-growing areas of the state of Chihuahua.

Modification of Tropical Cyclones

Experiments to modify tropical cyclones by seeding began in 1947, with an active field program in the late 1960's and 1970's. Experiments in the STORMFURY program ended in the late 1970's when results were not encouraging (Cotton and Pielke, 1995). Federal expenditures on weather modification in the U.S. began in the early 1960's, peaked in the mid-1970's, and currently are about 10% of the highest value (Cotton and Pielke, 1995).

Earthquake Mitigation

Most methods of controlling earthquakes which have been suggested were 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, smaller earthquakes with underground explosions in order to prevent one large shock (Waltham, 1978)–although structures can fail due to fatigue from numerous, small shocks. Similarly, in Arizona in 1935, the artificial reservoir Lake Mead on the Colorado River was found to induce earthquakes through the weight of the water on fault lines (Smith, 1996; Waltham, 1978). Carefully filling reservoirs could be used for inducing small shocks, or if a large earthquake were felt to be imminent, then a reservoir could be drained to try and reduce the earthquake's magnitude. Reservoirs also increase the groundwater pressure which would reduce friction along a fracture thereby inducing small earthquakes and eschewing a large one. 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 accidentally near Denver and the United States Geological Survey (USGS) conducted reasonably successful experiments in Colorado (Bolt, 1993). The fear of inadvertently causing a major earthquake is a powerful restraint on using such techniques; the Koyna Reservoir near Bombay, India was filled in 1967 and caused an earthquake which killed 177 people (Waltham, 1978).

Volcanic Hazard Mitigation

Volcanic eruptions are generally very difficult to stop or control, but the ground motion of ejected material 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 and floodways. Lava flows can also be diverted with barriers. 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).

(B) Sharing the Risk

Society shares the risk of disasters (top box of Figure 3) through the use of insurance programs or through government disaster assistance programs. Volunteer agencies and NGOs play important roles tool, largely through the donation and distribution of money, goods and services. Though these actions do not necessarily reduce the overall impact of the disaster, it makes the individual impacts manageable and creates a more stable and resilient society.

(i) Insurance

For those who purchase it, insurance provides protection from disasters by spreading their economic impact among a large group of policy holders. Insurance is based upon three principles: that a relatively large population is exposed to a risk; that a relatively small proportion of the exposed population is likely to incur a loss at any particular time; and that losses occur randomly. The Canadian property and casualty insurance industry currently provides a standard property insurance policy that provides coverage against perils such as fire, theft, strong winds, tornadoes, hurricanes, hail, and freezing rain. Coverage for additional perils such as torrential rain, sewer back-up, landslides, and damage caused by the weight of snow are also generally available as endorsements, or additions, to the standard property policy. Damage caused by the flooding of lakes, rivers, and streams, as well as waves, tides, and tsunamis are examples of localized risks which violate basic underwriting criteria, and thus, cannot be covered by standard insurance policies. Some insurance policies are based in the public sector (such as flood damage insurance in the U.S. or crop insurance in some provinces in Canada), while others are based in the private sector. In Canada, residential flood insurance is not available, though sewer backup is covered; however, commercial flood insurance can be purchased. An all-risk holders property and casualty policy covers all other natural hazards except for earthquakes.

In recent years, the number and cost of claims in Canada have been increasing. From 1983-1989, there were 9 catastrophic events totalling CAN$425 million in payouts. From 1990-1997 there were 41 events, totalling CAN$2.15 billion (Ross, 1997). Data from the Insurance Bureau of Canada summarizing payouts resulting from natural hazards are summarized in Tables 8a and b. Provincial crop insurance payments are often very large, with damage mainly due to hail and drought. Saskatchewan sustains the largest losses, which at times exceed CAN$500 million annually. The January 1998 Ice Storm alone may reach insured costs of $1.5 billion, over three times as large as the previous worst event! The Canadian insurance industry considers it to be a worst-case weather scenario.

For the U.S., data on estimated insured catastrophe losses (natural and non-natural catastrophes) are published by the Insurance Information Institute. Tables 9 and 10 summarize this information. The immense impact which a single catastrophe can have on one year's insured losses is illustrated by Hurricane Opal (1989), Hurricane Andrew (1992), and the Northridge earthquake (1994).

In Mexico, Chapter 6 of the decree establishing the bases of the National System of Civil Defence (from 1986) suggests devising a financial fund and an insurance system, but no clear alternatives are presented in this respect. In agriculture, only a relatively small portion of annual crops is insured. Agricultural insurance is managed by the public sector, while flood, earthquake, volcanic eruption, lightning, and fire damage are covered by the private sector (about 22 companies). The market for disaster insurance policies is essentially restricted to businesses and public buildings. Mexican society has not fully realized the benefits of insurance at either a personal level or a national level; a well-developed insurance culture is lacking. Tables 11 and 12 show the payouts for the 1985 earthquake and for Hurricane Pauline in 1997 respectively. For the former event, insurance payouts covered 10% of the total damage of about US$4 billion.

Insurance payouts worldwide due to natural disasters have increased exponentially during the past few decades (Figure 6). According to analyses from the industry, the losses partly result from more frequent and more severe natural disasters (Kovacs, 1997). Prior to 1988, there had never been a single event topping US$1 billion for the insurance industry, but between 1988 and 1996, there were fifteen such events worldwide ("Insurance Issues", 1996).

Recent innovative strategies include the use of capital markets to supplement catastrophe reinsurance capacity. Though the probable maximum loss of a major hurricane hitting a large city (US$80-100 billion) could destabilize the global insurance industry, it represents less than the daily variability of the U.S.

capital markets (White and Etkin, 1998). Catastrophe bonds or disaster derivatives tap into that market, and pay slightly more than similar corporate bonds; however, the investor can lose their entire principal should disaster strike. A potential market in the tens of billions of dollars can provide a solution to problems related to limited reinsurance capacity.

(ii) Disaster Financial Assistance

Disaster Financial Assistance (DFA) is provided by federal, state/provincial/territorial, and occasionally municipal governments. In Canada, the federal government provides disaster assistance when costs exceed CAN$1 multiplied by the provincial population. They pay for one-half of costs between CAN$1 and CAN$3 per capita, three-quarters between CAN$3 and CAN$5 per capita, and 90% of the remainder. Crop insurance payouts in Canada cost approximately CAN$328 million per year. Half of the costs of the premiums are borne by provincial and federal levels of government, while the provinces of Alberta and Saskatchewan absorb the bulk of the payouts. Federal payments administered by EPC were dominated by flood disasters up until 1997. Weather-related disaster payouts averaged CAN$82 million per decade (though the two-year period of 1995-96 totalled over CAN$135 million) but these values do not include 19 events still being negotiated, as well as major hailstorms in 1996, the Saguenay Flood of 1996, the Red River Flood of 1997, and the Ice Storm of January 1998 in eastern Canada, which together will make the previous total appear fairly small. The 1996 Saguenay Flood, the 1997 Red River Flood, and the January 1998 Ice Storm will likely result in payments of several hundred million dollars, CAN$150 million, and several hundred million dollars respectively. EPC maintains a database on Canadian disasters, the numbers of which are shown in Figure 7. Note that the number of disasters appears to be increasing relative to population. This trend may be due to the increased wealth of society, better reporting of disasters, a tendency to develop vulnerable regions, more frequent events, or any combination of the above.

In the U.S., the availability of public disaster relief is limited unless a presidential disaster declaration is made (Congressional Research Service, 1992). In this case, the type of relief provided might include low-interest loans, small grants, temporary housing, and 75% of the costs of damage to public facilities. In cases of the latter, state and/or local government are required to pay the remaining 25%. Table 13 lists some examples of natural disasters with high economic impacts for FEMA and the Small Business Administration. There are significant differences from the list in Table 10, indicating that the risk from natural disasters is not always "shared" equally. For more common but less catastrophic events which do not warrant a presidential disaster declaration, people must rely on insurance payments or funds from NGOs such as the Red Cross and other voluntary relief groups to recoup their losses.

In Mexico, a trusteeship was created in 1975 to care for the victims of disasters, with donations from a broad range of sectors. The executor is the Treasury Ministry and the manager is the Central Bank. Unlike the U.S., in Mexico there are no regulations concerning the provision of financial resources for civil defence purposes. They are managed in a centralized way by the Federal Government, under the assumption that disasters are a matter for the federation, deterring a more coordinated management by states and municipalities (Delgadillo, 1996). As previously mentioned, in the basic documents concerning civil defence (the decree of 1986 and the National Program of 1991), there are no explicit indications on responsibility for financing. Although Chapter 6 of the first document suggests establishing a financial fund and an insurance system, it does not present any clear method of implementing the suggestion. In the second document, this issue is mentioned neither in the five strategic lines nor in the eleven lines of action (Delgadillo, 1996).

(C) Reducing the Vulnerability of Society

A variety of activities encompassed in the broad overlapping categories shown in the bottom box of Figure 3 feed into vulnerability reduction. For example, appropriate forecasts and warning are required for both short-term preparedness and response; the most important aspect of mitigation likely relates to our built environment; and information and education is critical to developing community preparedness.

(i) Forecast and Warning (adapted from Etkin and Myers, 1999)

Lives can be saved and injuries reduced if reliable forecasts are available, if appropriate warnings are issued, and if people and organizations take suitable actions upon receipt of those warnings.

For example, the scientific capability for predicting weather and weather patterns has improved greatly in the 20th century. The advent of technologies such as Doppler radar have advanced meteorologists' abilities to anticipate and predict severe weather. Nonetheless, the lead time in warnings for some hazards such as severe thunderstorms tend to be much shorter (typically a few minutes) than it is for larger storms (e.g. hurricanes). This difficulty requires that warning systems be carefully designed and implemented.

Warning systems involve complex processes. Providing effective warnings for severe natural hazards to people requires a chain of events, beginning with the technology and personnel to observe and predict the events and ending with risk communication and human response. These components of warning systems are interdependent, making the system only as good as its weakest link. Good warnings not only include information about the potentially severe event, its location, and the time frame involved, but also give people information on appropriate actions to take in response to the warning. Mileti and Sorensen (1990) classified some hazards into warning typologies and noted that different approaches to warning are needed for different hazards. Thunderstorms fall into the typologies that call for highly automatic decision-making and quick warning using all available means of communication. Conversely, slow-onset hazards allow time for more considered response.

(ii) The Built Environment

Society's built environment plays a crucial role in the reduction or augmentation of vulnerability. Decisions about how and where to build structures are fundamental to determining resilience to natural disasters. A range of tools, including building codes, comprehensive land use planning, community facility planning, growth management, and capital improvement planning are available to governments so that when natural hazards do strike, damage to the built environment can be limited (Burby *et al.*, 1991). For example, requirements for lightning rods on structures can result in current being transferred safely to the ground when lightning strikes. Similarly, land use plans that guide development away from hazardous areas (e.g. areas prone to floods) allow communities to make decisions to avoid future damage, although people often live in high-risk areas because they do not know or do not care about the potential risks or because they have no choice but to do so because of poverty or other societal factors. California yields two good examples: in San Francisco's Marina District, residences built on reclaimed land prone to liquefaction succumbed during the 1989 Loma Prieta earthquake, and homes built near cliffs proved disastrous during several El Niño-induced landslides in the first few months of 1998. An example of a tool used to reduce society's vulnerability is comprehensive stormwater management programs which enable a community to prepare for heavy rains by providing storage areas for the excess flow of water.

Building codes, which determine how to build structures (especially their resistance to extremes of natural activity such as wind, snow, and ground shaking) play a very significant role in determining how resistant communities are to natural hazards. The American Constitution bars the federal government from enacting building codes, so they are the responsibility of local authorities–states, counties, and cities (Levy and

Salvadori, 1995). In Canada, the Constitution Act places the responsibility for regulating buildings on provincial and territorial governments, but provincial/territorial building codes and municipal by-laws 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). Both countries use building codes primarily to protect life, with protection of property as a secondary function; punishment for noncompliance is not explicitly mentioned in building codes, but is left to the law.

In Mexico, articles in the Constitution pertaining to urban development and housing are regulated by means of the Federal Law on Urban Development. This document establishes that every municipality must have a building code, although it allows a collection of municipalities to issue a regional or state building code. In most cases, these codes are just simple adaptations, or copies of the Mexico City Building Code. Other government agencies have issued codes and manuals applicable to structures other than buildings. The most prominent examples are those from the Ministry of Communications and Transportation and the Federal Commission of Electricity, aimed at the design and construction of highway infrastructure and power supply facilities, respectively. The main objective of Mexican regulations governing structures is to safeguard the population, and they give a minimum safety requirement for construction.

Historically, adaptation tended to be implemented reactively; i.e. society waited for a problem to arise, such as casualties and damage due to a natural disaster, and then created or changed codes and practices to prevent a recurrence. 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). Partly in response to two devastating tornadoes in Canada in the 1980's (in southern Ontario in 1985 and in Edmonton in 1987), the National Building Code of Canada started to examine the prevention of damage from tornadoes. Many of today's building codes and zoning regulations, in contrast, are proactive in that they use statistical techniques to predict rare events, although disasters such as Hurricane Andrew in 1992 and the Northridge Earthquake in 1994 can still create the impetus for code modification.

Mexico has had similar experiences. The first Mexico City Building Code that contained recommendations for seismic design was published in 1942 and explicitly identified the need to modify the procedures upon receiving results from additional studies. As well, the impossibility of designing and building structures that provide complete protection against earthquakes was recognized, and a greater degree of safety was mandated for the most important structures. A 1957 earthquake off the coast of the state of Guerrero eventually led to new regulations in 1966. In 1976 the Code was revised once more, though not as a result of a disaster. This Code was used for several years and then revised again in 1984; however, the 1985 earthquake prompted another revision and in July 1987 a new revision of the Mexican City Building Code was published.

A considerable percentage of buildings constructed in Mexico are non-engineered, especially one or two storey dwellings, typically constructed with masonry load-bearing walls, located in rural areas or in informally developed housing layouts. The latter are generally located on soils and in areas not appropriate for safe buildings, such as on hills with steep slopes prone to slope failures, or in old river beds prone to flooding during heavy rains. For such cases, building codes are of no help. Simple technical guidelines are therefore necessary to advise the owner and workers on achieving a satisfactory performance level for such aspects as the most appropriate construction techniques, structural layout, material quality, and detailing. Although some of these guides have been developed, their use is limited. Damage in recent earthquakes has shown large differences in dwelling performance, mainly attributed to poor layout, lack of proper detailing, and substandard material and construction quality. Efforts to influence non-engineering construction through a wider dissemination of guidelines, videos, and photographs have the potential to greatly reduce vulnerability. Retrofitting programs for existing, vulnerable dwellings (typically adobe houses) are essential.

Proactive approaches to structural design that reduces vulnerability to natural disasters can be limited due to a lack of understanding of physical processes. Most structural damage during the 1994 Northridge earthquake occurred because a previously unknown fault caused vertical shaking, and buildings had not been designed to withstand vertical shaking (Levy and Salvadori, 1995). Kobe's structures suffered severely during the 1995 earthquake because the region was not thought to be vulnerable to earthquakes, so building codes were created to protect structures from damage during typhoons; this design approach actually exacerbated the damage from the earthquake (Smith, 1996). As discussed, since 1942, Mexico City has twice altered its seismic design regulations after earthquakes caused unexpected shaking and revealed basic design flaws. Ignorance, however, can often be overcome by appropriate research, which is inexpensive compared to the damage wrought by disasters. Society then determines the appropriateness of incorporating research recommendations into building codes.

Proper enforcement is also required to ensure that building codes are effective in reducing vulnerability to natural hazards. In 1992, Dade County, Florida had one of the toughest building codes in the U.S., but much of the damage caused 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). In eastern Canada, deaths and injuries have occurred during tornadoes because some buildings did not meet building code standards (Allen, 1992). To some extent, this problem undoubtedly exists due to the competitive bidding process, which tends to minimize quality.

Improved building codes and enforcement, however, apply to structures built after the enactment of the new code. Structures already built will still be susceptible to the problems which changes have addressed, hence retrofitting is an option to overcome outdated or poorly enforced codes. Cost and inconvenience are generally reasons for avoiding retrofitting. Essential structures such as schools and hospitals are often given priority, with residential dwellings rarely retrofitted. For example, after Hurricane Andrew destroyed 97% of the mobile homes in Dade County, Florida in 1992, the standards for the resistance of manufactured housing to winds were raised. When a tornado storm hit Central Florida on February 22-23, 1998, approximately 90% of mobile homes in Florida had been sold before the new wind-resistance rules were enacted and approximately three-quarters of the 42 deaths during these tornadoes occurred in unretrofitted dwellings.

Levy and Salvadori (1995) describe another example: on March 10, 1933 an earthquake in Long Beach, California severely damaged all schools in the area, including several collapses. Because the earthquake struck at 5:54 p.m., the schools were empty and a large death toll was avoided. This near-catastrophe prompted strict standards for new schools with respect to earthquake resistance. When the 1971 San Fernando earthquake hit, all 500 schools constructed in accordance with the new building codes survived without structural damage while 10% of the remaining old schools were damaged so severely that they had to be demolished. The 1971 earthquake, though, collapsed several bridges. By 1994, fewer than 20% of California's bridges had been retrofitted based on the 1971 experience, yet the retrofitted bridges fared very well during the Northridge earthquake while unretrofitted structures sustained major damage.

Concerns are also raised with respect to historical buildings, because retrofitting may damage structures or items of historical value, may reduce the building's authenticity as an example of historical architecture, or may be completely unable to render the building safe. Pearce (1994) states that people in buildings preserved for historical reasons have higher vulnerability to atmospheric hazards than people in modern buildings.

(iii) Disaster Preparedness

Disaster preparedness involves building an emergency management capability in advance of an event in order to facilitate an effective response. Developing a vulnerability analysis that identifies the hazards of a particular place is critical to disaster preparedness. Preparedness also includes the necessary planning for emergency response. There are six basic functions that are carried out during response activities: hazard detection and warning; evacuation of threatened populations; sheltering of and caring for victims; provision of emergency medical care, food and shelter; conduct of search and rescue operations; and provision of security and protection for property (Drabek and Hoetmer, 1991). Other specific functions (dependent on the event) also may be called for in the response phase.

There is an extensive literature on natural disasters, including scholarly dissertations, textbooks, public information, and educational material. Federal agencies such as the Federal Emergency Management Agency (FEMA), Emergency Preparedness Canada (EPC), and Sistema Nacional de Protección Civil (SINAPROC) develop and distribute a large amount of material, ranging from short brochures to technical manuals. The World Wide Web (WWW) is rapidly becoming a remarkably good resource, and many agencies maintain sites with vast amounts of information. Table 14 lists of a number of useful WWW pages relevant to natural disasters in North America.

The United Nations designated the 1990's as the International Decade for Natural Disaster Reduction (IDNDR): "*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, wind storms, tsunamis, floods, landslides, volcanic eruptions, wildfires, grasshopper and locust infestations, drought and desertification and other calamities of natural origins.*" Ironically, the economic costs of natural disasters has exploded during this decade, illustrating the ever increasing importance of natural disaster reduction. Canada, the U.S., and Mexico each have national committees whose purpose is to fulfill the IDNDR's objective.

In Canada and the U.S., deaths from natural disasters are very few compared to other causes such as diseases and car accidents, and have generally been declining during this century. Costs, however, seem to be rising. The cause of this increase can be attributed in part to migration of populations to vulnerable regions, particularly in the U.S. (e.g. along coastlines). There is some evidence as well, that mitigation strategies have not been as effective as anticipated. For example, along the Chaudière river in Québec, many buildings have been erected in the 0-20 year flood zone despite a restriction on building, and increases in flood damage in the future are likely. The Mississippi floods of 1993 in the U.S. showed how a series of dams, dykes, and levees built over many decades can exacerbate a disaster. Development near hazardous areas in Mexico sets the stage for disasters in the future, of greater magnitude than have occurred in the past.

Governments have instituted a variety of programs to mitigate disasters. More research is needed on their effectiveness, so that future policy makers can learn and benefit from the good judgments or errors of the past. The potential benefits of such research are substantial. For example, in one study of flooding of similar magnitudes in Michigan and Ontario, it was found that non-agricultural damages in Michigan were around US$200 million, while in Ontario they were under CAN$500,000 (a factor of approximately 500 less), even though Ontario had higher flood yields (Brown *et al.*, 1997). The reason provided for the difference was the more stringent flood damage reduction (FDR) program in Ontario.

(D) Enacting Mitigation: The Influence of Federal Governments

(i) Canada

Canada has not yet developed either a national, comprehensive formal policy statement or an integrated delivery structure at any governmental level for mitigation of natural hazards, though many federal departments and provincial ministries have their own programs to reduce the impacts of natural hazards. The reason is that Canada has, until recently, been relatively disaster-free, compared to other places.

(ii) The U.S.

FEMA in the U.S. has developed a National Mitigation Strategy which is posted at *http://www.fema.gov/home/mit/ntmstrat.htm*. The strategy was designed in consultation with many stakeholders in the U.S., including other federal agencies; governments at the national, state, and local levels; academics; the private sector; and individual citizens. It is based on the premise that "current dollars spent on mitigation will save a significantly greater amount of future dollars by loss reduction" and sets two objectives:

By the year 2010:

(1) to substantially increase public awareness of natural hazard risk so that the public demands safer communities in which to live and work; and

(2) to significantly reduce the risk of loss of life, injuries, economic costs, and destruction of natural and cultural resources that result from natural hazards.

These objectives will be achieved through initiatives contained in the five major elements of the strategy: (1) identifying hazards and assessing the risks associated with those hazards; (2) encouraging applied research in technology used for response to hazard risk and transferring that technology to governments, the private sector, and citizens; (3) creating broad-based public awareness and understanding of natural hazard risks along with mitigation training programs; (4) providing incentives and resources to encourage mitigation activities; and (5) providing national leadership for, and coordination amongst, stakeholders.

The strategy incorporates continual evaluation both of how well the objectives are being achieved and of the amount of success in mitigation. The basis for establishing priorities in using resources is also provided. The Mitigation Action Plan (MAP) within the strategy encourages every stakeholder to accept responsibility for identifying and mitigating natural hazards which threaten them and their communities. As well, since 1994, 15% of federal disaster assistance has been dedicated to mitigation activities. FEMA (c. 1997) describes cost-benefit and cost-effectiveness analyses for 16 case studies which illustrate the substantial cost savings (and beneficial social impacts) which can result from appropriate mitigation measures, particularly for earthquakes, floods, and hurricanes.

(iii) Mexico

Before the 1970's, there was neither planning nor preparedness with respect to natural disasters in Mexico. Instead, the approach was to implement post-disaster actions, which rarely reduced the country's vulnerability to ensuing catastrophes (Delgadillo, 1996). In 1978, the National Program for Urban Emergencies was created within the National Plan of Urban Development, which envisioned studying the risk and vulnerability of human populations at state and municipality levels, as well as zoning and regulating land-use (Mansilla, 1993). This attempt, however, was not carried out as planned.

The 1985 earthquake in Mexico City was a breakthrough in the study and structure of disaster management. Both the National System of Civil Defence and the National Centre for Disaster Prevention were created as a consequence of this earthquake and its devastating effects.

The 1995-2000 Civil Defence Program was presented by the Federal Executive in 1995 after being prepared by the Ministry of the Interior (coordinator of the National System of Civil Defence, SINAPROC) on the basis of a preliminary proposal prepared by the Civil Defence Advisory and Participatory Commission. This program responds to the guidelines and the objectives of the 1995-2000 National Development Plan, especially with regards to promoting a new federalism (redistributing tasks, responsibilities, capacities, and financing between the three government levels), strengthening states and municipalities, supporting decentralization and regional development, and encouraging social participation.

The program's objective is "consolidating the operating structures and mechanisms of the National System of Civil Defence at the federal, state and municipality levels, by increasing the participation of social and private sectors, so that, with the joint effort of all administration entities and the population itself, the loss of human lives and goods as a result of natural and human disasters is substantially reduced". In order to meet this objective, a strategy was presented that involves strengthening the operation of state-level and municipal-level civil protection units and the internal units of the federal government with the cooperation of educational institutions and the federal government units, as well as the participation of private and social organizations. One of the most important goals is "reviewing the possibility of gradually establishing a fund and an insurance system for providing economic protection to the population that is subject to disasters".

These recent efforts to make Mexicans more aware of disasters and to define a planning authority aimed at damage prevention and mitigation have not had the expected outcome (Delgadillo, 1996). The damages caused by Hurricane Pauline in October 1997 in the states of Guerrero and Oaxaca illustrate the weaknesses of the Program; integrated solutions for disaster prevention are still needed. Mexico has problems in natural disaster mitigation due to its economic situation, its demographic growth, and its people's education, customs, and beliefs, among other factors. Notably, because of poverty, there is at present a high growth of irregular settlements in high-risk, ecologically-degraded zones with no urban services. Here, attempts at positive action must overcome the lack of planning and the fact that the priority for many people is short-term survival rather than thinking about risks from natural hazards. Setting up appropriate disaster handling and civil defence policies is a hard task without integrated solutions that take into account technical aspects (such as the design and construction of safe buildings) along with social and individual behaviour. This holistic approach would be the only way to reduce the loss of human lives. Achieving this stage will be the decisive step towards creating a "culture of disaster" in Mexican society.

Despite the aforementioned obstacles, Mexico has taken some positive steps for reducing the risk of damage and casualties in foreseeable disasters. For example:

- The Popocatépetl volcano has been monitored and studied, and a contingency plan has been set up for the zones subject to damage in case of an eruption; and
- In view of the damage caused by Hurricane Pauline, CENAPRED and the National Water Commission, along with the government of Japan, are launching an integrated project for building protective structures in Acapulco's ravines, for warning the population in case of substantial runoff, for forecasting the effects of hurricanes, and for analyzing social behaviour.

Both projects show that important steps towards disaster prevention and mitigation are being taken in Mexico.

(5) How Human Activity Contributes Towards Natural Disasters:

As mentioned in section 4, humanity invests enormous resources in order to reduce society's vulnerability to natural disasters. Section 3 illustrated that in North America these efforts have been successful in saving lives and preventing injuries–though perhaps not so in Mexico–yet the efforts at reducing the economic impacts of natural hazards in all three countries have not been entirely effective. In some situations, the magnitude of a natural disaster is largely a result of society's own making. Unfortunately, because of competing social or policy interests, lack of knowledge or resources, short-term thinking, or false beliefs, the human activities highlighted in the bottom box of Figure 3 can result in greater rather than reduced vulnerability. Generally, society has protected itself from smaller and more frequent events while often accumulating negative credit for larger and rarer events, i.e. society is creating the potential for increased catastrophic losses in the future.

How has this situation arisen? Disasters occur not only because nature has created an extreme event, but also because society has allowed itself to be vulnerable. Providing absolute protection against all possible future events is virtually impossible, and it is certainly not cost-effective to try; however, by implementing, as Gilbert White would say, "wise use" (i.e. ensuring that the cumulative costs paid do not exceed the benefits gained) an excessive price for damage by natural disasters can be avoided.

Canada, the U.S., and Mexico, have all suffered from short-term environmental thinking which permits unsustainable environmental projects and activities that exacerbate the effects of natural disasters on humanity. For example, widespread deforestation removes a watershed's ability to soak up rainfall, thus causing floods far downstream during heavy rains. Engineering waterways to make them more navigable often creates deeper and straighter channels which allow flash floods to move faster and in greater volumes. Additionally, if projected sea level rises due to climate change occur, storms and flooding along coastal areas will become much worse.

False beliefs (myths about, and poor perceptions of, nature's activities) often contribute to, or are responsible for, social characteristics impacting the effects of natural disasters. For example, in the past, many people believed that severe thunderstorms had a divine origin while others attributed them to evil Satanic spirits. When severe storms did threaten early Americans and Europeans, one of their responses was to go to church, where it was believed God might protect them. Unfortunately, munitions were commonly stored in churches and because of their height, churches were more likely to be struck by lightning than many surrounding places. The belief in divine protection from storms surely resulted in many unnecessary deaths.

Perceptions can increase vulnerability in subtle ways, as illustrated in Figure 8. More extreme events have larger return periods (i.e. they occur more rarely), which is illustrated by increasing values along the X-axis. The impact of these events increases with return period, that is society is more vulnerable to rarer events of greater magnitude. The dotted line (#1) depicts a situation where society has not mitigated the hazard, and is exposed to it at all levels of magnitude. Therefore the vulnerability of society and the resulting impact of the event increases with the magnitude of the event. Where mitigation has occurred (for example, dams or levees built to protect society against the 100-year flood, illustrated by the dashed line #2), vulnerability remains relatively low up to that return period; however, if increased development has occurred in, for example, flood-prone areas, then vulnerability may well have increased for events with return periods longer than 100 years, hence the large increase after the 100-year event. The areas of 'A' and 'B' in the figure represent the changes in vulnerability between the natural system and the protected system. Hopefully the area of A is greater than that of B, or the overall vulnerability of society has increased. Unfortunately, the area of B often grows quite large for several reasons, most notably: (1) society is often not very good at incorporating high risk, low probability events into cost–benefit analyses; (2) when people perceive that their risks have been reduced as a result of technology, they will tend to act in riskier ways if voluntary actions are available to them (Wilde, 1994). Since people tend to develop a false sense of security, they will tend to develop high risk areas.

(A) The Myths Which Influence Society's Reaction to Natural Disasters Today: Case Studies in Mexico

In Mexico, for thousands of years, natural phenomena have been explained by means of myths and coped with by means of religious ceremonies. In ancient Mexico, a close relationship existed between natural disasters and religious beliefs. Most pre-Hispanic indigenous groups of Mexico (such as the Mayans, the Lacandons, the Mixtecs, the Zapotecs, the Nahuas, the Tarascos, the Totonacs, and the Otomis) considered natural hazards to be the behaviour of one or more gods. Many of these beliefs persist today in some regions.

The arrival of Spanish conquistadores led to a synthesis between indigenous beliefs and catholic religion. Many ancient gods were then substituted by saints, Jesus Christ, Virgin Mary, or other Catholic symbols. Thus, for thunderstorms, many people would invoke Saint Isidro (equivalent to the Zapotecs' god *Cocijo*) or Saint John the Baptist (equivalent to the Totonacs' god *Old Thunder*), and for earthquakes, processions would be made for Saint Joseph.

Peasant culture and religion survive up to the present day in parts of Mexican society. This situation is the case for the volcanoes Popocatépetl (also called San Gregorio, The Old Man, San Juan, or Nicolás Antonio) and nearby Iztaccíhuatl (also called Rosita, Manuelita, or Mother Mountain): they are considered by the inhabitants of their slopes as sacred mountains and as people (the former is male and the latter female). These volcanoes were sacred before the conquest. *Tláloc*, a god of rain and the patron of peasants, was believed to inhabit the former, and his wife *Chalchiuhtlicue*, the latter. Sacrifices and ceremonies were made to honour them. Nowadays, they are paid tribute, so that they provide adequate rain and good crops. There is in every community a *granicero* or *tiempero* ("weatherman") in charge of organizing these ceremonies. They are in charge of making spells to prevent storm damage and to frighten away threatening or hailstorm clouds and in addition, they must satisfy the volcanoes' needs, to keep the mountains contented. They are highly respected and have a high position in the community's hierarchy, for they were actually elected "from up there": they were given as a gift by the volcanoes by means of a lightning stroke (Glockner, 1996).

During the Popocatépetl ash eruption of December 1994, several interesting phenomena occurred in peasant communities: when government officials exhorted the population to evacuate the villages, many people stayed to guard and care for their animals and homes. The local *graniceros* stayed as well, for Gregorio had not given them any warning. A few days afterwards, some of them had dreams where they were told by the volcano that there was no need to leave the villages. The belief by local inhabitants of whether or not an eruption will occur is based on faith, and a number of explanations based on myths were cited for the eruption. Some said that the volcano had appeared as a human being; others said that he was angry because the mountain had been drilled by the Japanese; and others said that he had complained about burns to his feet, which were associated with the burning of pastureland and the ensuing forest fires (Glockner, 1996).

Since the 1994 eruption the "granizero" has been involved with Civil Defence of his municipality and with geologist and geophysical experts. Though people continue making religious ceremonies in Popocatepetl's honour, they are also more aware of the hazard in which they live.

The case of Popocatépetl volcano is one example of the link between natural phenomena and social beliefs in Mexico. Studying how these old myths still have an influence on indigenous communities is very important, so that ways are found to teach them how to respond in appropriate ways, without sacrificing their ancient culture. Steps in this direction are examining to what extent the social response to natural disasters is based on the accumulation of experiences, and understanding the ways in which the traditional beliefs influence the collective explanation of natural disasters.

(B) Myths/Perceptions Which Influence Society's Reaction to Natural Disasters Today: General Discussion

Canadians, Americans, and Mexicans continue to be influenced by various forms and degrees of myths in their reaction to natural disasters. The behaviour of victims during disasters, for example, suffers from many myths. Fischer III (1994) describes a prevalent "disaster mythology":

> *The disaster mythology includes a belief in looting, price gouging, panic flight, contagious spread of deviant selfish behaviour, the necessity of martial law, psychological dependency and disaster shock. Shelters are seen as overused and evacuations are seen as likely to contribute to panic flight. It is also assumed that the death, injury and damage estimates* [mainly from the media] *are essentially accurate. The research literature has established that these beliefs are largely myth, thus they are collectively characterized as the* disaster mythology... *Well designed disaster plans attempt to counter the public's belief in the mythology and respond to the actual behavioural response their community will encounter during a disaster.*

People affected by disasters habitually have erroneous views about the specific disaster event in which they are involved. The accompanying box lists some popular misconceptions about tornadoes. Tsunamis are also subject to myths. Clague (1997) explains that a tsunami is not a single, very large wave that breaks onto the shore, as commonly believed, but consists of a series of waves separated by several minutes or more than an hour. These waves are not breakers, but are usually turbulent, onrushing surges with the largest one generally being the second or third wave. The term "tidal wave" is a misnomer, as tsunamis are caused by earthquakes, landslides, or volcanic eruptions under the sea rather than by a tidal phenomenon.

> **Myths about tornadoes (Grazulis, 1996)**
> - Tornadoes always follow rivers.
> - Tornadoes are always preceded by hail.
> - Cars can be carried over tall buildings.
> - Mobile homes attract tornadoes.
> - Opening windows will save a roof or a home from destruction.
> - A tornado will suck water from a swimming pool.
> - The southwest corner of a basement is the safest location.
> - A tornado can be outrun by driving a car (it can work occasionally, but it is very risky).

Entertainment media can perpetuate myths or ferment poor behaviour, as illustrated by forest fires in the U.S. Nash (1985) contends that Walt Disney's film Bambi, released in 1942, "did more to shape American attitudes toward fire in wilderness ecosystems than all the scientific papers ever published on the subject" and helped birth Smokey Bear, "one of the most potent advertising symbols in American history" for publicizing the currently rejected perception that fire is bad for ecosystems. Williams (1995) lambastes the doctrine of fire suppression, and although he identifies the roots of the American aversion to forest fires as being in the 19th century, he suggests that one of the main culprits influencing attitudes has been Smokey Bear who "along with the flames...was extinguishing ecosystems".

Such mistaken perceptions are very powerful in influencing behaviour and reactions to natural disasters. Risk perception is affected by a large number of complex factors, some of which tend to increase perception of risk and some of which tend to decrease perception of risk. The following factors (modified from Smith (1996)) are thought to increase risk perception:

- Involuntary hazard (e.g. tornadoes, as compared to a voluntary hazard such as driving a car).
- Immediate impact (e.g. lightning, as compared to a delayed impact such as that which occurs from drought).
- Direct impact (e.g. earthquakes, as compared to indirect impacts such as those from drought).
- Dread (e.g. cancer as compared to a slippery wet road).
- Many fatalities per event.
- Deaths clustered in space and/or time.
- Identifiable victims (victims from a tornado event, as compared to statistical victims, such as those from cigarette smoking).
- Processes not well understood.
- Uncontrollable hazard (e.g. volcanoes, as compared to something more controllable, such as seasonal river flooding).
- Unfamiliar or rare hazard (e.g. tsunamis, as compared to a more common hazard such as rain storms).
- Much media attention (e.g. deaths from tornadoes, compared to deaths from a hazard which does not get much coverage, such as lightning).

Generally, the public is willing to accept voluntary risks (e.g. driving a car) that are about 1,000 times the magnitude (Raphael, 1986) of involuntary ones (e.g. getting hit by lightning). Natural disasters usually fall into the involuntary category, although there is a certain degree of choice in where one lives. Geographical location and history certainly affect the response to and impacts of some of these factors. For example, although few people die from floods and earthquakes in Canada or the U.S., the toll is greater in Mexico and hundreds of thousands–and sometimes even millions–have died in areas such as Bangladesh and China. Similarly, many Mexicans and Americans should feel more concern about volcanoes than most Canadians.

Very rare, high-consequence events–such as the January 1998 Ice Storm in eastern Canada, Hurricane Andrew in 1992, Hurricane Gilbert in 1988, and the 1925 Tri-State Tornado–are often ignored during personal risk analyses (unless a similar event has been directly experienced), assuming that people actually do such risk analyses (after Wilde, 1994). There is always the possibility of a rarer, more high-consequence event than has occurred previously <u>or than is remembered</u>, leading to errors in extrapolating potential impacts during a risk analysis.

Experts and the manner in which they communicate risk analyses and warnings have interesting impacts upon people's responses. People tend to reinterpret warnings in non-threatening ways if expert information is perceived as being vague or uncertain (Raphael, 1986), suggesting that severe weather watches may not lead to the type of vigilance hoped for by weather services, since weather watches are less certain compared to weather warnings. People have adverse reactions to announcements containing uncertainty or probabilistic notions, and often assume that an expert's or scientist's prediction is 100% accurate. As John Ewert from the United States Geological Survey (USGS) stated, "People don't want probabilities, they want black and white, yes/no" (WGBH, 1992). If the expert or scientist happens to be wrong once, then criticism and disbelief are aimed at future predictions.

The continual jokes and criticisms of weather forecasters attest to such attitudes. Another noteworthy 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). People often assume that experts and scientists do or should completely understand nature's behaviour and can provide all the answers. There is often a misplaced faith in the extent of society's knowledge and capabilities when it comes to natural disasters.

Misplaced faith and expectations are also commonly placed on technology. Where people feel protected because of their belief in technology (e.g. dams, 'earthquake-proof' structures), they will tend to act in increasingly riskier ways if voluntary actions are available to them, until their perceived level of risk rises to what they feel is an unacceptable level (Wilde, 1994). Their "perceived level" may actually grossly underestimate their actual risk level due to a misplaced faith in technology to protect them. This tendency accounts for a great deal of increased development in flood plains: "...the extent of (flood) loss has not infrequently been increased through a false assessment of the risk circumstances or in the pursuit of profit" (Munich Re, 1997).

One problem with placing too much faith in technology is that nature will always provide an event greater than the specified design criteria, at some point in the future. A levee may protect a community from a 100-year return period flood, but nature will certainly exceed that event at some time. The "some time" could be tomorrow. Another problem with technology is that it sometimes fails–after all, it is designed by human beings. Mistakes can be made in design, materials, or construction. A built structure is not an absolute protector. The cumulative effect of society's decisions over the long-term can be increased, rather than decreased, vulnerability.

(6) Global Change and Sustainability

Natural disasters have evolved and continue to evolve. They have become more global and systemic due to the interconnectedness of society. Because society relies on technology and is very interconnected, in many ways today's society is more vulnerable than previous generations. In industrialized nations, deaths due to natural disasters have decreased whereas the socioeconomic impacts have increased; in lesser industrialized nations, both deaths and socioeconomic impacts continue to be significant. In recent decades, the number and cost of disasters has increased dramatically, far more than can be accounted for simply by changes in population and wealth.

Natural disasters, however, enable society to identify the mistakes that have created its vulnerability, and therefore, potentially, to rectify them. When severe damage occurs due to a natural disaster, the event can become a turning point in the development of disaster prevention and management policies.

What is the relationship between natural disasters and sustainability? When society or a population is so vulnerable that the frequency and severity of natural disasters threatens its ability to recover, or the cost is exorbitant, then sustainability is threatened. History has provided important lessons. Great disasters can dramatically alter a society, disasters have been increasing in recent decades, and many disasters have occurred because of society's own actions. Though nature sets the stage, society moulds its own vulnerability and therefore is a key player in manufacturing natural disasters.

In one sense, coping with natural disasters is like a game: the Natural Disasters Game. Once the rules are known, a potentially winning strategy can be devised. The chances of good or bad events occurring are usually fairly well-known, and tradeoffs can be calculated with some level of comfort.

But what if after playing the Natural Disasters Game for some time, it turned out that the rules were about to change? Additionally, what if exactly when and where the rules were going to change, and precisely what the new rules would be, were not well known? Even worse, the new set of rules would not be constant, but would evolve over time, and not planning for them could result in 'losing' the game. These effects on the Natural Disaster Game arise from global change. Fortunately, society is not just a passive player, but plays a major role in creating the game's rules.

Global change is a multi-faceted issue, that incorporates issues such as urbanization; increases in and migration of populations; more frequent and severe extreme weather events due to climate change; and changes in wealth and land-use. Change is easy to perceive as being slow, but in fact, the human population has increased from a fairly steady few hundred million over thousands of years, to more than 5 billion over the past 150 years, with huge impacts on society, culture, the land, the oceans, the atmosphere, and ecosystems. Global change is not something that will happen in the future; it has been happening for generations.

One important facet of global change relates to the climate. How do climate and sustainability relate to each other? The spatial scales of climate range from local to global, as do those of sustainability. As a result, local hazards need to be well-understood in order to foster sustainable development. Traditionally, the temporal scales of climate have been very long-term, but these scales are being reevaluated downward to decadal time-frames. The temporal scale of sustainable development is on the order of a generation or more. Whereas historically there has been an assumed mismatch in temporal scales, these scales appear to be merging. As these temporal scales merge, a new set of assumptions is required in terms of how climate and sustainability relate to each other; i.e. rapid climate change must be considered as a potentially important factor in sustainable hazards mitigation.

Greenhouse gases (gases such as water vapour and carbon dioxide that absorb radiation emitted from the earth that would otherwise escape to space) in the atmosphere warm the surface of the earth by 33°C and are one of the most important parts of the climate system. Humanity, as a result of industrial emissions and alteration of the earth's surface (e.g. cutting down forests), is rapidly increasing the concentration of these gases in the atmosphere. Currently, the atmospheric concentration of carbon dioxide far exceeds any value in the past 200,000 years, and is expected to double before the end of the next century. The atmospheric concentrations of other greenhouse gases such as methane are also increasing rapidly. Climate models predict that changes in the atmospheric concentration of greenhouse gases resulting from human activities will soon alter the earth's climate. More frequent extreme events–particularly heat waves, severe thunderstorms, floods, and droughts–and a rising sea level seem likely to be a part of this new climate, with important consequences for society. Even relatively small changes in averages can result in much more frequent extremes (White and Etkin, 1998). With reference to Figure 8, more frequent extremes will increase the area of 'B' and decrease the area of 'A', thereby making the world less sustainable. This issue can also be understood with reference to Figure 3, except that in the Human Activity box, global change would substitute the response/mitigation/preparedness cycle. The effect of global change, unlike mitigation, is to increase vulnerability.

A great deal of uncertainty, though, is associated with climate change, with respect to magnitudes, rates, and regional characteristics. This uncertainty has important implications in terms of adaptation strategies. Sustainability relates to designing a system where the current and future losses incurred from natural hazards do not exceed the value gained through use. Thus, the issue of having an adapted society (i.e. mitigation has rendered the costs of current hazards affordable) as compared to having an adaptable society (society can easily accommodate itself to changing risks in the future) becomes critical within the context of climate change.

Since natural disaster conditions in the future are expected to be different in unclear but significant (and probably more severe) ways, a sustainable society needs to place greater emphasis on being flexible and adaptable. The larger or the more uncertain the change, the more important adaptability becomes. Understanding how well society is adapted is important, and resilience to the negative impacts resulting from climate change can be tested by evaluating vulnerability to disasters currently experienced. By increasing resilience to the disasters we experience now, adaptability to more frequent disasters in the future is improved and a more sustainable society is developed.

Mileti *et al.* (1998), in a new research assessment of natural hazards, offers a vision of sustainable communities and disaster reduction. This vision of sustainable hazard mitigation incorporates the five principles of environmental quality, quality of life, disaster resiliency, economic vitality, and intra- and inter-generational equity. Much progress has been made in North America towards vulnerability reduction, "but our national path [U.S.] is leading us toward natural and related technological catastrophes...larger than any we have ever experienced...Our past actions to deal with risk have done more to postpone losses into the future than to eliminate them" (Mileti *et al.*, 1998). Albert Einstein once said "We can't solve problems by using the same kind of thinking we used when we created them"; solving problems related to natural disasters requires different thinking and an interdisciplinary approach involving such disparate fields as the physical sciences (e.g. meteorology, geology, forestry), the social sciences (e.g. psychology, political science, economics), and engineering. Moving towards substantial disaster-resistant communities requires holistic problem-solving, cooperative and integrated approaches, and long-term thinking.

(7) Summary and Concluding Statement

Disasters ruin lives and kill people. North Americans have a long history of disasters, and through a continuous cycle of response and recovery, mitigation and preparedness we have endeavoured to reduce our risk and therefore the disasters that we experience. Recent experience, however, suggests that disasters are becoming more frequent and expensive than they were in the past (it seems that, at times, our efforts to mitigate disasters ultimately lead to greater ones!) in spite of our advanced technology - and one must wonder how this can be? Our understanding of disasters now reflects to a much greater degree the importance of the social factors that lead to the unsafe conditions. Natural events are the triggers that create disasters, but they are just as much a function of society as nature.

Global change, both in the natural and human spheres, seem likely to exacerbate disasters in the future, and it behoves us to think carefully about how we create vulnerability by our adaptive decisions. We live in a hazardous world, and some disasters are inevitable. Either a fatalistic or a narrow technocratic world-view destines us to a path of ever worsening disasters. A course of sustainable hazards mitigation, more effective than what we have done before, lies before us. We just need to step upon the broader road of environmental and social sustainability.

(8) References

Alejandro, N. 1987. Terremotos, la ciencia desde México/34, Fondo de Cultura Económica, Federal District, Mexico.

Allen, D.E. 1992. "A design basis tornado: Discussion". Canadian Journal of Civil Engineering, vol. 19, p.361.

AMIS. 1997. "Siniestralidad. Huracán Pauline.", Asociación Mexicana de Instituciones de Seguros, A.C. (AMIS), Dirección Técnica de daños, México, diciembre 1997.

AMIS. 1985. "Datos relevantes del terremoto del 19 de septiembre de 1985", Asociación Mexicana de Instituciones de Seguros A.C. (AMIS), México.

Andrews, J. 1993. Flooding, Canada Water Book. Ministry of Supply and Services Canada, Environment Canada, Cat. No. En 37-96/1993E.

Arnold, C. 1995. "Northridge earthquake of January 17, 1994: reconnaissance report, Volume 1 -- architectural background". Earthquake Spectra, vol. 11, supp. C, April, pp. 443-452, EERI Publication 95-03. Abstract reprinted by http://www.eerc.berkeley.edu (accessed December 31, 1997).

Blaikei, P., Cannon, T., Davis, I. and Wisner, B. 1994. At Risk, Natural Hazards, People's Vulnerability and Disasters.

Bolt, B. 1993. Earthquakes. W.H. Freeman and Company, U.S.A.

Bolt B. 1986. "Terremotos", Muy Interesante, Biblioteca de Divulgación, Orbis, Segunda Edición, Barcelona, España.

Botkin, D.B. and E.A. Keller. 1995. Environmental Science, Wiley and Sons. New York, New York.

Bove, M.C. 1997. Impacts Of ENSO On United States Tornadic Activity, Center For Ocean-Atmospheric Prediction Studies, The Florida State University. http://www.coaps.fsu.edu/~bove/tornado/main.html

Bowyer, P. 1997. "Hurricanes - Canadian Style". Section III in Employers Reinsurance Corporation, Hail, Tornadoes & Hurricanes, seminar at the Toronto Hilton in Toronto, Ontario on September 25, 1997.

Brown, W.D., Moin, S.M.A. and Nicolson. M. 1997. "A Comparison of Flooding in Michigan and Ontairo: 'Soft' Data to Support 'Soft' Water Management Approaches. Canadian Water Resources Journal, Vol. 22, no. 2, pp. 125-139.

Brun, S.E. 1997. "Atmospheric, Hydrologic and Geophysical Hazards". Pages 15-65 in EARG (Environment Canada) and IES (University of Toronto), Coping With Natural Hazards in Canada: Scientific, Government and Insurance Industry Perspectives, June 1997.

Burton, Ian, R. Kates, and G.F. White. 1993. The Environment as Hazard, 2nd Edition. The Guilford Press, New York, NY. 290 pp.

Burby, Raymond J., B.A. Cigler, S.P. French, E.J. Kaiser, J.Kartez, D. Roenigk, D. Weist, and D. Whittington. 1991. Sharing Environmental Risks: How to Control Governments' Losses in Natural Disasters. Westview Press, Boulder, CO, 280 pp.

Byrnes, M. 1998. "El Niño's nasty streak had weather watchers worried". The Toronto Star from Reuters, January 2, 1998.

Canadian National Report - IDNDR. 1994. "Report to the World Conference on Natural Disaster Reduction", Yokohama, Japan.

Changnon, S.A., D. Changnon, E.R. Fosse, D.C. Hoganson, R.J. Roth Sr., and J.M. Totsch. 1997. "Effects of Recent Weather Extremes on the Insurance Industry: Major Implications for the Atmospheric Sciences". Bulletin of the American Meteorological Society, vol. 78, no. 3, March 1997, pp. 425-435.

Clague, J.J. 1997. "Tsunamis" (draft). Manuscript prepared for the Geological Survey of Canada's National Geological Hazard Synthesis Project.

Coch, N.K. 1995. Geohazards: natural and human. Prentice-Hall, New Jersey.

"Codice 90, Resultados Definitivos". 1990. XI General Census of Population and Housings, INEGI.

Cotton, W.R. and Pielke, R.A. 1995. Human Impacts on Weather and Climate. Cambridge Univ. Press, Cambridge, NY

Delgadillo, M.J. 1996. Desastres Naturales: Aspectos sociales para su prevención, y tratamiento en México, Instituto de Investigaciónes Económicas, UNAM, Federal District, Mexico.

Drabek, Thomas E., and Gerard J. Hoetmer (eds.). 1991. Emergency Management: Principles and Practice for Local Government. International City Management Association, Washington, D.C. 416 pp.

Environment Canada. 1997. "The Impact of Storm 96". Produced by Pan Pacific Communications Inc., February 1997.

EPC. 1998. Tri-Lateral Project on Natural Disasters. Emergency Preparedness Canada, Ottawa.

Etkin, D. 1997. "The Social and Economic Impact of Hydrometeorological Hazards and Disasters: a Preliminary Inventory". Pages 74-110 in EARG (Environment Canada) and IES (University of Toronto), Coping With Natural Hazards in Canada: Scientific, Government and Insurance Industry Perspectives, June 1997.

Etkin, D. and A. Maarouf. 1995. "An Overview of Atmospheric Natural Hazards in Canada". Pages 1-63 to 1-92 in D. Etkin (ed.), Proceedings of a Tri-Lateral Workshop on Natural Hazards, Sam

Jakes Inn, Merrickville, Canada, Feb. 11-14, 1995.

Etkin, D.A. and Myers, M.F. 1999. "Thunderstorms in a Social Context." In R. A. Pielke, Jr. and R. A. Pielke, Sr. (eds.) 1999. 'Storms', Volume XX, in Definitive Series on Hazards and Disasters, A. Z. Keller (series editor), Routledge Press: London. In Press.

Evans, S.G. 1997. "Landslide Disasters in Canada 1840-1996". Unpublished data, Geological Survey of Canada.

Felknor, P.S. 1992. The Tri-State Tornado. Iowa State University Press, Ames, Iowa.

FEMA. 1997. The Federal Emergency Management Agency of the U.S., http://www.fema.gov/library/stats.pdf on December 18, 1997.

FEMA. c. 1997. "Report on Costs and Benefits of Natural Hazard Mitigation". Contract Number 132 with Woodward-Clyde Federal Services, Gaithersburg, Maryland.

Fischer III, H.W. 1994. Response to Disaster: fact versus fiction & its perpetuation, the sociology of disaster. University Press of America, Maryland/England.

Friedman, D.G. 1992. "What are the Likely Categories of Loss and Damage? Presentation of Don G. Friedman" pp. 49-76 in National Research Council (Committee on Earthquake Engineering), 1992, The Economic Consequences of a Catastrophic Earthquake, Proceedings of a Forum, August 1 & 2, 1990, National Academy Press, Washington D.C.

García A., V. 1994, "Estudios históricos sobre desastres naturales en México", Centro de Investigaciones y Estudios Superiores en Antropología Social (CIESAS), México.

Glockner J. 1996, "Los Volcanes Sagrados. Mitos y rituales en el Popocatépetl y la Izatccíhuatl", Grijalbo, México, D.F.

González T., Y. 1991, "Diccionario de Mitología y Religión de Mesoamérica, Ediciones Larousse, México.

Gray, J. and T.T. Ha. 1997. "Tragedy yields promises, grief: Deadly Route". The Globe and Mail, October 15, 1997, pp. A1 and A6.

Grazulis, T.P. 1996. Significant Tornadoes, 1680-1991: Environmental Films, St. Johnsbury, Vermont, 1326 pp.

Haas, J. E. 1974. Sociological aspects of weather modification, pp. 787-812 in W. H. Hess (ed.) Weather and Climate Modification (John Wiley & Sons: New York).

IJC. 1997. Red River Flooding: Short Term Measures, Interim Report of the International Red River Basin Task Force to the International Joint Commission, Ottawa, Washington.

"Informe General del Huracán Pauline", Sistema Nacional de Protección Civil, Secretaría de Gobernación, México, octubre 1997.

"Insurance Issues". 1996. "Hazards Assessment Update" in the Natural Hazards Observer, May 1996, p. 6.

Jamieson, B. 1997. "Snow avalanche hazards in Canada" (draft, November 8, 1997). Manuscript prepared for the Geological Survey of Canada's National Geological Hazard Synthesis Project.

Jones, R.L. 1997. "Canadian Disasters–An Historical Survey". An update (October 21, 1997) of a paper by the same title published in C.M.O.S. Newsletter, vol. 20, no. 5, October 1992, pp. 10-14. Unpublished.

Klebs, R.W. with R.T. Sylves. 1996. "The Northridge Earthquake: Memoir of a FEMA Inspector", Chapter VI, pp. 126-160 in R.T. Sylves and W.L. Waugh Jr., Disaster Management in the U.S. and Canada, 2nd ed., Charles C. Thomas, Publisher Ltd., Springfield, Illinois.

Kovacs, P. 1997. Personal communication from the Insurance Bureau of Canada.

Krafft, M. 1993. Volcanoes: Fire From the Earth. Harry N. Abrams, New York and Thames and Hudson, London.

Kuribayashi, E, M. Kawamura, H. Zhang, and Y. Matsui. 1996. "A comparative study on typical measures of earthquake preparedness in local governments between Japan and the USA: lessons from the disaster of Japan's earthquake in Kobe on 17 January 1995", Chapter 7, pp. 111-145 in C.A. Brebbia (ed.), The Kobe Earthquake: Geodynamical Aspects, Computational Mechanics Publications, Southampton/Boston.

Lambright, W. Henry, and Stanley A. Changnon, Jr. 1989. "Arresting Technology: Government, Scientists, and Weather Modification," Science, Technology, & Human Values 14(4):340-359.

Lawford, R.G., T.D. Prowse, W.D. Hogg, A.A. Warkentin, and P.J. Pilon. 1995. "Hydrometeorological Aspects of Flood Hazards in Canada". Atmosphere-Ocean, vol. 33, no. 2, June, pp. 303-328.

Lekkas, E., H. Kranis, M. Leounakis, and P. Stylianos. 1996. "The seismotectonic setting of the Kobe area (Japan) - the concomitant geodynamic phenomena of the Hanshin Earthquake (17 January 1995)", Chapter 1, pp. 1-16 in C.A. Brebbia (ed.), The Kobe Earthquake: Geodynamical Aspects, Computational Mechanics Publications, Southampton/Boston.

Levy, M. and M. Salvadori. 1995. Why the Earth Quakes: The Story of Earthquakes and Volcanoes. W.W. Norton & Company, U.S.A.

Lisk, D.M. 1997. http://www.d-n-a.net/users/dnetGOjg/Disasters.htm on December 18, 1997.

Liverman Diana M. 1996, "Capítulo 6. Variación Ambiental y Transformación Económica: Cambios de la vulnerabilidad a amenazas naturales en el México Rural", in "Desastres. Modelo para armar. Colección de piezas de un rompecabezas social", Elizabeth Mansilla, La Red, Perú.

López V., S. 1961, "Fundamentos de la modificación del Tiempo (siembra de nubes), tesis de licenciatura en Física, UNAM, julio 1961.

Lowe, A.B. and G.A. McKay. 1962. The Tornadoes of Western Canada. Meteorological Branch, Department of Transport, Government of Canada, Cat. No. T56-2462.

Luhr, J.F. and T. Simkin (eds.). 1993. Parícutin: The Volcano Born in a Mexican Cornfield. Smithsonian Institute, Geoscience Press, Phoenix, Arizona.

Maloney, W.E. 1976. The Great Disasters. Grosset & Dunlap, New York.

Mansilla, E. 1993. "Desastres y Desarrollo en México", in "Desastres & Sociedad", Revista Semestral de la Red de Estudios Sociales en Prevención de Desastres en América Latina (LA RED), Año 1, No 1, Lima, Perú, edited in Colombia, Julio-Diciembre 1993.

McCulloch, J. (chair). 1994. Discussion, pp. 3-69 to 3-91, of E. Collier "Modelling and Risks in the Insurance Industry", pp. 3-1 to 3-6 in D. Etkin and J. McCulloch, Proceedings of a Workshop on Improving Responses to Atmospheric Extremes: The Role of Insurance and Compensation, Toronto, Ontario, Oct. 3-4, 1994.

McFarlane, R.C. 1985. "Snow Avalanche Impacts and Management in Canada". Ph.D. Thesis, University of Waterloo, Waterloo, Canada. Referenced in Jamieson (1997).

Meli, R. 1998. Damage in Acapulco by Hurricane Pauline. Natural Hazards Observer, Vol. XXII, No. 4, pp.1-2.

Mileti *et al.* 1998 (Forthcoming). Designing Future Disasters: An Assessment and Bolder Course for the Nation. Natural Hazards Research and Applications Information Center, Joseph Henry Press, Washington, D.C.

Mileti, D.S. and J. Sorensen. 1990. Communication of Emergency Public Warnings: A Social Science Perspective and State-of-the-Art Assessment. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Munich Re: 1997a. Annual Review of Natural Catastrophes 1996.

Munich Re: 1997b. Flooding and Insurance. 79 pp.

Musa, T. 1998. "Tanker explosion claims 120 lives". The Globe and Mail from Reuters News Agency, February 16, 1998, p. A10.

Nash, J.R. 1976. Darkest Hours. Nelson-Hall, U.S.A.

Nash, R. 1985. "Sorry, Bambi, but man must enter the forest: Perspectives on the old wilderness and the new". Section 7, "Banquet Address", pp. 264-268 in J.E. Lotan, B.M. Kilgore, W.C. Fischer, R.W. Mutch (technical coordinators), Proceedings--symposium and workshop on wilderness fire, 1983 November 15-18, Missoula MT, General Technical Report INT-182 from U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

National Geographic. 1997. Our Restless Earth. National Geographic Society, U.S.A.

National Geographic. 1986. Nature on the Rampage: Our Violent Earth. National Geographic Society, U.S.A.

NOAA. 1997. "Billion Dollar U.S. Weather Disasters 1980-1997". National Climatic Data Center, http://www.ncdc.noaa.gov/ol/reports/billionz.html on December 15, 1997.

NRCC. 1995. The National Building Code of Canada 1995, 11th ed. Issued by the Canadian Commission on Building and Fire Codes and the National Research Council of Canada. Ottawa, Ontario, NRCC 38726.

Pearce, L. 1994. "The Vulnerability of Society to Atmospheric Hazards", pp. 2-12 to 2-28 in D. Etkin and J. McCulloch, Proceedings of a Workshop on Improving Responses to Atmospheric Extremes: The Role of Insurance and Compensation, Toronto, Ontario, Oct. 3-4, 1994.

Pérez, C. 1969. "19 años de Estimulación de lluvias en las cuencas de Necaxa (Pue.) y Lerma (Mex.), Compañía de Luz y Fuerza del Centro, S.A., Informe 1948-1968, México, junio 1969.

Phillips, D. 1990. The Climates of Canada. Environment Canada, Ministry of Supply and Services, Catalogue No. En56-1/1990E.

Pielke, R. Jr. and Landsea, C.W. 1997. "Normalized Hurricane Damages in the United States: 1925-1995" http://www.dir.ucar.edu/esig/HP_roger/hurr_norm.html

Pindera, G. 1997. "Red River Dance". Canadian Geographic, vol. 117, no. 4, pp. 52-62.

"Poder Ejecutivo Federal. Programa de Protección Civil 1995-2000", Secretaría de Gobernación, México, 1996.

"Programa de Desarrollo Humano, Tema: Agua", Comisión Nacional del Agua (CNA), México, 1994.

"Prontuario de Contingencias en el Siglo XX Mexicano", Dirección General de Protección Civil, Subsecretaría de Protección Civil y de Prevención y Readaptación Social. Secretaría de Gobernación, 1994.

Quarantelli, E.L. 1989. "Human behavior in the Mexican City earthquake: some implications from basic themes in the survey findings". Preliminary paper #137, Disaster Research Center, University of Delaware, U.S.A.

Raphael, B. 1986. When Disaster Strikes: How Individuals and Communities Cope with Catastrophe. Basic Books, Inc., New York, New York. 342 pp.

Rappaport, E.N. and Fernández-Partagás, J.J. 1997. "History of the Deadliest Atlantic Tropical Cyclones Since the Discovery of the New World". Pages 93-108 in H.F. Diaz and R.S. Pulwarty (eds.), Hurricanes: Climate and Socioeconomic Impacts, Springer-Verlag Berlin Heidelberg, Germany.

"'Reckless' jet accused in ski car plunge". 1998. The Toronto Star from Reuters-AP, February 5, 1998, p. A2

Renick, J. 1997. "Hailstorms and Hail Suppression: Alberta's Unique Approach". Section V in Employers Reinsurance Corporation, Hail, Tornadoes & Hurricanes, seminar at the Toronto Hilton in Toronto, Ontario on September 25, 1997.

Rosengaus M., M., Sánchez-Sesma, J. 1990. "Gilbert: ejemplo de huracanes de gran intensidad", Ingeniería Hidráulica en México magazzine, México, enero-abril.

Ross, A. 1997. Kyoto and Beyond. Canadian Insurance, pp. 10, 19, 26.

"Sismos de 1985, Control de Edificaciones, México, D.F. 1985-1988". Federal District Department, Ministry of Construction, Building Control Coordination.

Smith, K. 1996. Environmental Hazards: Assessing Risk and Reducing Disaster, 2nd ed. Routledge, London/USA/Canada.

Sorkin, A.L. 1982. Economic Aspects of Natural Hazards. D.C. Heath and Company, Toronto/Lexington, Massachusetts.

Statistics Canada. 1994. Human Activity and the Environment. Minister of Industry, Science and Technology, Cat. No. 11-509E.

"Summer flood damage in Poland set at $4-billion". 1997. The Globe and Mail from Reuters News Agency, October 6, 1997.

Swiss Re. 1988. "Statistical appendix". Sigma, No. 1/2, January/February 1988, pp. 13-17. Swiss Reinsurance Company.

Swiss Re Canada. 1996. "Appendix 1: Tables for report year 1995". Sigma, No. 2, pp. 17-38. Swiss Reinsurance Company.

Thompson J. E. 1987. "Historia y Religión de los Mayas", Siglo veintiuno XXI, América Nuestra, México.

Tierney, K. 1995. "Social Aspects of the Northridge earthquake", pp. 255-262 in The Northridge, California Earthquake of 17 January 1994, Special Publication 116, California Division of Mines and Geology, Sacramento. Abstract reprinted by http://www.eerc.berkeley.edu (accessed December 31, 1997).

University of Manitoba 1997. "The Flood of the Century: An International Research Workshop". Sept. 11-12, St. John's College, Winnipeg.

Vázquez C., M. T. 1997. Hurricane and flood tables for the North American Hazards map (México, U.S. and Canada), CENAPRED; Mexico.

Waltham, T. 1978. Catastrophe: The Violent Earth. Crown Publishers, New York.

WGBH Educational Foundation. 1992. "In the Path of a Killer Volcano", from the program NOVA, 60 min. video.

Wheaton, E.E. and L.M. Arthur (eds.). 1992. "Environmental and Economic Impacts of the 1988 Drought: With emphasis on Saskatchewan and Manitoba", Volume 1. SRC (Saskatchewan Research Council) Publication No. E-2330-4-E-89, December 1989, Revised October 1992.

White, R. and Etkin, D. 1998. "Climate Change, Extreme Events And The Canadian Insurance Industry". J. of Natural Hazards, In Press.

Wilde, G.J.S. 1994. Target Risk. PDE Publications, Toronto.

Williams, T. 1995. "Only You Can Postpone Forest Fires". Sierra, July/August, pp. 36-43, 67-69.

World Meteorological Organization. 1995. Programme on Physics and Chemistry of Clouds and Weather Modification Research: Meeting of Experts to Review the Present Status of Hail Suppression, WMP Report No. 26.

TABLES

Table 1. High Risk Zones in Mexico by Phenomenon Type (Data are from 1991)

Locality	Hazard due to type of phenomenon			Population density (people/km^2)
	High seismic risk zones (from 50 to 100%)	High volcanism risk zones	High inland hurricane penetration risk zones	
Aguascalientes				128.7
Baja California			x	23.6
Baja California Sur			x	4.3
Campeche			x	10.3
Coahuila				13.0
Colima	x	x	x	78.5
Chiapas	x	x	x	43.4
Chihuahua				9.8
Distrito Federal	x	x		5495.4
Durango				11.2
Guanajuato	x			130.2
Guerrero	x		x	41.0
Hidalgo				89.9
Jalisco			x	66.1
México	x			457.3
Michoacán	x		x	59.2
Morelos	x	x		241.8
Nayarit	x		x	29.8
Nuevo León				48.0
Oaxaca	x		x	31.6
Puebla	x	x		121.6
Queretaro				89.3
Quintana Roo			x	9.8
San Luis Potosí				31.8
Sinaloa	x		x	37.9
Sonora			x	9.8
Tabasco	x		x	60.9
Tamaulipas			x	28.1
Tlaxcala	x			194.5
Veracruz	x	x	x	85.5
Yucatán			x	34.6
Zacatecas				17.0
National Average				413

Table 2: A Selection of Severe Natural Disasters in Canada

Date	Disaster	Location	Casualties	Economic Impact (real dollars unless otherwise noted)	Source & Other Notes
1885	Smallpox Outbreak	Montréal, Québec	5,864 dead	no information	Jones (1997)
September 9-12, 1775	Hurricane	Grand Banks, Newfoundland	4000 dead	UK£140,000	Nash (1976) Jones (1997) Rappaport and Fernández-Partagás (1997) -the most lethal recorded hurricane in Canada to date
1936	Drought/Heat Wave	entire country	780 dead	CAN$514 million of wheat losses in 1989 dollars	Jones (1997) Phillips (1990) -the longest recorded Canadian heat wave to date
August 24-25, 1873	Hurricane	Nova Scotia	600 dead	no information	Nash (1976)
1881	Forest Fires	near Lake Huron, Ontario	500 dead	no information	Jones (1997) -likely the most lethal forest fire in Canada to date
October 14-16, 1954	Hurricane Hazel	Greater Toronto Area	81 dead	CAN$25 million	Andrews (1993)
April 23, 1903	Landslide	Frank, Alberta	70 dead	no information	Evans (1997) -the most lethal recorded landslide in Canada to date
March 4, 1910	Avalanche	Avalanche Crest, Rogers Pass, B.C.	62 dead	no information	McFarlane (1985) -the most lethal recorded avalanche in Canada to date
1930	Lightning strikes "The John B. King", a freighter carrying explosives, causing an explosion	St. Lawrence River	30 dead	no information	Jones (1997) -Canada's only major lightning disaster recorded to date

June 30, 1912	Tornado	Regina, Saskatchewan	28 dead, hundreds injured	CAN$4 million	Etkin and Maarouf (1995) Lowe and McKay (1962) -the most lethal tornado recorded in Canada to date
November 18, 1929	Tsunami triggered by a submarine landslide which was triggered by an earthquake	south coast of Newfoundland, especially the Burin Peninsula, and Nova Scotia	28 dead	CAN$400,000	Clague (1997) -the most lethal tsunami and the most lethal earthquake-related event recorded in Canada to date
July 31, 1987	Tornado	Edmonton, Alberta	27 dead, 253 injured	CAN$250-300 million in 1989 dollars	Etkin and Maarouf (1995) Phillips (1990)
January 1998	Ice Storm and subsequent cold wave	Eastern Ontario and Southern Québec	at least 25 dead	possible CAN$2-3 billion	contemporary media reports
May 31, 1985	Tornado	southern Ontario	12 dead, 155 injured	CAN$100 million	Etkin and Maarouf (1995)
July 19-21, 1996	Flood	Saguenay region, Québec	7-10 dead	CAN$1 billion	Etkin (1997) Jones (1997)
July 28, 1981	Hail Storm	Calgary, Alberta	2 dead	CAN$100 million in 1989 dollars	Phillips (1990) Statistics Canada (1994)
May 1997	Flood	Red River, southern Manitoba	1-3 dead	approximately CAN$300 million	
July 14, 1987	Flood	Montréal, Québec	1-2 dead	CAN$229 million	Andrews (1993) Swiss Re (1988)
December 22, 1996 to January 3, 1997	Winter Storms	B.C.	at least 1 dead	CAN$200 million	Environment Canada (1997)
Spring 1950	Flood	Red River, southern Manitoba	0-1 dead	CAN$125.5 million in 1957 dollars	Andrews (1993) Phillips (1990)
May 1-30, 1995	Forest Fires	Saskatchewan	no deaths	CAN$122 million	Swiss Re Canada (1996)
September 6, 1995	Flood	Alberta and British Columbia	no deaths	CAN$100 million	Swiss Re Canada (1996)

Summer 1988	Drought/Heat Wave	Prairies and Ontario	no information	CAN$4 billion of export losses CAN$1.8 billion of production losses in 1981 dollars	Phillips (1990) Wheaton and Arthur (1992)
Summers 1979-1980	Drought	Prairies	no information	CAN$2.5 billion in 1989 dollars	Phillips (1990)
1984	Drought/Heat Wave	western provinces	no information	CAN$1 billion	Wheaton and Arthur (1992)
1961	Drought	Prairies	no information	CAN$668 million of wheat losses in 1989 dollars	Phillips (1990)
September 7, 1991	Hail Storm	Calgary, Alberta	no information	CAN$343 million	Brun (1997) Kovacs (1997)
July 1985	Forest Fires	British Columbia	no information	CAN$300 million in 1989 dollars	Phillips (1990)
1993	Flood	Winnipeg, Manitoba	no information	CAN$175 million	Lawford *et al.* (1995)
July 16, 1996	Hail Storm	Calgary, Alberta	no information	CAN$150 million	Brun (1997)
July 16, 1996	Hail Storm	Winnipeg, Manitoba	no information	CAN$105 million	Brun (1997)

Table 3: A Selection of Severe Natural Disasters in the U.S.

Date	Disaster	Location	Casualties	Economic Impact (real value unless otherwise noted)	Source & Other Notes
June to September, 1980	Drought/Heat Wave	Central and Eastern states	estimated 10,000 dead	US$20.0 billion	NOAA (1997)
Summer 1988	Drought/Heat Wave	Central and Eastern states	estimated 5,000 to 10,000 dead	US$40.0 billion	NOAA (1997)
September 8, 1900	Hurricane	Texas	6,000 dead in Galveston; 2,000-6,000 dead outside of Galveston	US$12.9 billion in 1977 dollars	Rappaport and Fernández-Partagás (1997) National Geographic (1986) Sorkin (1982) -the most lethal natural disaster in the U.S. to date
September 10-16, 1928	Hurricane	Florida	2,500 dead	$25 million	Nash (1976)
May 31, 1889	Flash Flood due to a dam break	Johnstown, Pennsylvania	2,209 dead	no information	Maloney (1976) -the most lethal localized flood in the U.S. to date
October 1, 1893	Hurricane	Louisiana	reportedly 2,000 dead	millions of dollars	Nash (1976)
March 18, 1925	Tornado (possibly up to seven tornadoes)	Missouri, Illinois, and Indiana	689 dead, 1980 injured	US$16.532 million	Felknor (1992) -the most lethal tornado(es) known in North America to date
March 1993	Winter Storm	eastern states	estimated 270 dead	US$3.0-6.0 billion	NOAA (1997)
January 1996	Blizzard followed by Floods	Appalachian, Mid-Atlantic, and northeast states	187 dead	US$3.0 billion	NOAA (1997)

April 1, 1946	Tsunami triggered by an earthquake near Unimak Island, Alaska	Hilo, Hawaii	159 dead	millions of dollars	Clague (1997) National Geographic (1997) -one of the most lethal tsunamis in the U.S.
June 18-19, 1972	Hurricane Agnes	states on the Atlantic coast and Pennsylvania	129 dead	US$3.5 billion	Bowyer (1997)
September 21-22, 1989	Hurricane Hugo	North Carolina, South Carolina, Puerto Rico, and the U.S. Virgin Islands	86 dead	US$9 billion	NOAA (1997)
October 17, 1989	Loma Prieta Earthquake	Northern California	63 dead, 3757 injured	US$5.6 billion	Bolt (1993) FEMA (1997)
January 17, 1994	Northridge Earthquake	Southern California	61 dead, 11,700 injured	US$13-$20 billion	Klebs and Sylvies (1996) FEMA (1997)
May 18, 1980	Volcano	Mt. St. Helen's, Washington	60 dead	no information	Krafft (1993)
August 1992	Hurricane Andrew	Florida and Louisiana	58 dead	US$27.0-$30.0 billion	NOAA (1997) FEMA (1997)
Summer 1993	Flood	Central states	48 dead	US$12-20 billion	NOAA (1997) FEMA (1997)
September 1996	Hurricane Fran	North Carolina and Virginia	37 dead	US$5.0 billion	NOAA (1997)
May 1995	Flood	Texas, Oklahoma, Louisiana, and Mississippi	32 dead	US$5.0-6.0 billion	NOAA (1997)
October 1991	Forest Fires	Oakland, California	25 dead	US$1.5-2.0 billion	NOAA (1997) FEMA (1997) -most expensive forest fire in the U.S. to date
Fall 1995 to Summer 1996	Drought	Southern Plains, especially Texas and Oklahoma	no deaths	US$4.0 billion	NOAA (1997)
May 1995	Hail Storm	Dallas/Fort Worth, Texas	no information	US$1.125 billion of insured property losses	Renick (1997) -the costliest hail storm in the U.S. to date

Tables 4: A Selection of Severe Natural Disasters in Mexico

Date	Disaster	Location	Casualties	Economic Impact (real value unless otherwise noted)	Source & Other Notes
1520	Smallpox Epidemic	entire country	3 million dead	no information	Nash (1976) -smallpox brought in by the Spaniards
September 19, 1985	Earthquake	Michoacán, México City	9,500 dead, 30,000 injured	more than US$4 billion	Bolt (1993) Mansilla (1993)
October 29, 1959	Landslides and tsunami	Minatitlan and surrounding area	5,000 dead	no information	Nash (1976)
March 29, 1982	Volcano	Chichonal, Chiapas	5,000 dead	no information	Delgadillo (1996)
June 20, 1629	Floods	Mexico City	thousands dead	no information	Nash (1976)
October 23, 1847	Earthquake	Atlixco	thousands dead	no information	Nash (1976)
October 27, 1959	Hurricane	Manzanillo	1,500 dead	no information	"Prontuario de Contingencias" (1994)
August 27, 1909	Hurricane	northeastern states (Monterrey City)	about 1,500 dead	no information	Nash (1976)
September 30, 1976	Hurricane Liza	La Paz, Baja California Sur	more than 600 dead, 14,000 injured	US$3 million	Delgadillo (1996) Vázquez (1997)
August 28, 1973	Earthquake	Puebla	600 dead, 4075 injured	no information	Delgadillo (1996)
July 20, 1912	Earthquake	Guadalajara	hundreds dead	no information	Nash (1976)
August 23, 1951	Flood from hurricane rains	Tampico, Valles, and Cardenas	260 dead	no information	Nash (1976)
September 14-15, 1988	Hurricane Gilbert	entire country	approximately 250 dead	approximately US$766 million	Rosengaus (1990)

October 8-9, 1997	Hurricane Pauline	Guerrero and Oaxaca	228 dead	no information	"Informe General del Huracán Pauline" (1997)
July 13, 1976	Flood	Guanajuato	200 dead	no information	Vázquez (1997)
September 14, 1995	Hurricane Ismael	Sonora and Sinaloa	130 dead	no information	Vázquez (1997)
July 5, 1973	Flood	Guanajuato	100 dead	no information	Delgadillo (1996) "Prontuario de Contingencias" (1994)
February 5, 1943 to February 17, 1952	Volcano	Parícutin	3 from volcanic lightning; approximately 100 due to resettlement	no information	Krafft (1993) Luhr and Simkin (1993)
May 27, 1937	Landslide	Tlalpujahua	70 dead	no information	Nash (1976)
July 28, 1957	Earthquake	Mexico City	70 dead	no information	Nash (1976)
June 1, 1995 to July 9, 1995	Drought	northern states	no information	US$100 million	Swiss Re Canada (1996)

Table 5: The Economic Toll of Droughts and Floods in Mexico (1973-1994)
(Note: The data represent cumulative damage to December 31th, 1994)

	Floods		Drought	
Year	Millions of Pesos	Millions of U.S. Dollars	Millions of Pesos	Millions of U.S. Dollars
1973	100.84	25.7	----------	----------
1974	229.17	58.3	----------	----------
1975	146.67	37.3	----------	----------
1976	476.67	121.3	----------	----------
1977	64.17	16.3	----------	----------
1978	220	56.0	----------	----------
1979	110	28.0	2120.20	536.95
1980	233.75	59.5	538.78	137.10
1981	210.83	53.6	448.98	114.24
1982	284.17	72.3	808.16	205.64
1983	201.67	51.3	359.18	91.40
1984	229.17	58.3	404.08	102.82
1985	91.67	23.3	583.68	148.52
1986	91.67	23.3	359.18	91.40
1987	73.33	18.7	628.58	159.95
1988	220	56.0	718.40	182.80
1989	201.67	51.3	322.25	82.0
1990	224.58	57.1	404.08	102.82
1991	220	56.0	448.98	114.24
1992	275	70.0	673.47	171.36
1993	476.67	121.3	179.60	45.70
1994	100.83	25.7	2120.20	536.95

Table 6: A Selection of Severe Natural Disasters in the World

Date	Disaster	Location	Casualties	Economic Impact (real value)	Source & Other Notes
1347-1351	Bubonic Plague (Black Death)	Europe, Russia, and North Africa	approximately 50 million dead (1/3 of the population)	no information	Maloney (1976)
1851 to 1866	Floods	Beijing-Shanghai-Hankow triangle, China	40 to 50 million dead	no information	Nash (1976)
1917-1919	Influenza	World	25 million dead	no information	Maloney (1976) Nash (1976)
1936	Drought/Famine	western China	5 million	no information	Nash (1976)
August 1931	Flood	Huang He River, China	approximately 3.7 million dead	no information	Lawford *et al.* (1995)
January 23, 1556	Earthquake	Shensi, China	830,000 dead	no information	Bolt (1993)
November 12, 1970	Cyclone and Tidal Wave	Bangladesh	300,000 to 500,000 dead	no information	Nash (1976)
November 1, 1530	Flood	Netherlands	400,000 dead	no information	Nash (1976)
May 26, 526	Earthquake	Antioch, Syria	250,000 dead	no information	Nash (1976)
September 1, 1923	The Great Kanto Earthquake	Sagami Bay, Japan	142,800 dead	no information	National Geographic (1997) Waltham (1978)
1815	Volcano	Tambora, Indonesia	92,000 dead (82,000 from famine)	no information	Krafft (1993)
August 27, 1883	Tsunami triggered by the volcanic eruption of Krakatoa	Indonesia	36,500 dead	no information	Clague (1997)
May 8, 1902	Volcano	Mount Pelée, Martinique	28,000 dead	no information	Krafft (1993)
1896	Tsunami triggered by an earthquake	east coast of Japan	27,000 dead	no information	Clague (1997)
November 13, 1985	Lahars (mudflows) from the volcanic eruption of Nevado del Ruiz	Colombia	23,000 dead	no information	National Geographic (1997)

October 10-16, 1780	Tropical Cyclone	Martinique, St. Eustatius, and Barbados (offshore)	over 20,000 dead	no information	Rappaport and Fernández-Partagás (1997) -the most lethal recorded Atlantic storm to date
January 17, 1995	Hyougo-Ken Nanbu Earthquake	Kobe region, Japan	5,426 dead, 26,804 injured	approximately US$125 billion	Kuribayashi *et al.* (1996) Lekkas *et al.* (1996) -the most expensive recorded natural disaster to date
April 3, 1856	Lightning ignites a powder vault in the Church of St. John	Island of Rhodes, Greece	4,000 dead	no information	Nash (1976)
January 10, 1962	Avalanche	Peru	3,000 dead	no information	Maloney (1976)
August 21, 1986	Toxic gas release from Lake Nyos	northwest Cameroon	1,746 dead	no information	Musa (1998)
1989	Tornado	near Dhaka, Bangladesh	1,100 dead	no information	National Geographic (1997) -100,000 people were left homeless
May 1996	Tornado	near Dhaka, Bangladesh	400 dead, more than 50,000 injured	no information	National Geographic (1997)
July 1993	Tsunami triggered by an earthquake	Hokkaido, Japan	more than 200 dead	no information	National Geographic (1997)
July 1997	Flood	Eastern Europe, especially Poland	54 dead	CAN$4 billion	"Summer flood..." (1997)
1997-1998	El Niño	world	ongoing information collection	ongoing information collection	contemporary media reports
1982-1983	El Niño	world	no information	US$13 billion	Byrnes (1998)
January 25-26, 1990	Winter Storm Daria	Europe	no information	US$6.8 billion	FEMA (1997)
September 27-28, 1991	Typhoon Mireille	Japan	no information	US$6 billion	FEMA (1997)
1984	Hail Storm	Munich, Germany	no information	US$1 billion in property damages	Renick (1997)

Table 7: A Selection of Severe Non-Natural Disasters in the World

Date	Disaster	Location	Casualties	Source & Other Notes
1939-1945	World War II	World	as high as 55 million	Nash (1976)
1570	City-wide fire	Moscow, Russia	200,000 dead	Nash (1976)
January 30, 1945	The German holiday ship *Wilhelm Gustloff* is torpedoed by a Soviet submarine	near Danzig, Poland	7,700 dead	Nash (1976) -the most lethal ship sinking to date -1,000 survived
December 3, 1984	Methyl Isocyanate Leak	Bhopal, India	6,400 dead, 200,000 injured	Smith (1996) -the most lethal industrial disaster to date
December 1952	Chemical emissions trapped over city by warm air mass (the London fog)	London, England	4,000 dead immediately; up to 8,000 dead from long-term effects	Nash (1976)
February 12, 1931	Fire in the Fushun coal mines.	Manchuria, China	3,000 dead	Nash (1976)
July 12-15, 1863	Riot	New York City	up to 1,500 dead	Maloney (1976)
January 18, 1915	train derails into a gorge	Guadalajara, Mexico	allegedly more than 600 dead	Nash (1976)
March 27, 1977	Two airplanes colliding (on the ground)	Tenerife, Canary Islands	583 dead	Lisk (1997) -the most lethal airplane disaster to date
December 12, 1917	train derails into a gorge and catches fire	Modane, France	officially, 543 dead; probably several hundred more	Nash (1976)
November 20, 1984	Liquid petroleum gas explosion	San Juan Ixhuatepec, Mexico	500 dead, 1959 injured	Delgadillo (1996)
September 1971	Mercury poisoning due to contaminated grain being stolen and distributed	Al Basrah, Iraq	officially 459 dead and 6,071 injured; possibly up to 6,000 dead and 100,000 injured	Nash (1976)
May 25, 1964	Stampede	Lima, Peru	218 dead	Nash (1976)

June 11, 1955	Racing car crashes into spectators at the Grand Prix	Le Mans, France	83 dead, 100 injured	Nash (1976)
October 13, 1997	Bus crashes into a gorge	St.-Joseph-de-la-Rive, Québec	43 dead	Gray and Ha (1997) -the most lethal road accident in Canada to date
March 9, 1976	Cable car crashes after its steel cable is severed by another cable	Cavalese, Italy	42 dead	"'Reckless' jet accused..." (1998) -the most lethal cable car accident to date -the second most lethal cable car accident also occurred in Cavalese, when 20 people died on February 3, 1998 after an American military jet cut the cable.

Table 8: Payouts from the Insurance Bureau of Canada Due to Natural Hazards

Table 8a: Losses From Catastrophic Insurance Events in Canada

(Note: Catastrophic events are defined to be those resulting in 1 percent of annual claims payments within a province)

Type of Event	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Total Losses
	Loss in millions CAN$										
Storms	21	0	0	0	28	0	18	40	87	0	194
Tornado	148	50	0	0	39	0	0	12	0	0	249
Hail	0	37	0	16	343	35	8	13	92	178	722
Floods	0	0	14	0	0	9	198	13	11	318	563
Wind	0	0	0	0	8	52	0	0	0	0	60
Total	169	87	14	16	418	96	224	78	190	496	1,788

Table 8b: Number of Catastrophic Insurance Events in Canada

Type of Event	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Total Number of Events
	Number of Events										
Storms	1	0	0	0	1	0	1	4	4	0	11
Tornado	1	1	0	0	1	0	0	1	0	0	4
Hail	0	1	0	1	1	3	1	2	3	3	15
Floods	0	0	1	0	0	2	3	1	1	3	11
Wind	0	0	0	0	2	3	0	0	0	0	5
Total	2	2	1	1	5	8	5	8	8	6	46

Table 9: Total Insured Losses in the U.S. for All Catastrophes
(from the Insurance Information Institute)

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Real US$ (millions)	905	1,409	7,642	2,825	4,723	22,970	5,705	17,010	8,310	7,375

Table 10: The 10 Most Expensive Disasters for the Insurance Industry in the U.S.
(from the Insurance Information Institute)

Date	Catastrophe	Estimated Insurance Loss (millions US$)
August 1992	Hurricane Andrew	15,100
January 1994	Northridge, California earthquake	12,500
September 1989	Hurricane Hugo	4,195
October 1995	Hurricane Opal	2,100
March 1993	Winter storm	1,750
October 1991	Oakland, California wildfires	1,700
September 1996	Hurricane Fran	1,600
September 1992	Hurricane Iniki	1,600
May 1995	Wind, hail, and flooding in Texas and New Mexico	1,135
October 1989	Loma Prieta, California earthquake	960

Table 11: Economic Losses from the 1985 Mexican Earthquake

PAYOUT SHARE BY SECTORS	
Public administration	US$1,360 million (34%)
Health	US$640 million (16%)
Housing	US$600 million (15%)
Education	US$440 million (11%)
Industry and commerce	US$240 million (6%)
Tourism	US$200 million (5%)
Miscellaneous	US$520 million (13%)
TOTAL LOSS:	US$4,000 million
NUMBER OF CLAIMS	7,000
PAYOUT SHARE BY KIND OF INSURANCE	
Fire and Earthquake	97.24%
Technical Categories	2.14%
Cars	0.26%
Life	0.20%
Transport	0.16%
Claimed Loss	US$400 million (10%)
Claimed Loss Assumed by Policy-holders	US$75 million (1.9%)
Insured Loss	US$325 million (8.1%)
Contribution of Policy-holders for Co-insurance And Deductibles	US$85 million (2.1%)
Net Compensation	US$240 million (6%)

Table 12: Insurance Payouts for Damage from Hurricane Pauline in Mexico

Sector	Guerrero Fire Insurance	Oaxaca Fire Insurance
Telecommunication	US$9,855,898	
Industry	US$8,959,350	US$184,410
Commerce	US$8,498,116	US$196,851
Hotels	US$7,647,144	US$587,890
Education	US$2,631,774	US$4,488,312
Offices	US$2,101,737	US$1,282,510
Housing	US$1,961,963	US$52,925
Warehouses	US$581,996	US$99,214
Hospitals	US$273,476	
Sports	US$204,538	
Restaurants	US$102,509	
Cars		
Total	US$42,818,501	US$6,892,112
Overall Total: US$49,710,613		

Table 13: The 10 Most Expensive Disasters for FEMA in the U.S. (1987-1996)
(from FEMA, 1997)

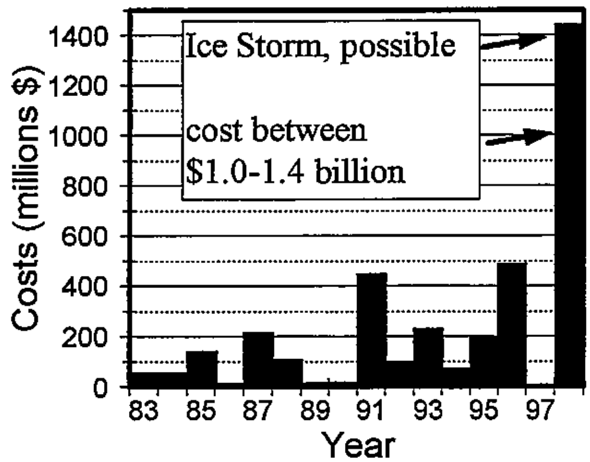
Year	Catastrophe	FEMA Relief Costs (millions US$)	Small Business Administration Disaster Lending Activity (millions US$)
1994	Northridge, California earthquake	5,558	4,100 (124,245 loans)
1992	Hurricane Andrew	1,803	696 (25,992 loans)
1989	Hurricane Hugo	1,320	491 (27,168 loans)
1993	Flooding in the Midwest	1,144	626 (19,993 loans)
1989	Loma Prieta, California earthquake	837	584 (15,473 loans)
1995	Hurricane Marilyn	542	222 (8,459 loans)
1996	Hurricane Fran	496	no information
1994	Tropical Storm Alberto	433	210 (5,340 loans)
1995	Winter storms in California	372	no information
1996	Mid-Atlantic and Northeast Floods	359	no information

Table 14: Useful WWW Pages Relevant to Natural Disasters in North America

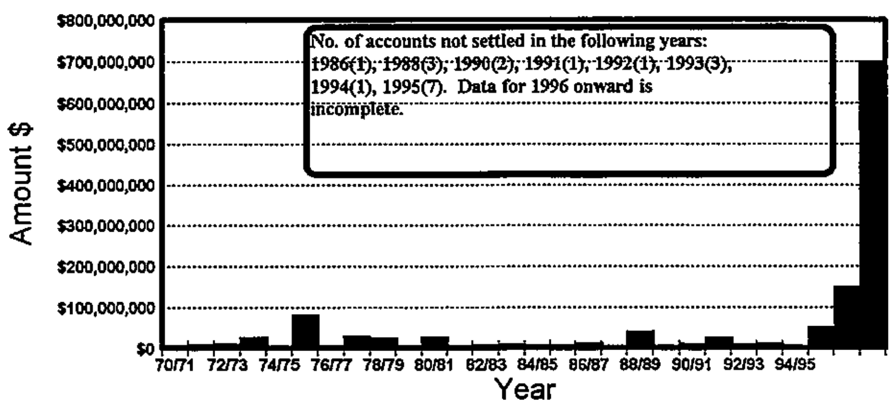
Natural Hazard	Site	Organization
General	http://www.cenapred.unam.mx/general.html	CENAPRED
	http://www.itn.is/~gro/disaster/disintro.html	The Disaster Connection
	http://hoshi.cic.sfu.ca/epc	Emergency Preparedness Canada
	http://hoshi.cic.sfu.ca/~anderson	Emergency Preparedness Information eXchange (EPIX)
	http:/www.unam.mx/ciesas/	Estudios históricos sobre desastres naturales en México (CIESAS)
	http://www.fema.gov	Federal Emergency Management Agency (U.S.)
	http://hypnos.m.ehime-u.ac.jp/GHDNet	Global Health Disaster Network
	http://hoshi.cic.sfu.ca/~idndr	International Decade for Natural Disaster Reduction (IDNDR 1990-2000)
	http://www.usc.edu/dept/puad/ijmed	International Journal of Mass Emergencies and Disasters
	http://mediccom.org/public/default.htm	MedicCom.Org
	http://ltpwww.gsfc.nasa.gov/ndrd/disaster	NASA's (National Aeronautics and Space Administration) Natural Disaster Reference Database
	http://www.nedsite.nl/search/disaster.htm	NEDSITE Search Center, Subject Disasters
	http://www.ngdc.noaa.gov/seg/hazard/hazards.html	NOAA's (National Oceanic and Atmospheric Administration) National Geophysical Data Center, Natural Hazards Data
	http://www.ieaust.org.au/societies/redr/soc_redr.htm	Registered Engineers for Disaster Relief (RedR)
	http://www.colorado.edu/hazards	University of Colorado's Natural Hazards Research and Applications Information Center
	http://www.yahoo.com/Society_and_Culture/Environment_and Nature/Disasters	Yahoo!
Earthquakes	http://www.eqnet.org	Earthquake Hazards Mitigation Information Network
	http://www.igeofcu.unam.mx	Servicio Sismológico Nacional, Instituto de Geofisica, UNAM

	http://www.cicese.mx	Centro de Investigación Científica y Educación Superior de Ensenada
	http://www.seismo.nrcan.gc.ca	Canadian National Earthquake Hazards Program
	http://www.earthquake.org	Global Earthquake Response Center
	http://www.eerc.berkeley.edu	Earthquake Engineering Research Center (California)
Fire	http://www.nfpa.org	National Fire Protection Association
Hurricanes	http://www.nhc.noaa.gov	National Hurricane Center (U.S.)
	http://wxp.atms.purdue.edu/hurricane	WXP Purdue Weather Processer, Hurricane/Tropical Data
	http://smn.cna.gob.mx	Servicio Meteorológico Nacional, Comisión Nacional del Agua
	http://geicweb.cfemex.com/meteor2.html	Comisión Federal de Electricidad
	http://www.ns.ec.gc.ca/weather/hurricane/	Canadian Hurricane Centre
Lightning	http://www.lightningsafety.com	National Lightning Safety Institute
Tornadoes	http://www.tornadoproject.com	The Tornado Project
	http://geowww.gcn.uoknor.edu/WWW/Debris/Debris.html	The Tornado Debris Project Home Page
Tsunamis	http://www.ccalmr.ogi.edu/STH/society.html	Tsunami Society
Volcanoes	http://www.dartmouth.edu/~volcano	The Electronic Volcano at Darmouth College (New Hampshire)
	http://www.geo.mtu.edu/volcanoes	Michigan Technological University's Volcano Page
	http://www.nmnh.si.edu/gvp/index.htm	Smithsonian Institute's Global Volcanism Program
	http://volcanoes.usgs.gov	USGS's (United States Geological Survey's) Volcano Hazards Program

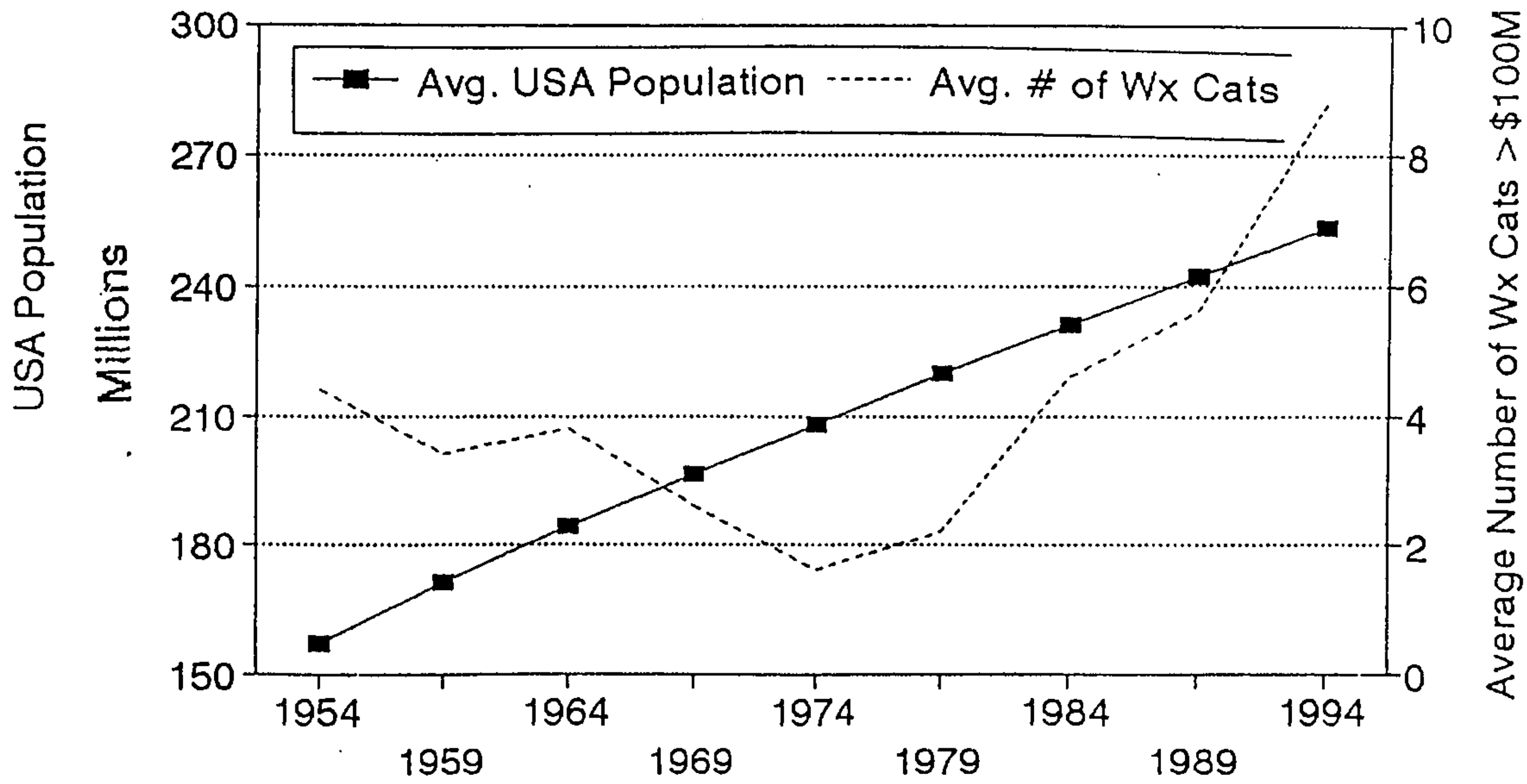
Figures 1



Weather Related Insurance Costs from Major Multiple Payouts (1995$). Source: Insurance Bureau of Canada



EPC Payouts from 1970 to 1998, adjusted to 1995/96 $. Preliminary estimates for the 1997 Red River flood and the Quebec Saguenay and Ice Storm disasters are included.
Source: Emergency Preparedness Canada (EPC)



Five-year totals of number of catastrophes >$100 million in losses and U. S. population values.

Fig. 2

Disaster Adaptation Cycle

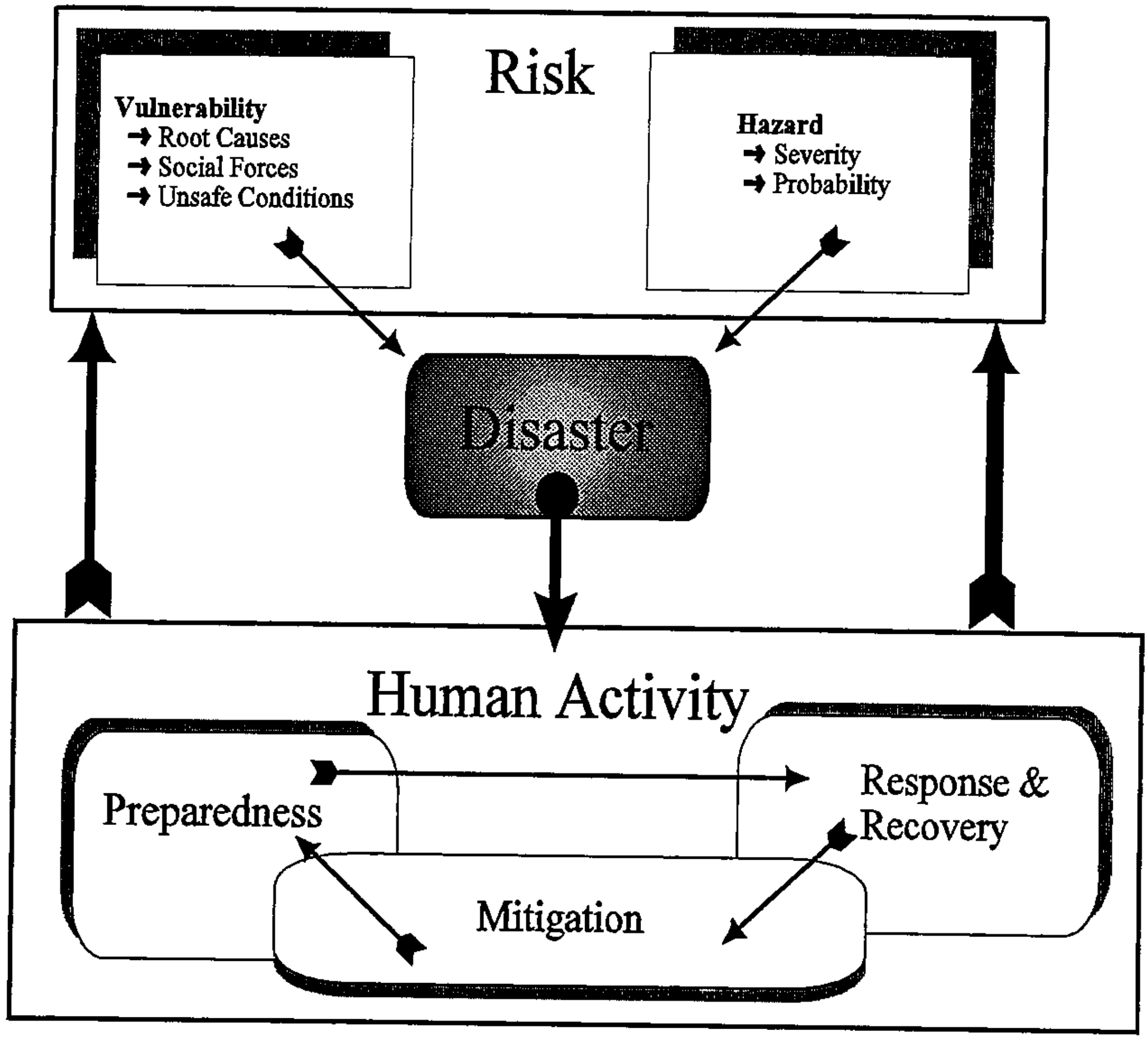


Figure 3: A disaster typically triggers a cycle of human response of response and recovery, mitigation and preparedness. This response can alter our vulnerability and thereby influence future disasters.

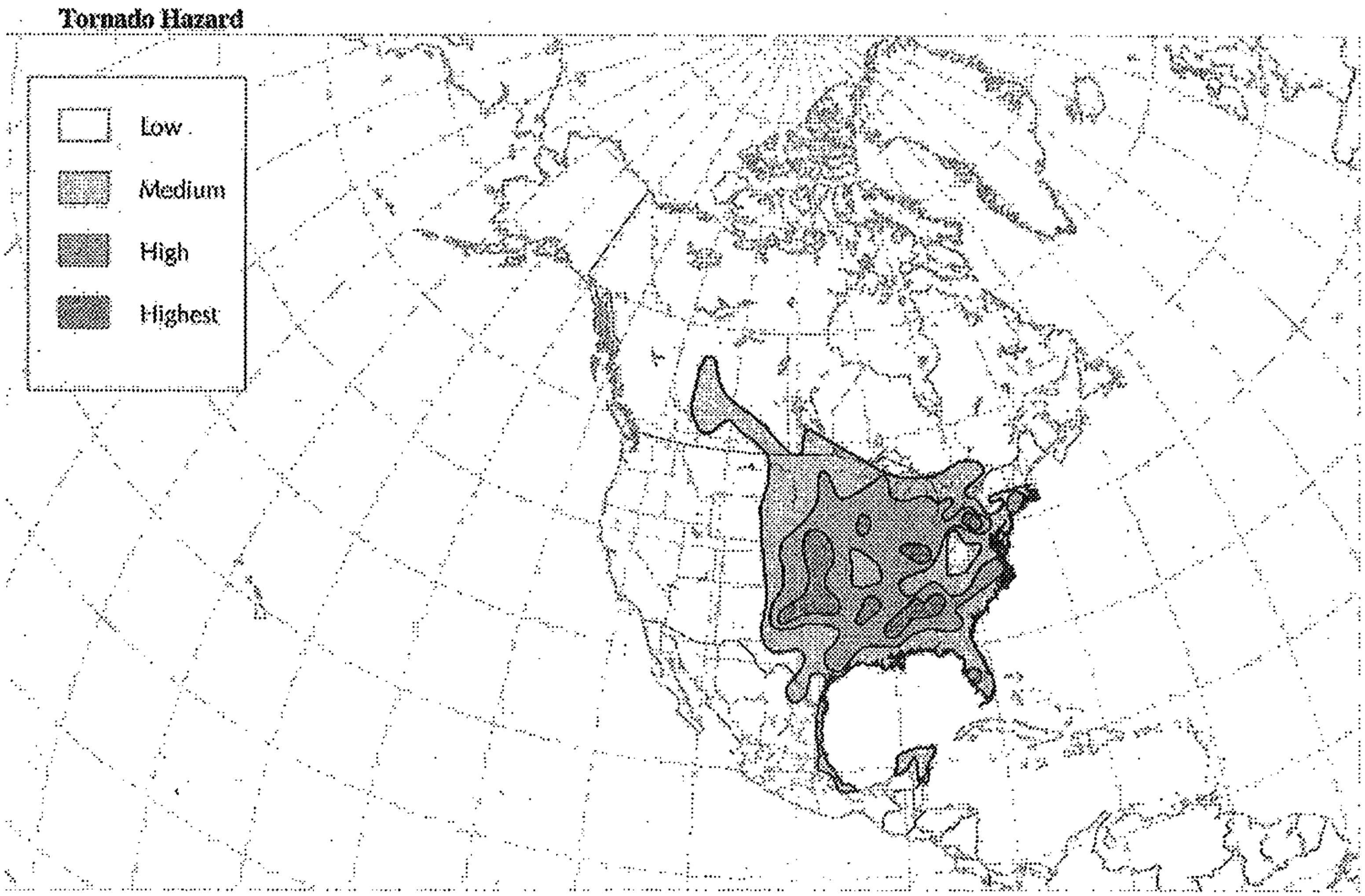


Fig. 4

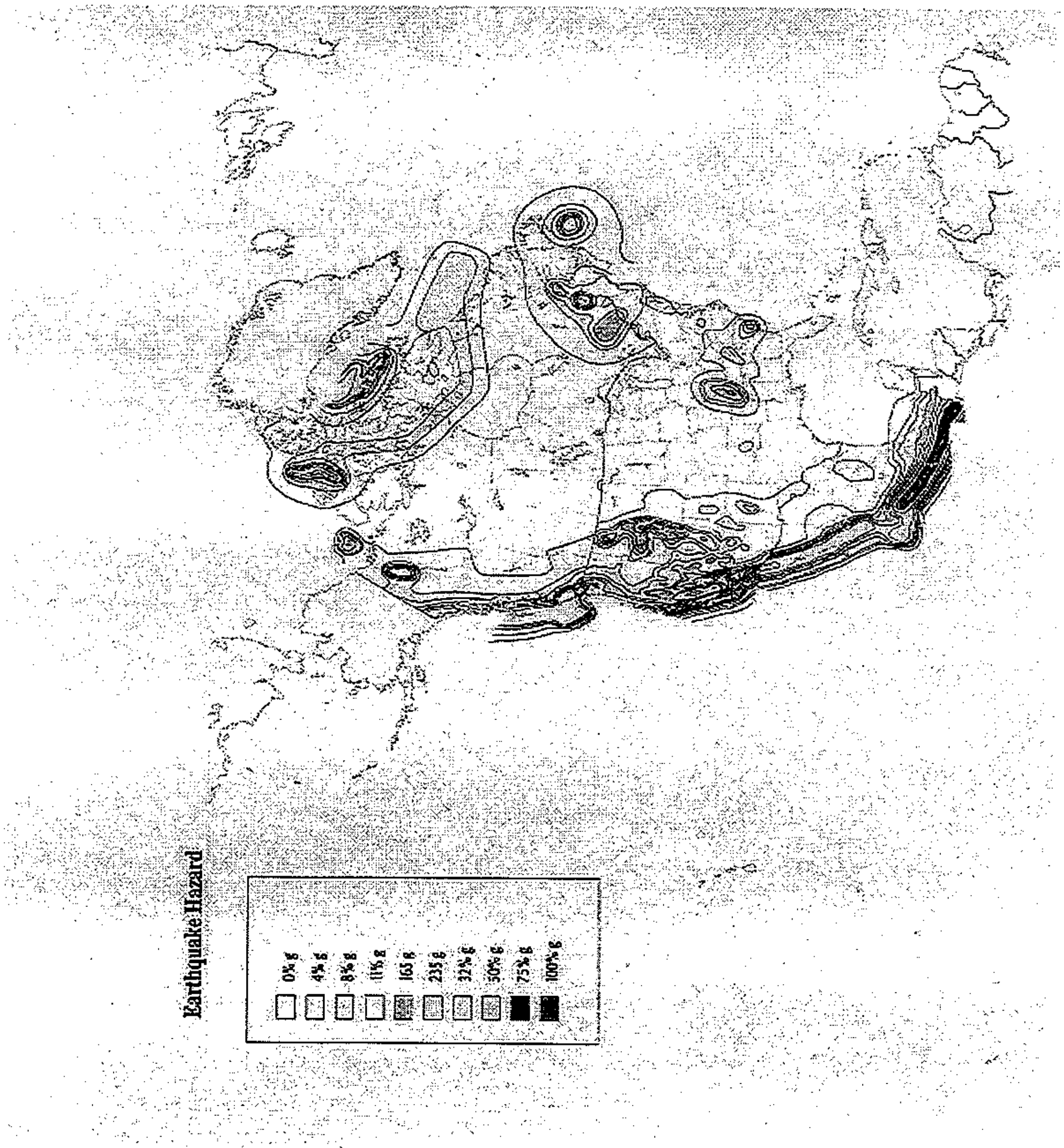


Figure 5: Seismic Risk in North America
Source: Trilateral project on natural Hazards (EPC)

Great Natural Catastrophes 1960 - 1996

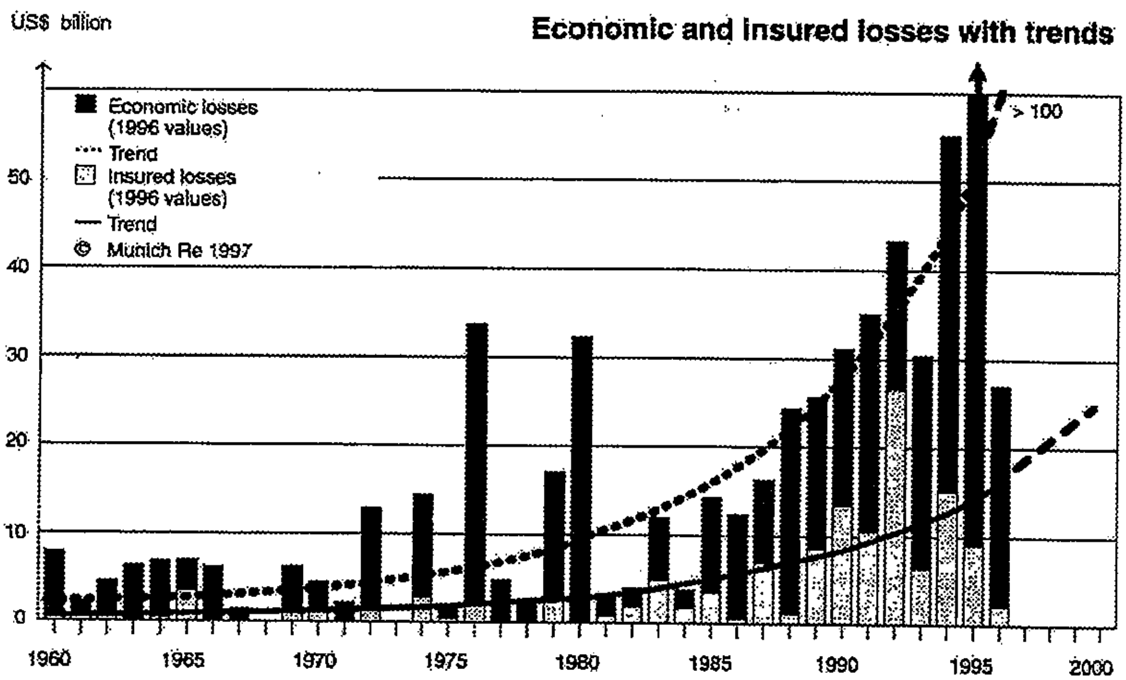


Figure 6:

The losses from great natural catastrophes since 1960. (Munich Re, 1997)

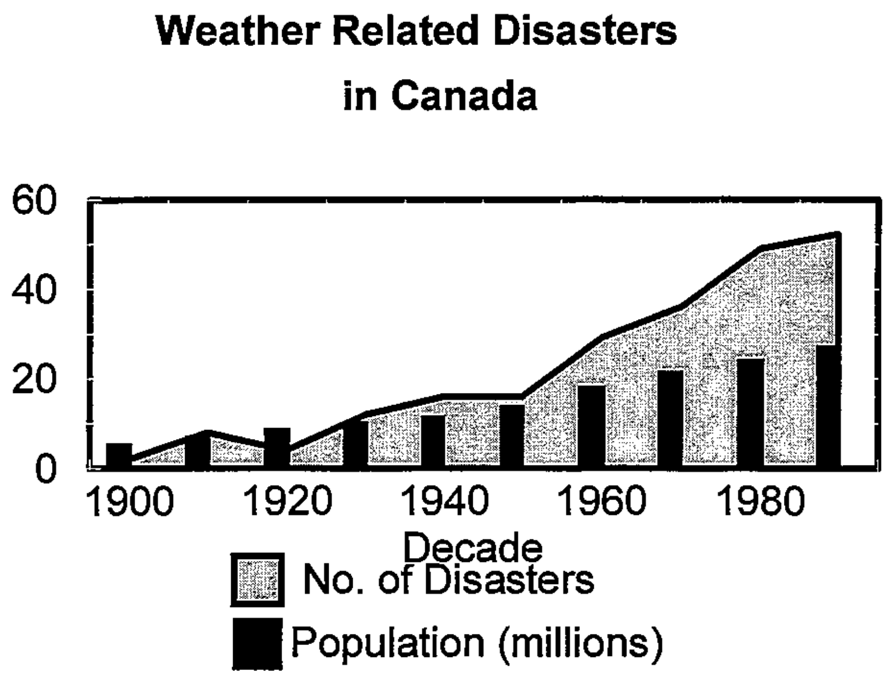


Figure 7:

Comparison of the number of weather related disasters (from EPC) in Canada with population at the beginning of the decade since 1900. Note that since the 1950's, the relative number of disasters has increased. The 1990's disaster data point only includes 1991-mid 1997 and has been corrected by dividing by 0.65

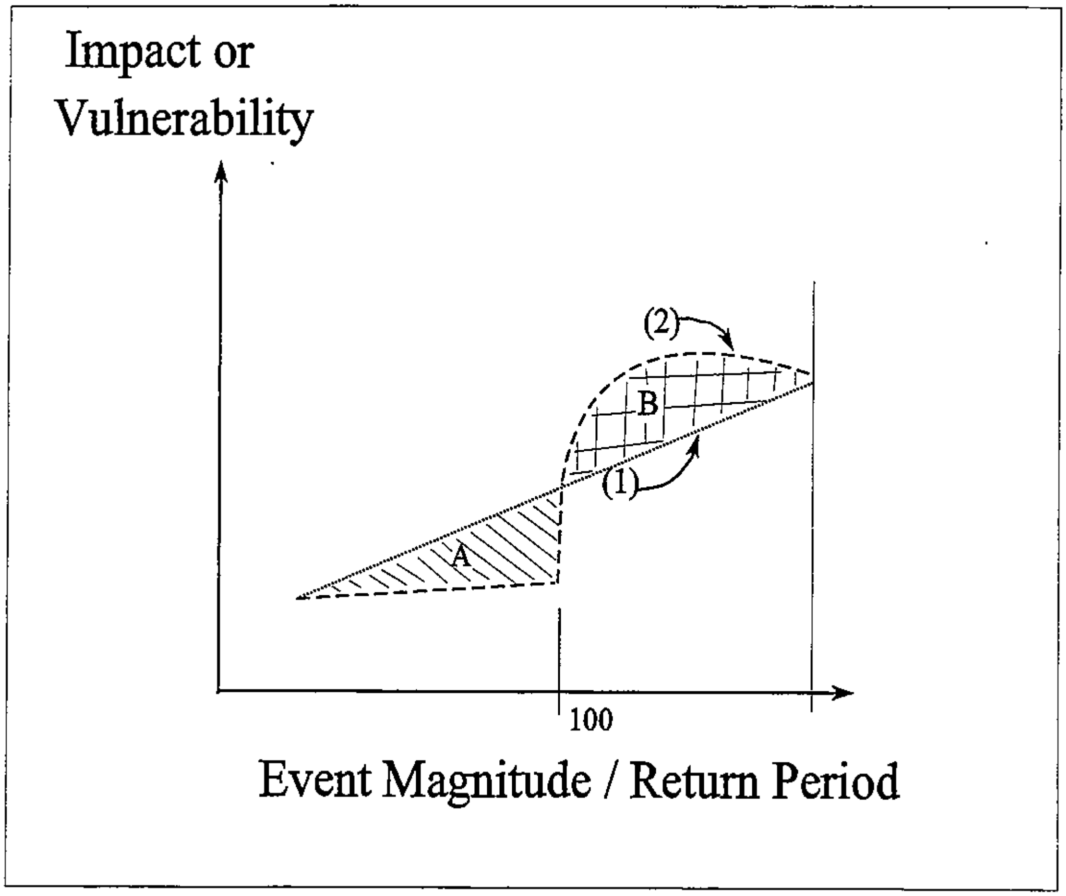


Figure 8:

Illustration of the Effect of Mitigation on Vulnerability

AES

Este Sol, su nombre 4 movimiento, éste es
nuestro Sol, en el que vivimos ahora.

Y aquí está su señal, cómo cayó en el fuego
el Sol, en el fogón divino, allá en
Teotihuacán.

Igualmente fue éste el Sol de nuestro
príncipe, en Tula, o sea de Quetzalcóatl.

El quinto Sol, 4 movimiento su signo,

se llama Sol de movimiento porque se mueve,
sigue su camino.

Y como andan diciendo los viejos, en él habrá
movimiento de tierra, habrá hambre y con esto
pereceremos.

Leyenda de los Soles

Cada minuto
Cada hora
Cada día
En algún lugar
Fuerzas de la naturaleza
Se movilizan
Gestan fenómenos meteorológicos
Como son
Los huracanes y ciclones.

Cada minuto
Cada hora
Cada día
Cada individuo
Cada País
Lucha por tener
Más y mejores patrimonios
Que, se ven afectados por
Los huracanes y ciclones.

Sequía
Lluvia
Inundaciones
Pérdidas irreparables
Afectan nuestra economía.

En este proceso
El Prof. Luna Bauza
Vigila silencioso
Día y noche
Los horizontes
Desde Veracruz
En el mismo Puerto
Música, ruido, café y alegría
Del jacarandoso Veracruz.

Ahí mismo
Existe
Callado
Un espíritu de sacrificio
Siempre pendiente
Que vigila
Día y noche
Los horizontes
Para prevenirnos
Avisarnos
A defendernos
De las inclemencias del tiempo.

La ignorancia
El temor
Las lamentaciones
No ayudan
A mejorar
Nuestras vidas.

Estudiar
Trabajar
Interpretar los fenómenos
Prevenir y actuar
Es igual
Como en nuestra vida cotidiana.

¿Es de vigilancia permanente nuestra vida?

Prefacio escrito por el Ing. Luis Kasuga Osaka, Director del Instituto Nacional de Pesca para la publicación: "Huracanes en el océano Pacífico y en el océano Atlántico" producida por la Comisión de Estudios del Territorio Nacional (CETENAL)

Dicen que la tierra tenía fiebre y que tembló

Shakespeare, Macbeth, II.3

El Monte de los Olivos se hendirá por medio del Oriente a Occidente haciendose un enorme valle: la mitad del monte se retirará al norte y la otra mitad al sur.

Zacarías 14:4

¿Que mano poderosa con fuerza desconocida
puede hacer estos temblores repetidos?
¿O hacer gemir los vapores aprisionados?
¿O agitar las playas con tridentes fabulosos?
¡Ah, no! la pisada de los pies impíos,
soporta la consciente tierra impaciente;
y estremeciéndose con el peso culpable,
prepara una tumba común para su mala raza.

Anónimo

... después del huracán, un temblor de tierra, pero no estaba Yahveh en el temblor!
Después del temblor, fuego pero no estaba Yahveh en el fuego.
Después del fuego, el susurro de una brisa suave.

Primer libro de los Reyes, 19:12

Popocatépetl, cumbre paterna, que se rompa
tu frente, en el fracaso de una explosión sin fin,
y la ciudad destruye, y el árbol, y la pompa
de nuestro valle, espléndido como un vasto jardín.

Que el sol en los caminos del cielo, se corrompa
sobre la tumba hollada de Hidalgo, el Paladín,
y hurgue el chacal inmundo con su sinietra trompa
la tierra, brava madre del gran Cuauhtemotzin.

Que se vuelquen los mares, que estalle una de aquellas
catástrofes que avientan los montes de revés:
que abra los cielos una tempestad de centellas.

Que cave hondos abismos la tierra a nuestros pies,
para no ver las "barras con las turbias estrellas"
flotar sobre el antiguo palacio de Cortés!

Fragmento del poema
"La Bestia de Oro" de
Rafael López