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Canada

# COPING WITH NATURAL HAZARDS IN CANADA:

## SCIENTIFIC, GOVERNMENT AND INSURANCE INDUSTRY PERSPECTIVES

**A study written for the Round Table on Environmental Risk, Natural Hazards and the Insurance Industry**

by

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June, 1997

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# List of Acronyms

| | |
|---|---|
| ACA | All-Channel-Alert |
| AGAFC | Agriculture and Agrifoods Canada |
| ALS | Advanced Life Support |
| ATC | Applied Technology Council report |
| BLS | Basic Life Support |
| CC | Cloud-to-Cloud lightning |
| CCC | Canadian Climate Centre |
| CEPC | Canadian Emergency Preparedness College |
| CERPs | Claims Emergency Response Plans |
| CF | Canadian Forces |
| CG | Cloud-to-Ground lightning |
| CMHC | Canadian Mortgage and Housing Corporation |
| DART | Disaster Assistance Response Team |
| DFAA | Disaster Financial Assistance Arrangement |
| DFAIT | Department of Foreign Affairs and International Trade |
| DFO | Department of Fisheries and Oceans |
| DND | Department of National Defense |
| EAL | Expected Annual Losses |
| EBS | Emergency Broadcast System |
| EIS | Emergency Information System |
| EMO | Emergency Measures Organization |
| EMS | Emergency Medical Services |
| EPC | Emergency Preparedness Canada |
| EPEDAT | Early Post-Earthquake Damage Assessment Tool |
| EPICC Industry | Emergency Preparedness for and Commerce Council |
| ERCC | Emergency Response Communications Centre |
| FDRP | Flood Damage Reduction Program |
| FEMA | Federal Emergency Management Agency |
| FICO | Financial Institutions Commission |
| FMR | Fire Medical Responder |
| GCM | Global Climate Model |
| GDP | Gross Domestic Product |
| GRIP | Gross Revenue Insurance Plan |
| GSC | Geological Survey of Canada |
| HRDC | Human Resources Development Canada |
| IBC | Insurance Bureau of Canada |
| IIPLR | Insurance Institute for Property Loss Reduction |
| INAC | Indian and Northern Affairs Canada |
| IRC | Institute for Research in Construction |
| ISO | Insurance Services Office |
| JEPP | Joint Emergency Preparedness Program |
| LIRMA | London Insurance and Reinsurance Market Association |
| M | Guttenberg-Richter scale |
| MMI | Modified Mercalli Index |
| MOTH | Ministry of Transportation and Highways |
| NBCC | National Building Code of Canada |
| NERT | Neighborhood Emergency Response Team |
| NETC | National Emergency Telecommunications Committee |
| NHEMATIS | Natural Hazards Electronic Map and Assessment Tools Information |
| NISA | Net Income Stabilization Account |
| NRC | National Research Council |
| NRCan | Natural Resources Canada |
| OGS | Ontario Geological Survey |
| OSFI | Office of the Superintendent of Financial Institutions |
| PACIC | Property and Casualty Insurance Compensation Corporation |
| PED | Probable Expected Damage |
| PEL | Probable Expected Loss |
| PEP | Provincial Emergency Program |
| PGA | Peak Ground Acceleration |
| PMD | Probable Maximum Damage |
| PML | Principal insured Maximum Loss |
| PWGSC | Public Works and Government Services Canada |
| RCMP | Royal Canadian Mounted Police |
| RECC | Regional Emergency-operations and Communications Centre |
| RETCs | Regional Emergency Telecommunications Committees |
| RMS | Risk Management Solutions |
| SCIC | Saskatchewan Crop Insurance Corporation |
| SEP | Saskatchewan Emergency Planning |
| SONRA | Society of Newfoundland Radio Amateurs |
| SST | Sea Surface Temperature |

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# EXECUTIVE SUMMARY

*by Rodney White*

## The Process

This report is the outcome of a meeting that was held at the University of Toronto in January 1996, titled "A Round Table on the Insurance Industry, Natural Hazards and Environmental Risks". (A list of the participants is given in Appendix A.) The purpose of the meeting was to assess the potential for further co-operation between the insurance industry (Property & Casualty) and scientists from the government and from the university with regard to catastrophic losses and environmental liability. A Steering Committee, established to pursue the matter, decided to concentrate on catastrophic losses from natural hazards as a test case for a co-operative enterprise. Within this focus, the committee identified three topics:

- the definition of an occurrence
- the validation of computer models of estimates of probable maximum loss
- an analysis of the patchwork of responsibility for losses from natural
- hazards.

These were problems that were of current interest to the industry and which could be managed within the timeframe set for the exercise, namely the summer and fall on 1996.

This task turned out to be far more vast than originally anticipated, and as a result parts of this report became very selective in terms of the breadth of analysis. The unanticipated complexity of the problem was partly due to the unprecedented size of losses suffered from natural hazards in Canada while the report was written.

## Rationale Behind Problem Selection

Occurrence definition has long been a point of contention due to the arbitrariness of such conventional definitions as the "72 hour rule". The committee wanted to know if scientific definitions of hazardous occurrences might provide something less arbitrary. This issue is likely to become increasingly important since climate change may produce a greater number of extreme atmospheric events, such as hail, storms and tornadoes, and hence potentially more frequent disagreements on the nature of the phenomenon.

Similarly, the validation of computer models of probable maximum loss from natural hazards has become a matter of increasing concern, especially due to the unexpectedly high losses that were incurred by the Northridge earthquake and the possibility of an earthquake of similar magnitude striking the Vancouver area - an event for which the insurance industry is not prepared. One underlying cause of concern in using these models is that most are based on the U.S. experience transferred to the Canadian context. With the software companies being responsible for the model and the insurance companies responsible for the financial data, it is important that each party has a complete understanding of the validity of the data and the assumptions implicit in the models. Recognition of the importance of risk models was highlighted by a survey conducted by the Office of the Superintendent of Financial Institutions to assess the current use of these models by insurance companies in Canada.

Concern over the evolving patchwork of responsibility for losses from natural hazards was also topical due to the variety of practices across Canada, resulting from the preponderance of provincial legislation and the lack of harmonisation of these regulations. This concern has been deepened by the reduction of federal support for emergency preparedness, coupled with reductions in provincial spending across the country at a time when the frequency and the severity of these events appear to be increasing.

## Organisation and Focus

This report opens with a review of the many factors which contribute towards natural hazard risk in Canada and world-wide. Chapter two assesses current exposure in Canada to various atmospheric, hydrologic and geophysical hazards. This is followed by a chapter on the implications of climate change for atmospheric hazards. The final chapter of the introductory section draws together data on the social and economic impact of natural hazards in Canada. The remainder of the report covered the three selected problems areas.

Within each of these problem areas the focus was further refined to fit the time constraint set for the task. Specifically, the work on occurrence definition was confined to atmospheric events and took the Barrie-Leamington tornado(es) as its principal case study. The assessment of the use of computer models was limited to seismic risks because of the salience of the California - British Columbia comparison and the unanswered questions that surround the implications of a major earthquake in the Vancouver area. The analysis of the patchwork on responsibility was in the most danger of becoming unmanageable due to the variety of hazards and the even greater variety of legislative responses. In order to keep this presentation coherent discussion was limited to those government bodies most concerned with the major risks.

## Conclusions and Recommendations

The conclusions are tentative and the recommendations are developed for discussion purposes. Clearly the resolution of the problems and the improved management of risks from natural hazards in Canada will require a great deal of further effort and consultation. The exercise of producing the report met its first objective, which was to demonstrate the value of closer co-operation between the insurance industry, and scientists from the government and the university.

Historically, for Canada, the four most devastating natural hazards are floods, droughts, hail, and tornadoes, to which should be added significant potential damage from future earthquakes, severe winter storms and windstorms. In each case there is a need for a more thorough analysis of our exposure to these risks, especially as losses are mounting dramatically. It is quite clear that traditional reliance on the historic record for estimates of exposure has been overtaken by events. The increase in exposure is partly due to well-understood phenomena such as population concentration in regions of high risk, the increase in value of household and commercial property and so on. More disturbing is the possibility that extreme weather events may become more frequent under the climate change scenario.

The scientific evidence is most consistent for the prediction of more heat waves, more frequent and severe convective storms (which are responsible for thunderstorms, tornadoes and hailstorms), and more frequent floods.

Our work uncovered serious data gaps when trying to assess social and economic costs from natural hazards, both from the direct impact of the events themselves and from the longer term costs of adaptation and recovery. There is a need and an opportunity for interested parties to work more closely on this issue. Improved data collection might encourage more determined efforts towards loss prevention, which is an area where improved co-operation among the players will bring mutual benefits. In some cases this points to the need for changes in legislation (to ensure adequate coverage and to encourage a pro-active response from policy-holders); in other cases existing legislation, such as that relating to building codes, needs to be better enforced.

For the definition of atmospheric occurrences, an alternative to the current time-delimited definition is offered, based on the physical processes that form them. The proposal offers definitions of occurrences classified by a space-time scale which demonstrates the linkages between occurrences that lie close together. For instance, a cold front – a synoptic scale occurrence – can produce tornado families. A synoptic scale specification in a contract would provide the temporal and spatial dimensions of the catastrophe and implicitly attribute the tornadoes to a common cause. It should be possible to develop a set of sample contracts to test the implications of this proposal for past and hypothetical occurrences.

The computer models of seismic risk, most widely in use in Canada, share a similar structure although they differ in their purposes, applications, attenuation and vulnerability functions, sensitivities and assumptions. The differences between the models tend to occur in how unknowns are treated, and the assumptions made about the sensitivities of the seismic parameters. A series of questions is presented which should allow a prospective model-user to assess the suitability of a particular model for an insurance company's needs. The questions relate to the reasons for the insurance company's use of the model, the cost calculations it requires, and the factors it wishes to include. It is recommended that a similar exercise be undertaken for models of atmospheric events, especially windstorms.

The third task was to assess Canada's patchwork of responsibility for natural hazards from the point of view of mitigation (both physical and financial), emergency preparedness, disaster response and relief, and recovery. This patchwork has grown in response to local needs and capacities and in many cases would benefit from review, especially in circumstances where some partners in the patchwork have taken unilateral decisions which could negatively affect the others. At a time of federal and provincial government reductions in expenditures, it is important that any proposed changes are examined for their potential impact on citizens and businesses. This is something than cannot be ignored at a time of increasing losses due to natural hazards in Canada.

Finally, the reports encourages all the parties - the government, the insurance industry, and the university to critically examine the assumptions they bring to their analysis of natural hazards in Canada.

# PART I: THE SCOPE OF THIS REPORT

## 1.0 The Impact of Natural Hazards

*by Lindsay Wallace and Rodney White*

# 1.0 The Impact of Natural Hazards

*by Lindsay Wallace and Rodney White*

## 1.1 Introduction

This document is the outcome of a process of consultation among government scientists, university scientists, and representatives of the insurance industry who are disturbed by trends in the natural and environmental hazards experienced in Canada and world-wide. In part, these events are the outcome of increasing population, continuing urbanisation and industrialisation, and the resultant concentration of the human population in places exposed to hazards.

A Round Table convened at the University of Toronto in January 1996 explored the potential for co-operation among governments, universities, and the insurance industry in seeking to understand the implications of these trends for the management of risks, of both the catastrophic and the environmental kind. They formed a steering committee to suggest ways of exploring the potential for co-operation, such as development of a joint research project, the results of which could then be brought back to the Round Table and distributed to a wider audience for comment and participation.

The Steering Committee on the Insurance Industry, Natural Hazards and Environmental Risks is composed of representatives of the insurance industry, the University of Toronto, and government scientists from Environment Canada and Emergency Preparedness Canada. The committee decided to concentrate first on catastrophes, leaving the environmental problems associated with pollution for later consideration.

The pilot activity selected was the preparation of a background paper to synthesise what each of the three groups knows about certain aspects of the natural-hazard risk in Canada. Three salient issues for this exercise were selected – the definition of an "occurrence", the validation of computer models of "maximum possible loss", and the emerging patchwork of responsibility for natural hazards in Canada. Three principal authors – Søren E. Brun, Dionne Gesink Law, and Lindsay Wallace – funded by Environment Canada, prepared a draft of the document during the summer of 1996, under the direction of two members of the steering committee – David Etkin and Rodney White. They then presented the report to the steering committee, for comment and modification.

Part 2 of this study offers current scientific explanations of the natural hazards – atmospheric, hydrologic, and geophysical – that Canada has faced (chapter 2) and is likely to face (chapter 3) and analyses the impact of these hazards (chapter 4).

The second focus (Part 3) of our research emerged from the realisation that few outside the insurance industry ever pause to ask if two storms occurring close in time and space constitute one event or two, yet the question is of great significance within the industry. Primary insurance companies, which sell policies directly to households and companies, usually lay off a portion of their liability for potential catastrophes to reinsurance companies, which insure insurance companies. Reinsurance comes into play when a catastrophic storm, or other event such as an earthquake, produces settlements of claims that exceed a certain amount. Hence the importance of defining what an event is. Chapter 5 (in part 3) takes some of the findings presented in part I and proposes an approach that may reduce ambiguity in reinsurance contracts for atmospheric occurrences, where current definitions seem ambiguous.

The third issue – examined in part 4 – concerns the accuracy of estimates based on computer models of the probable maximum insured loss (PML) from catastrophic natural hazards. These computer models have come into widespread use since Hurricane Andrew (1992) and the Northridge Earthquake (1994). The effects of these disasters shocked the industry, the public, and all levels of government into a sudden realisation of just how much a major catastrophe could cost. Quite suddenly, reliance on the historical record for estimating the PML for a particular company, or the property-and-casualty industry as a whole, became obsolete. Computer simulation models for earthquakes, hurricanes, and other atmospheric events were quickly developed by specialised software companies to fill the gap. How were risk managers in the insurance industry to assess the reliability of the estimates produced by these models? The approach mapped out in chapter 6 (in part 3) focuses on seismic risk, as that is the largest catastrophic risk in Canada today.

The third of the three major insurance issues examined, explored in part 3, was the network of responsibilities in Canada for the effects of catastrophes. Part 5 pays special attention to British Columbia, which is exposed to the highest risk through Greater Vancouver's vulnerability to earthquakes. As the risks have become greater in magnitude there has been growing realisation that most people have little conception of how the responsibilities for different kinds of risks are shared among governments, insurers, and the insured. The magnitude of the occurrence itself determines how insurance and reinsurance companies share the risk. The magnitude also affects the relative shares incurred by municipal, provincial, and federal governments. The greater magnitude of events has also blurred the distinctions among types of events, making traditional definitions of responsibility difficult to apply. Huge rainstorms have produced flash flooding and sewer back-ups simultaneously in urban areas. As the public sector usually pays for the former and private insurance for the latter, determining the source of the water that damages household basements and business premises is crucial. Also, as these events become more common, deductibles and the cost of coverage tend to rise, thus increasing the insured's share of the burden. The four chapters of part II examine the tasks and duties of various public and private actors in the four phases of human response to a natural disaster – mitigation of hazards, preparation for an emergency, response to a disaster, and recovery from the disaster.

In each of the three areas of interest the scope of the problem expanded as the work progressed, and it became impossible to consider all kinds of risk in all parts of Canada in such a pilot exercise. The writers could not keep updating coverage as events unfolded during the summer of 1996, such as the hail storms in the prairies and floods in Quebec in July and the heavy rains in

Ottawa/Hull in August. The purpose of this document is more modest – to explore the potential for mutually rewarding co-operation among governments, universities, and the insurance industry in the field of natural hazards and risk management. The exercise was exploratory, and in this respect it has met the expectations of the committee. It has identified a host of issues that require urgent attention if Canada is to be fully prepared to manage the catastrophic risks to which it is exposed.

## 1.2 The Impact of Natural Hazards

The public and private costs of natural hazards have been increasing in Canada and around the world. For example, in July 1996, while this paper was being written, hail storms on the Canadian prairies were generating insurance claims worth in excess of $295 million, not including crop damage, and flooding in the Saguenay region of Quebec is expected to cost the economy over $1 billion (insured and uninsured). Up until 1994, the most costly year on record in terms of insurance costs from major multiple payouts was $450 million. In 1996 it amounted to $920 million, over twice the previous record. Up until fiscal year (FY) 1994/95, disaster financial assistance (DFA) payments from the federal government had never exceeded $80 million. In FY 1996/97 it was $144 million, of which $100 million was for the Saguenay disaster. It is estimated that the total DFA costs for the Saguenay will be around $250 million. The recent flooding in Manitoba (April/May, 1997) may well cost the DFA program $200 million or more. An increase in the frequency and severity of disasters may account partially for these costs. An interplay of geographical, economic, political, and demographic factors influence the number of people vulnerable to hazards, the total potential effect of those hazards, and how this impact is shared by the private and public sectors. Furthermore, activities of the construction and insurance sectors can affect the influence of natural hazards on different groups in society.

This introductory section explores a variety of these factors – demographic factors, economic growth, constitutional responsibility, construction, the role of insurance, and perception of risk – and seeks to explain how they can affect the impact of a disaster and its distribution among people and groups.

### *1.2.1 Demographic Factors*

Chapter 2 will describe how the physical geography of Canada affects its vulnerability to natural hazards. Human geography – especially population size and distribution – also affects losses from natural hazards. Canada's population has been growing steadily since Confederation and now stands at 29 million (Statistics Canada, 1996). Eighty percent of the population lives within a narrow band stretching 300 km north of the U.S. border (EPC, 1995). Consequently, some hazards, particularly those that occur in the sparsely populated north, do not jeopardise the lives and property of many Canadians. However, Canada is vulnerable to some American hazards, for example, volcanic ash from Mt. St Helens and earthquakes in Puget Sound.

Canada has become increasingly urban; 75 % of the population now live in urban areas and their outlying suburbs (EPC, 1995a). Urbanisation has increased the potential losses arising from natural hazards because of greater concentrations of people and assets. For example, the potential loss of life and cost of an earthquake in Greater Vancouver have been rising with population growth. Between 1986 and 1991, British Columbia's population increased by 13.8 % – much faster than the national average of 7.9 % (Statistics Canada, 1996). Moreover, Vancouver has been the second-fastest-growing urban area in the country, with average annual growth of 2.9 % between 1987 and 1995 (Statistics Canada, 1996). Urbanisation has also increased potential losses from localised atmospheric hazards such as tornadoes and hail storms.

In the case of earthquakes, for which separate insurance can be purchased, demographic factors can affect the way the financial impact of an event is shared among private and public sectors. Research in California found that the propensity to buy earthquake insurance increases with age (Palm, 1990). Age distribution in Canada, as in most Western countries, is skewed towards the "baby boomers" – the generation born after 1945. Consequently, a larger proportion of the population is likely to own homes, buy insurance, and hence make claims in the event of an earthquake.

### *1.2.2 Economic Growth*

Economic growth also affects the financial impact of natural hazards. Canada has experienced a large increase in its gross domestic product (GDP) since 1945, though growth has been slowing since the 1970s and currently stands at approximately 3 % per annum. Economic growth has varied across the country over the past 30 years and moves in concert with population growth. Provinces such as Alberta and British Columbia have experienced significant growth, while others, including the Atlantic provinces and some areas of Quebec, have grown much more slowly. Canada's most devastating natural hazard – an earthquake in the lower B.C. mainland – could now cost $30 billion, or one-third of the province's annual GDP. Such an event could cause an economic shock 10 times greater than the most recent recession, and less than half of this loss would be covered by insurance (IBC, 1994a). If current trends continue, the economic vulnerability of Canadians to an earthquake in British Columbia will increase.

### *1.2.3 Constitutional Responsibility*

The division of powers between different levels of government can also affect the impact of natural hazards. The Constitution Act, 1867 (formerly the British North America Act, 1867), delineates jurisdiction for various activities between the federal and provincial governments. The federal government has jurisdiction in such areas as defence, foreign affairs, criminal law, money and banking, international trade, air, marine and rail transportation, citizenship, and Native affairs. Provincial governments are responsible for such matters as education, health and welfare, civil law, highways, natural resources, and local government (EPC, 1995b). Local and municipal governments provide such services as police, fire, public transportation, urban roadways, local public works, sanitation, snow removal, and health and welfare administration.

Political factors can affect the distribution of economic and social costs among levels of government. Costs and benefits regarding natural hazards, for mitigation, preparation, relief, and response may be paid for, or received by, different governments. Consequently, the incentive for one level to minimise hazard is reduced if another level ultimately pays for that loss. One such example is building codes, which are researched and recommended nationally, legislated by the provinces, and enforced at the municipal level. If building codes are not enforced, funds for repairing avoidable damage come from private insurance companies or the federal and provincial governments.

### *1.2.4 Construction*

The ability of a building to withstand a natural disaster is influenced by age, type of construction, materials used, and type of hazard.

The National Research Council (NRC) conducts research on buildings and makes recommendations about the National Building Code of Canada (NBCC) and the National Fire Safety Code. Construction standards rest with the provinces. Saskatchewan, Quebec, New Brunswick, and Nova Scotia have adopted the 1990 National Building Code unamended, with the remaining provinces adapting it before doing so (IBC, 1994a).

Municipal enforcement, however, is uneven. Unanchored mobile homes have been shown to be hazardous in the event of a tornado. To mitigate this hazard, the NBBC recommends that mobile homes be anchored to their foundations. Eight of the people killed in the tornadoes that occurred in western Quebec and eastern Ontario between 1970 and 1984 were inside light mobile homes or frame cottages that became airborne (Allen, 1984). In the Barrie-Orangeville tornadoes of 1985, all but possibly one of the deaths and very serious injuries inside residential buildings occurred in houses not properly anchored to the foundation (Allen, 1986). Similarly, in Florida, insurers estimate that $4 billion (U.S.), or 25 % of total insured losses from Hurricane Andrew could have been averted if building codes had been properly enforced (IBC, 1994a).

Another construction-related problem is lack of knowledge concerning the vulnerability of various locations. In the earthquake of 1995 in Kobe, Japan, house construction contributed to the high death toll. Japan's Ministry of Construction had thought that tropical storms and hurricanes, not earthquakes, were the primary threat to Kobe. Consequently, houses were built with heavy roofs and light walls to withstand high winds. However, because of heavy motion during the Kobe quake, most houses lost their footings, causing roofs to collapse. This was how 90 % of Kobe's 5,470 deaths occurred (Valery, 1995).

In earthquake-prone regions in Canada, the threat from ensuing fires is often overlooked in building codes. Construction materials can affect the size and development of fires that may follow a quake. The National Fire Safety Code, however, does not contain special provisions for earthquake-prone regions susceptible to large fires afterward (IBC, 1994a).

Age of building stock also affects the impact of natural hazards. Many buildings were erected when knowledge of natural hazards, earthquakes in particular, was in its infancy. Consequently, much of Canada's private building stock, as well as public infrastructure, fails to meet current standards for structural integrity during an earthquake (IBC, 1994a). In British Columbia, buildings constructed since 1985 have been designed to withstand shaking resulting from an earthquake. It is estimated that only half of British Columbia's buildings constructed between 1960 and 1985 can withstand shaking, and those erected before 1941 have little or no earthquake tolerance (IBC, 1994a). Furthermore, while the NRC provides guidelines for evaluating buildings for seismic resistance, there are no similar codes for retrofitting (IBC, 1994a).

While research in construction has helped reduce the potential for deaths from natural hazards, this improvement may be costly. If buildings are designed to collapse slowly and incrementally, rather than suddenly and massively, during an earthquake, so as to protect human life, non-structural damage, particularly to interiors, increases. The value of damage done to non-structural components can exceed that done to the building structure. Thus, technology-dependent firms may be particularly vulnerable to earthquakes (Murphy, 1992).

### *1.2.5 Insurance*

When an individual faces a risk such as loss from a natural hazard, he or she can usually manage that risk by purchasing insurance. Insurance works on the principle of pooling risks and charging customers a premium based on the average risk of the pool with some variation based on individual risk characteristics. It allows the individual to substitute a small, defined expenditure (the premium) for a large but uncertain future loss. Policy holders who escape losses help to compensate those who are directly and adversely affected by loss (IBC, 1995a). If a large number of individuals in a hazard zone purchase insurance, then a greater proportion of the costs resulting from natural hazards will be borne by the insurance industry. This section discusses aspects of insurance that can affect the division of costs of natural hazards between the public and private sectors: coverage, pricing, reinsurance, and the solvency of the industry.

The property-and-casualty sector of the insurance market insures natural-hazard losses to property. In Canada, it registered total sales of more than $17.6 billion in 1995 and controlled assets were more than $41 billion (IBC, 1996). Over the years, the industry has paid more than $1 billion to 400,000 home, business, and vehicle owners to compensate for losses caused by natural hazards (EPC, 1996). It is estimated that the insured loss from a major earthquake in the Vancouver area could range from $9 billion to $12 billion (EPC, 1996) and three regulatory and economic multipliers could drive up the costs. First, inflation in the price of building materials can occur in areas hit by the disaster as a result of high demand, low supply, and/or price gouging. After Hurricane Andrew, for example, costs for building material increased 300% and inflation also followed the Calgary hailstorm of 1991 (Ross, personal communication). Second, older buildings would have to be rebuilt and/or repaired to meet current by-laws, which are generally much stricter than old ones. Finally, modern buildings are designed to reduce the losses of life during an earthquake, and so many that would remain standing would probably be declared unsafe.

The coverage of homeowners' insurance policies varies with price and company, but is also guided by provincial legislation. For example, Co-operators Insurance covers a number of natural hazards including fire, lightning, wind storm, and hail damage. Homeowners can also purchase earthquake coverage for an additional premium. Natural hazards not covered include damage caused by snowslides, landslides, and other earth movement, in addition to damage caused by sewer back-up (although coverage for the latter is available for an extra premium). As well, there is no coverage for damage caused by waves, flooding, and the weight or pressure of melting ice or snow (Co-operators, 1994).

Localised risks such as flooding and waves do not satisfy basic underwriting requirements (IBC, 1994b) and so are not covered by standard insurance policies. For insurance to be actuarially sound, a large population must be exposed to a risk, with only a small proportion likely to sustain a loss at any given time (IBC, 1994b). Furthermore, losses must be random, so that the risk is spread among the larger population. With flood and landslide losses, adverse selection occurs - individuals who have the greatest incentive to buy insurance are those who pose the worst risk. Insuring individuals who live in a floodplain or below a landslide-prone slope means an inevitability of a claim and offering coverage at affordable prices would no longer be actuarially sound. To avoid adverse selection and inevitability of loss, insurers do not cover certain perils.

Earthquakes, however, are not affected by adverse selection because they place a relatively large population at risk (for example, Vancouver). Furthermore, damage to individual homes within this risk area is randomly distributed and consequently satisfies a key criterion for underwriting acceptability (IBC, 1994a). An individual's decision on whether or not to purchase home insurance can be affected by price, and this choice then can change the division of public and private costs of natural hazards. When more people are insured against natural hazards, a greater proportion of the total cost of that hazard is borne by the insurance industry. Premiums for property-and-casualty insurance are determined by the interplay of market forces, risk, government regulations, taxes, and availability and costs of reinsurance (IBC, 1995a). In recent years, the cost of reinsurance increased substantially, although it is now dropping again, and some government regulations have made proper pricing of certain insurance risks extremely difficult.

A frequency of major catastrophes internationally tends both to reduce the amount of reinsurance available and to increase the cost of reinsurance, and this affects Canadian insurers who also have to pay higher reinsurance premiums. During the 1995/1996 renewal season, many reinsurers imposed an event or occurrence limit on contracts where no such limit had previously existed and which limit the reinsurers loss from natural perils or catastrophes (Fredette, 1995). These developments have an impact on the capability of the insurance industry in Canada to withstand a major disaster, and also on the public and private distribution of natural hazard costs.

While the pricing of insurance is somewhat controlled by external forces, pricing and underwriting mechanisms can affect losses as seen in the following areas.

Premiums and deductibles can encourage mitigation. For property and casualty insurance, companies could use deductibles or premiums to encourage individuals to adopt mitigation measures in their homes and businesses. Levying a smaller premium or deductible on those who took mitigative action - such as securing larger objects in their homes - would increase the incentive for individuals to perform such activities. Moreover, losses from the hazards would decrease. However, the Insurance Bureau of Canada feels that the current insurance market fails to encourage efforts to reduce losses (IBC, 1994a).

Also, easing of legal requirements might affect losses and encourage better coverage. The common-law provinces (all except Quebec) require insurers to include coverage for fire, regardless of its cause, in their standard homeowner's policies. The industry argues that this requirement makes it unable to price effectively homeowner's policies in British Columbia. For insurance to be actuarially sound, premiums must be based on the average risk of a pool of individuals. In the event of an earthquake, it is often the fire that follows which causes the most damage. Open flames, electrical malfunctions, chemical spills, and ruptured fuel tanks and natural-gas lines are often catalysts of such post-quake fires, and they are usually fuelled by flammable building materials and modern building furnishings (Munich Re, 1992). In the most devastating earthquakes, these small fires can coalesce into larger fires, posing a threat to human life and property. The Munich Re study of the economic impact of an earthquake in the lower B.C. mainland estimated that fire would cost approximately #3.39 billion to $6.20 billion.

Requiring that fire following a quake be covered poses three problems for the insurance industry. First, it makes the risk difficult to price, as the risk of fire must include the potential loss from earthquakes. Second, as the Insurance Bureau of Canada has argued, distribution of quake-related fire protection may be inciting insurance firms, under competitive market conditions, to underestimate further, or ignore, earthquake-related fire losses in computing prices for basic coverage (IBC, 1994a). This situation places at a disadvantage firms that attempt to price fire damage properly. Third, the fire coverage provided by homeowners' policies is more generous and less costly than earthquake coverage. In general, deductibles for earthquake-shake damage are much greater than those for fire damage. Consequently, two households facing similar dollar amounts of damage from the same catastrophic event may face significantly different levels of support from their insurance company (IBC, 1994a). This inequality creates a moral hazard for the industry, as those who have earthquake coverage could commit arson in order to benefit from a lower fire deductible and this could greatly compound damage resulting from fire following a quake. A second moral hazard is that an insured with no earthquake shake damage coverage, but whose building was damaged by the shaking ,could also be tempted to commit arson as the fire damage would be covered and it could be very difficult at time of a major quake to determine which damage was fire and which arose from the shake.

The combination of limited availability of reinsurance, moral hazard, failure to reward efforts at mitigation, and the legislative requirement to cover fire following an earthquake, has hindered efficient pricing of insurance. Some observers are concerned about the solvency of the property-and-casualty insurance industry. In the event of a major B.C. earthquake, the industry would face a probable maximum loss of $9.7 billion to $12 billion. The industry's capacity in the province was estimated in 1994 to be $2.3 billion - far short of possible needs (IBC, 1994c). The Canadian insurance industry is at risk, should there be such an event (IBC, 1994c).

The IBC has estimated that roughly one-quarter of companies writing property insurance in British Columbia would become insolvent following an earthquake in Vancouver (IBC, 1994d). Furthermore, these insolvencies would be felt throughout the Canadian insurance market, which might not be able to meet claims from other areas of the country. A contagion effect could occur if policy holders cancelled policies with companies that they felt might become insolvent, making insolvency a self-fulfilling prophecy for many firms. Chapter 6 looks at regulation of the industry and efforts to mitigate the potential financial effects of a B.C. quake.

### *1.2.6 Perception of Risk*

Finally, how individuals perceive their vulnerability to natural hazards shapes responses to them and hence their cost. If they see themselves as vulnerable to certain risks, they try to manage that risk. Natural hazards are typically viewed as involuntary risks, but preparing the household for an emergency and purchasing insurance are voluntary responses to this unchosen risk. Standard household insurance does not cover earthquakes, but homeowners can purchase coverage for an additional premium. Consequently, if many people feel vulnerable to such a risk, sales of earthquake insurance rise. In turn, insurance claims may increase after a quake and perhaps further challenge the industry's solvency. Recent studies have shown, however, that Canadians and Americans underestimate their vulnerability to earthquakes and the likelihood that any resulting loss is covered by insurance (IBC, 1995b; Palm, 1990).

In a longitudinal study of Californian homeowners, Palm (1990) found that perceived vulnerability to quake damage substantially affects whether or not people purchase earthquake insurance. While everyone in quake-prone regions is potentially susceptible, not all see themselves as being such. First, many believe in the gambler's fallacy – after one hazard occurs, there will not be another (Petak and Anderson, 1982). Consequently, those who have already experienced one "act of God," such as an earthquake, may feel that another is not likely to affect them. Second, because of the psychological process of editing, some people assume that improbable events, such as "acts of God," are impossible. If they do not feel at risk, they will not purchase insurance or attempt other efforts at reducing their vulnerability. For example, 60% of homeowners in Vancouver buy earthquake insurance, while less than 5% of people in Montreal do so, even though the risks are similar.

Given that individuals generally have skewed perceptions about the extent to which they are at risk, it is not surprising that Canadians are confused about their insurance coverage for quake damage. An IBC survey found that in the event of an earthquake, 70% of Canadians would turn to insurance companies for financial support, and 17%, to government (IBC, 1995b). Surprisingly, 60% of Canadians who have no home or tenant insurance at all would look to insurance companies for support, and 23%, to government (IBC, 1995b). These results point to the need for increased public education about risks related to natural hazards and ways of reducing vulnerability, such as insurance coverage.

Perceptions of risk related to hydrometerological hazards can have a significant impact. For example, development in flood plains, even if they are protected by dams, dykes and levees can occasionally lead to costly disasters, when nature provides a hazardous event beyond the design period of our protections (e.g. Saguenay). Homes, especially trailer homes, can be made much more wind and tornado resistant by anchoring their roofs and walls. These mitigative actions will only occur, though if the owners perceive the risk as great enough.

In sum, geographical, political, economic, demographic, insurance, construction, and psychological factors all affect both the absolute cost of natural hazards to Canadians and the division of cost between and within public and private entities.

## References

Allen, D. E. (1986). *Tornado damage in the Barrie/Orangeville Area, Ontario.* National Research Council, Ottawa. May, 1985.

Allen, D. E. (1984). *Tornado damage at Blue Sea Lake and Nicabong, Quebec.* National Research Council, Ottawa. July, 1984.

Co-operators General Insurance Company. (1994). *Homeowners Insurance Policy.*

Fredette, A. (1995). Kobe: A lesson for Canada. *Canadian Insurance* (March): 8-10.

Emergency Preparedness Canada (EPC). (1996). *Natural Hazards.* National Atlas of Canada.

Emergency Preparedness Canada (EPC). (1995a). *A Summary of Federal Emergency Preparedness in Canada.* EPC, Ottawa.

Emergency Preparedness Canada (EPC). (1995b). *Departmental Planning Responsibilities for Emergency Preparedness.* EPC, Ottawa. June.

Insurance Bureau of Canada (IBC). (1995a). *Facts About Property and Casualty Industry.* IBC, Toronto.

-Insurance Bureau of Canada (IBC). (1995b). *Public Opinion Environment.* IBC, Toronto. February.

Insurance Bureau of Canada (IBC). (1994a). *Canadian Earthquake Exposure and the General Insurance Industry: A Proposal for Action.* IBC, Toronto. October.

Insurance Bureau of Canada (IBC). (1994b). *Insurance Bureau of Canada Position Paper: A Statement of Principles Regarding Insurance and Natural Hazards.* IBC, Toronto. November.

Insurance Bureau of Canada (IBC). (1994c). *Canadian Earthquake Exposure and the General Insurance Industry: Part I -- Probable Maximum Loss Analysis.* IBC, Toronto. February.

Insurance Bureau of Canada (IBC). (1994d). *Canadian Earthquake Exposure and the General Insurance Industry: Part II -- Financial Impact Analysis.* IBC, Toronto. February.

Munich Insurance Company of Canada (Munich Re). (1992). *A Study of the Economic Impact of a Severe Earthquake in Lower Mainland B.C.* Munich Re, Toronto.

Murphy, R. (1992). Storm clouds ahead for buyers. *Best's Review* (January): 31-91.

Palm, R. (1990). *Natural Hazards: An Integrative Framework for Research and Planning.* John Hopkins University Press, Baltimore.

Petak, W. J. and Atkinson, A. A. (1982). *Natural Hazard Risk Assessment and Public Policy: Anticipating the Unexpected.* Springer-Verlag, New York.

Ross, A. (personal communication). SOREMA. 1996.

Statistics Canada. (1996). CANSIM Database. Various matrices.

Valery, N. (1995). Survey of earthquake engineering. *Economist*, 22, April.

Zeckhauser, R. (1988). *Insurance and Catastrophes.* The Geneva Convention Annual Lecture, Harvard University, May.

# PART 2: NATURAL HAZARDS IN CANADA

## 2.0 Atmospheric, Hydrologic and Geophysical Hazards

*by Søren E. Brun*

## 3.0 Climate Change and The Future of Atmospheric Hazards

*by David Etkin and Søren E. Brun*

## 4.0 The Social and Economic Impact of Hydrometeorological Hazards and Disasters: a Preliminary Inventory

*by David Etkin*

# 2.0 Atmospheric, Hydrologic and Geophysical Hazards

*by Søren E. Brun*

## 2.1 Introduction

*Natural Hazards are costly, and becoming more so. In this section, various hazards to which Canadians are exposed are overviewed, in terms of their impacts, their physical causes and their frequency of occurrence.*

There has recently been increasing concern about the occurrence of natural hazards throughout the world. The number of disasters and their impacts resulting from these hazards have steadily increased during the past twenty years (Canadian National Report - IDNDR, 1994). **To what extent they are due to increased human exposure or to an actual increase in the frequency and magnitude of the hazards, or both, is not clear**. Regardless of the reason, these disasters have had an impact on millions of people around the world, and mitigation measures and reconstruction have been very costly.

From 1984-1994, the Canadian insurance industry has paid more than $1 billion to compensate for the losses sustained by major natural disasters for damage to homes, businesses and vehicles. This total represents an average outlay of $100 million per year for claims arising from events such as thunderstorms, tornadoes, hail, windstorms and flooding. The total costs to Canada, including the uninsured costs and damage to public property, is estimated at more than double the insurance costs (Canadian National Report - IDNDR, 1994). Figure 2.1 shows costs incurred by the insurance industry for major multiple payouts resulting from atmospheric hazards. The most expensive events are hail, tornadoes, flood, storm and windstorm. This figure does not include the costs of smaller events, and therefore the true costs are much higher.

Three recent examples of Canadian disasters occurred in July 1996, when damaging hailstorms hit Calgary, Alberta and Winnipeg, Manitoba, and severe flooding devastated the Saguenay region of Quebec. The costliest single Canadian event was the Calgary hailstorm of 1991 which totalled $450 million in economic losses with $360 million sustained by the insurance industry. The drought of 1988 cost Canada about $1.4 billion in insurance and government subsidies. The costs of the Saguenay flood have been estimated between $1–1.5 billion.

**Though historical costs for atmospheric and hydrologic hazards are substantial, future geophysical events (e.g. earthquakes) could be staggeringly expensive**. For instance, if a single high magnitude earthquake occurred in Vancouver or lower Quebec, the economic losses could range from $14 to $32 billion (Canadian National Report - IDNDR, 1994).

Therefore it seems imperative for scientists, government, and the insurance industry to gain an understanding of the potential threats, as well as their effects on Canadian society. Accordingly, this section is devoted to documenting the occurrence of Canadian atmospheric, hydrologic and geophysical hazards.

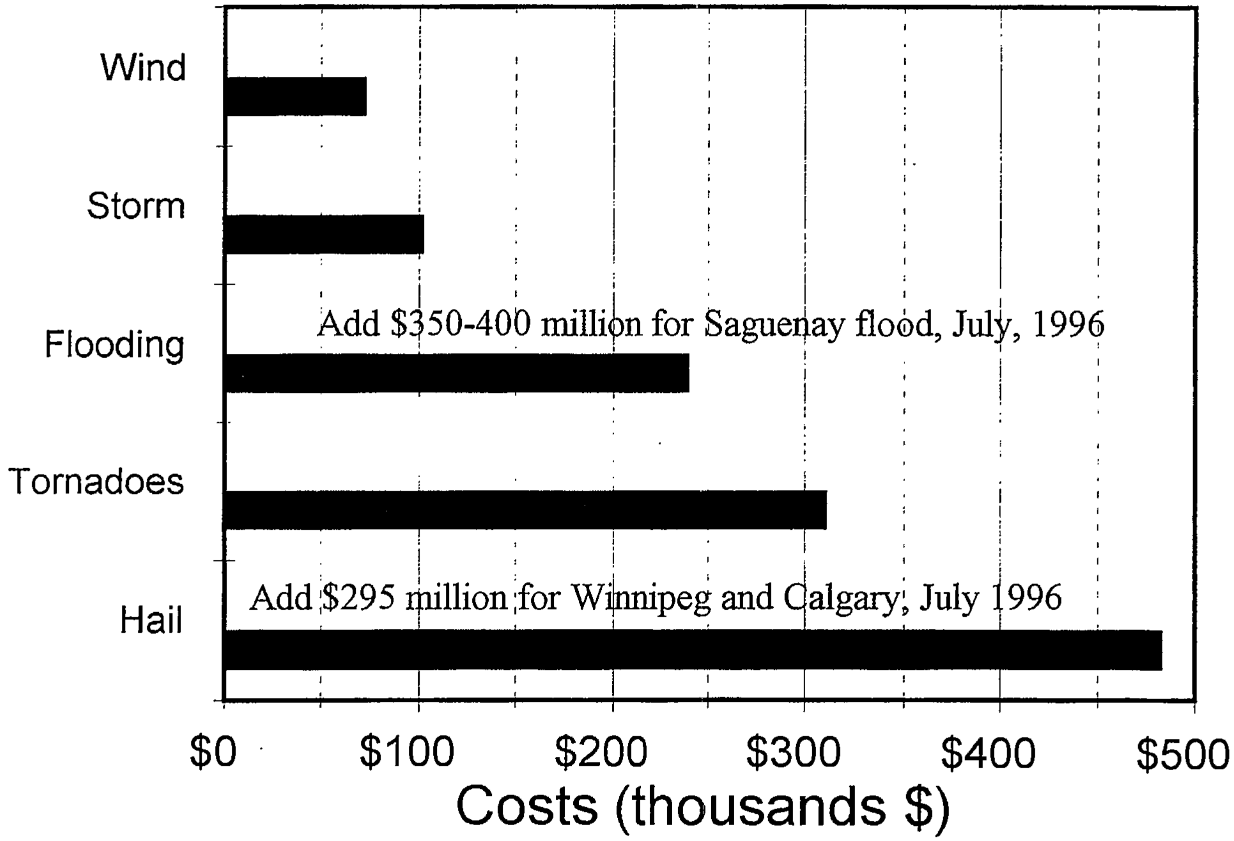


Figure 2.1 Weather Related Insurance Costs (1984-1994) from Major Multiple Payouts (1995$).
Source: Insurance Bureau of Canada

## 2.2 Atmospheric Hazards

**Of all the natural hazards which threaten human society, those caused or facilitated by weather extremes are the most common** (Smith, 1996). On a world-wide basis, relatively few people are directly exposed to geologic hazards (e.g. earthquakes or mass movement of the earth's surface); everyone, however, is exposed to the variability of weather and climate. Canada, like many countries, is exposed to a wide variety of weather extremes (Etkin and Maarouf, 1995). These include cold waves and blizzards, thunderstorms, tornadoes, hail, windstorm, lightning and even tropical cyclones and geomagnetic storms.

The section provides an overview of the major atmospheric hazards that threaten Canadian society. For each hazard, a summary of both the temporal and spatial distribution of each hazard and the physical processes that lead to its development will be given.

### *2.2.1 Thunderstorms*

**Thunderstorms are a significant natural hazard, producing a variety of potentially dangerous situations: damaging hail, tornadoes, high winds, intense rainfall and lightning.** Furthermore, a single, well developed thunderhead can produce all of these hazards. A thunderstorm is loosely defined as any storm which contains lightning and thunder.

On any given day, there are about 40,000 thunderstorms of various intensities occurring around the globe (Ahrens, 1994). In Canada, they occur typically in the warm season, between early spring and early fall. Heavy thunderstorm activity in summer results from the presence of warm, moist, unstable air masses that migrate northward into Canada. Figure 2.2 shows the spatial distribution of the mean number of thunderstorm days across Canada for the years 1951 to 1980. The eastern maximum of more than thirty per year occurs in south-western Ontario. The western Canadian maximum, of between twenty-five and thirty, occurs on the prairies encompassing much of Alberta.

*Thunderstorm Development*
There are three stages to thunderstorm cloud development: cumulus, mature and dissipation (see Figure 2.3). These three stages can take as little as thirty minutes and as long as a couple of hours (even longer for more intense supercell thunderstorms).

Thunderstorms are initiated in unstable atmospheric environments when warm, moist air rises. As it ascends, it cools and reaches its condensation level where the moisture in the air condenses to form cumulus clouds which have a billowing, white appearance (see Figure 2.3). As more incoming moisture-laden air rises from below, eventually an extensive vertically developed cumulus cloud will form. The updraft formed in this stage is strong enough to keep the water droplets suspended within the cloud, and no precipitation occurs.

The *mature stage* is marked by a well defined updraft on the leading edge of the storm, with a downdraft immediately aft (see Figure 2.3). Two processes produce the downdraft:

1. As warm, moist air rises and cools, it condenses to form rain drops. When these drops grow too large to be supported by the updraft, they begin to fall. As they do, they drag air down with them, initiating the downdraft. This will form a precipitation shaft in the

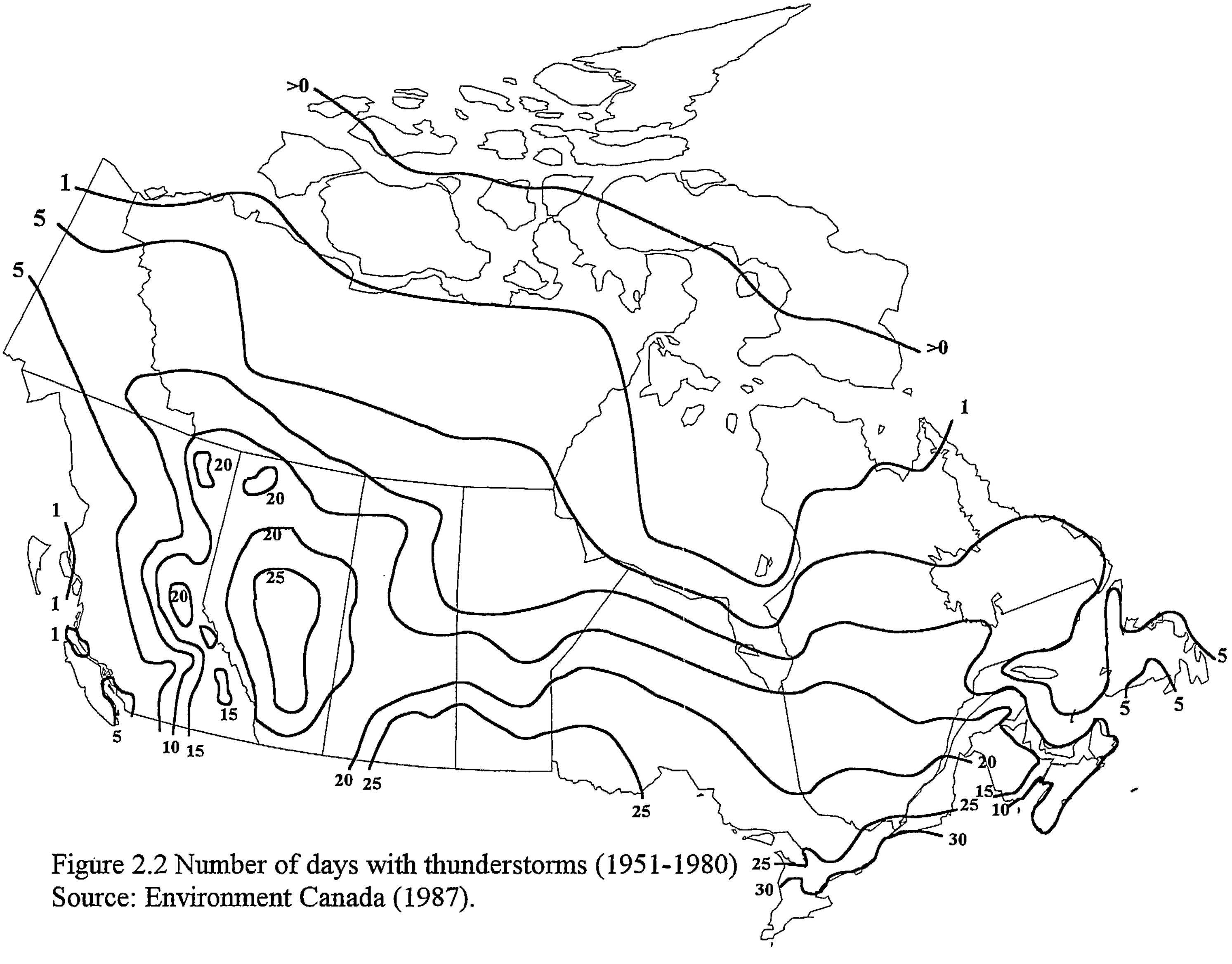


Figure 2.2 Number of days with thunderstorms (1951-1980)
Source: Environment Canada (1987).

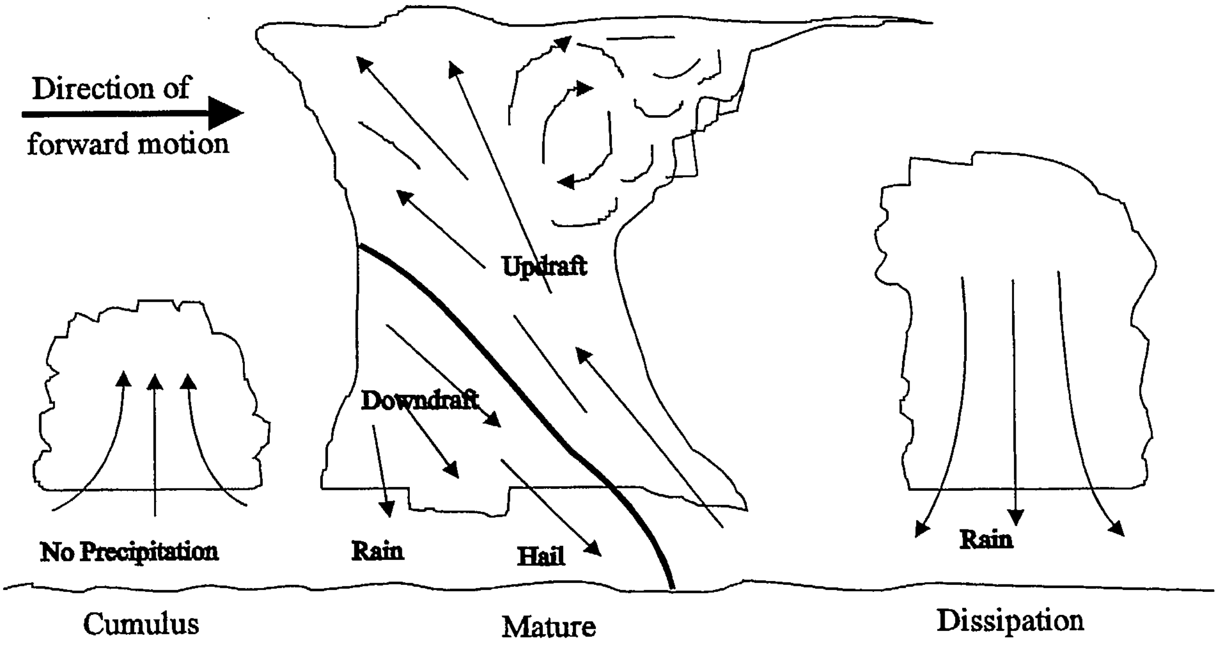


Figure 2.3 Stages in thunderstorm development.

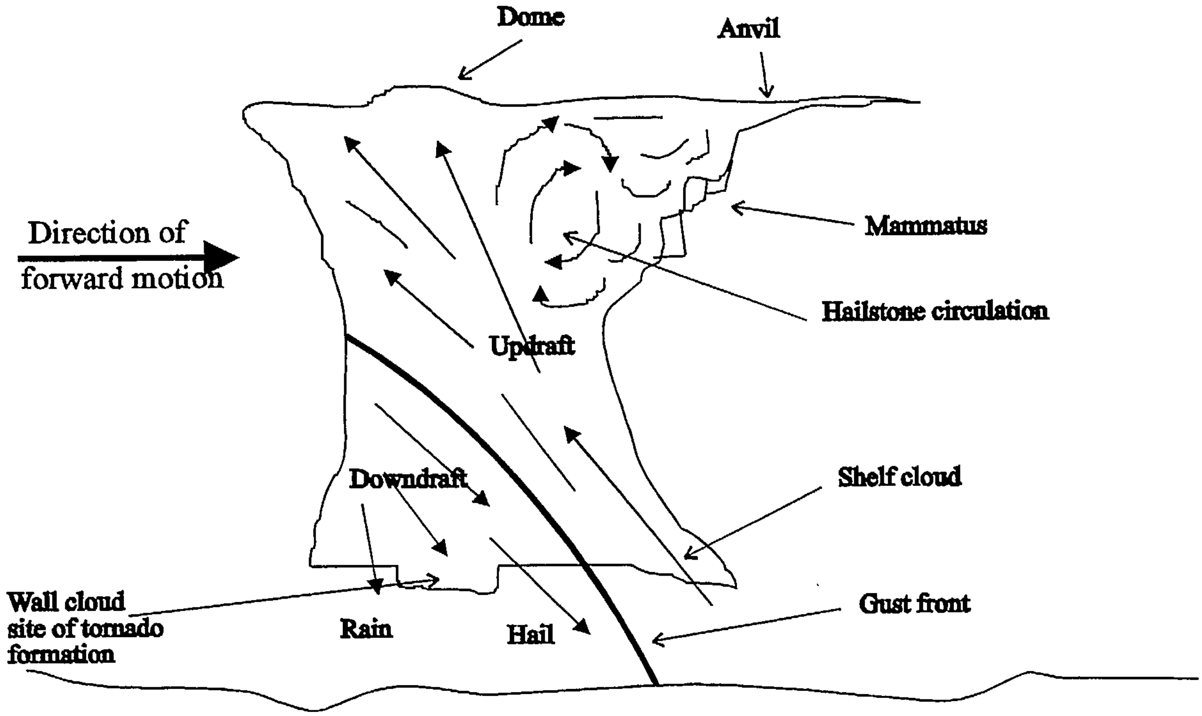


Figure 2.4 Potential sites for severe weather of an ordinary thunderstorm

aft portion of the storm, which is now called a towering cumulonimbus cloud.

2. The downdraft is initiated by the evaporative cooling of the air within the cloud. Because cooler air is more dense and less buoyant than warm air, some of the air inside the cloud will begin to sink back down to the earth's surface, thereby forming the downdraft.

When the downdraft becomes dominant, because of its cooling effect and precipitation drag, it will interfere with the updraft. This cuts off the storm moisture and energy supply, and the storm will begin to dissipate.

In its mature stage, a thunderstorm helps to maintain the balance of moisture, heat and electricity between the earth's surface and the atmosphere. This stage can be thought of as analogous to a large vacuum cleaner. Warm moist air is injected into the leading edge of the storm. This air then rises, cools, condenses and releases the energy (called latent heat) previously stored in the moisture. The energy released from condensation is used as fuel for the storm. The waste product is water which exits in the rear portion of the cloud (see Figure 2.3).

For thunderheads to form, the unstable atmosphere must possess two characteristics – an abundance of low level moisture to serve as fuel for the growing storm, and a lifting mechanism to induce upward motion (the 'trigger'). In general, there are four kinds of lifting mechanisms: orographic, convection, convergence and frontal. *Orographic* refers to lifting due to a barrier to the flow (e.g. a mountain). Though this mechanism does not usually form thunderstorms, it can produce heavy rainfall in mountainous regions and lead to flooding. *Convection* is often caused by the daytime solar heating of the earth's surface, which warms the surface air and causes it to rise on its own. In *convergence*, air streams narrow, forcing air to move vertically, which happens with low-pressure areas. *Frontal* lifting takes place where warm and cold air masses meet. As the air masses collide, warm air is forced up and over the cold air. In general, cold fronts have a steeper frontal surface than warm fronts and therefore, cold fronts force surface air up more rapidly than do warm fronts. Cold fronts more commonly form major thunderstorms and severe weather. In general, thunderstorms initiated by convection or convergence are weaker than those produced by cold fronts.

**The majority of thunderstorms do not become severe.** In most instances, when the updraft can no longer support the larger water drops within the cloud, they begin to fall back to earth through the updraft itself, weakening it in the process. For a thunderstorm to become severe – with 3/4 inch hail and/or surface wind gusts of 50 knots (Ahrens, 1994) – a strong vertical wind shear must be present. Such a shear is produced when wind speeds aloft are greater than and/or from a different direction than those near the surface, causing the updraft to tilt during the mature stage. Any falling precipitation will then fall away from the updraft into the downdraft below. This helps to build the strengths of both the updraft and downdraft allowing more air to be circulated through the system. Figure 2.4 depicts an ordinary thunderstorm in the mature stage, showing the potential sites for severe weather.

### *2.2.2 Tornadoes*

**Tornadic thunderstorms are the most violent and damaging type of weather extreme** (Klemp, 1987). In comparison to average thunderstorms, which normally only produce heavy rainfall and decay within 40 minutes, tornadic thunderstorms can last for several hours (Klemp, 1987; Ahrens, 1994). Although tornadic events in Canada are relatively rare and have limited damage paths in comparison to other natural hazards, they still represent a significant hazard because of their rapid speed of onset and violent wind speeds. They can reach devastating levels within minutes. The structure, dynamics, prediction and hazards of tornadoes is reviewed by Church et al. (1993).

Tornadoes are rapidly spinning columns of air which extend down from the base of thunderheads. Their diameter at the earth's surface is usually from 100 to 600 m. Occasionally, however, especially with the more violent ones, the tornado's diameter has exceeded 1.6 km (Ahrens, 1994). Tornadoes usually remain in contact with the ground for only short distances – rarely more than 25 km. Their forward motion averages 65 kph, but they have been known to travel as fast as 100 kph (Ahrens, 1994).

To make tornadoes even more hazardous, they commonly occur in families; a single line of thunderstorms can spawn numerous tornadoes. In the most extreme case, on April 3-4, 1974, 148 tornadoes cut through 13 U.S. states, killing 307 people, injuring more than 6000, and causing an estimated $600 million in damages (Ahrens, 1994). In Canada, a family of seven tornadoes travelled through South-western Ontario on May 31, 1985 (Newark, 1988), extensively damaging Barrie, Orangeville and Grand Valley. Twelve people were killed, 155 were injured, and total damage was estimated at $100 million. Table 2.1 lists the 10 worst Canadian tornadoes, by the number of fatalities.

Tornado intensities are classified by the Fujita Scale (Fujita, 1973) (see Table 2.2). F0 and F1 tornadoes are weak, causing little damage; while F4 and F5's can cause major devastation. Canada, unlike the United States, does not receive many of the more damaging tornadoes. From 1918 to 1992, Canada recorded no F5's and only 8 F4's (Etkin and Brun, unpublished). Most Canadian tornadoes range from F0 to F2 (see Table 2.3). Table 2.4 lists the mean areal extent of damage caused by each F-scale type.

Figure 2.5 gives the tornado frequency for Canada, adjusted to include tornadoes that likely occur, but which are not observed (Etkin and Brun, unpublished) – surpassed only by the United States (Etkin and Maarouf, 1995). Extreme south-western Ontario has the highest tornado frequency in Canada, with approximately 10 events per year per 10,000 km$^2$. A maximum of approximately five events per year per 10,000 km$^2$ occurs in western Canada. The annual and diurnal patterns of tornadic events are shown in Figures 2.6 and 2.7, respectively (Etkin and Brun, unpublished). The peak number of events occurs during the month of July, between 2 and 4 p.m.

*The Mechanics of Tornadic Thunderstorms*

There are two basic atmospheric conditions required for the development of tornadic thunderstorms: very unstable air and cloud rotation resulting from wind shear. Where very unstable air is present, severe thunderstorms are produced. These thunderstorms are often associated with frontal lifting mechanisms, where air is

Table 2.1 Ten most deadly Canadian tornado occurrences.

| Rank | Location | Date | No. of fatalities | No. of injured | Damage ($) |
|---|---|---|---|---|---|
| 1 | Regina | 30 June, 1912 | 28 | hundreds | 4 million |
| 2 | Edmonton | 31 July, 1987 | 27 | 253 | 250 million |
| 3 | Windsor | 17 June, 1946 | 17 | hundreds | 1.5 million |
| 4 | St. Zotique to Valleyfield Quebec | 16 August, 1888 | 9 | 14 | extensive damage |
| 5 | Windsor | 3 April, 1974 | 9 | 30 | 1.5 million |
| 6 | Barrie, Ontario | 31 May, 1985 | 8 | 155 | 100 million |
| 7 | Buchtouche, New Brunswick | 6 August, 1879 | 7 | 10 | 100 thousand |
| 8 | Sudbury, Ontario | 20 August, 1970 | 6 | 200 | 5 million |
| 9 | Montreal | 14 June, 1982 | 6 | 26 | unknown |
| 10 | Portage la Prairie, Manitoba | 22 June, 1922 | 5 | unknown | extensive damage |

Source: Phillips (1990).

Table 2.2 F-scale classification according to wind speed and damage.

| F number | Maximum gust speed (kph) | Type of damage |
|---|---|---|
| F0 | 64–115 | Light: broken tree branches and signs |
| F1 | 116–179 | Moderate: trees snapped, windows broken |
| F2 | 180–251 | Considerable: large trees uprooted, weak structures destroyed |
| F3 | 252–329 | Severe: trees levelled, cars overturned, walls removed from buildings |
| F4 | 330–416 | Devastating: wooden frame houses destroyed |
| F5 | 417–508 | Incredible: severe damage to steel-reinforced structures. |

Source: Fujita (1973); Ahrens (1994).

Table 2.3 F-scale intensities for eastern and western Canada (1918 – 1992).

| F scale | Total no. of each type Western Canada | Percentage Western Canada | Total no. of each type Eastern Canada | Percentage Eastern Canada | Total no . of each type All of Canada | Percentage All of Canada |
|---|---|---|---|---|---|---|
| 0 | 209 | 40.6 | 459 | 47.6 | 668 | 45.1 |
| 1 | 139 | 26.9 | 290 | 30.1 | 429 | 29.0 |
| 2 | 138 | 26.7 | 177 | 18.4 | 315 | 21.3 |
| 3 | 29 | 5.6 | 31 | 3.2 | 60 | 4.1 |
| 4 | 1 | 0.2 | 7 | 0.7 | 8 | 0.5 |
| Total | 516 | 100 | 964 | 100 | 1480 | 100 |

Source: Etkin and Brun (unpublished).

Table 2.4 National Severe Storms Forecasting Centre mean path dimensions.

| F scale | Length (km) | Width (km) | Area ($km^2$) |
|---|---|---|---|
| 0 | 1.77 | 0.04 | 0.08 |
| 1 | 4.18 | 0.10 | 0.36 |
| 2 | 9.14 | 0.15 | 1.40 |
| 3 | 19.49 | 0.27 | 5.17 |
| 4 | 36.16 | 0.40 | 14.29 |

Source: Grazulis et al. (1993).

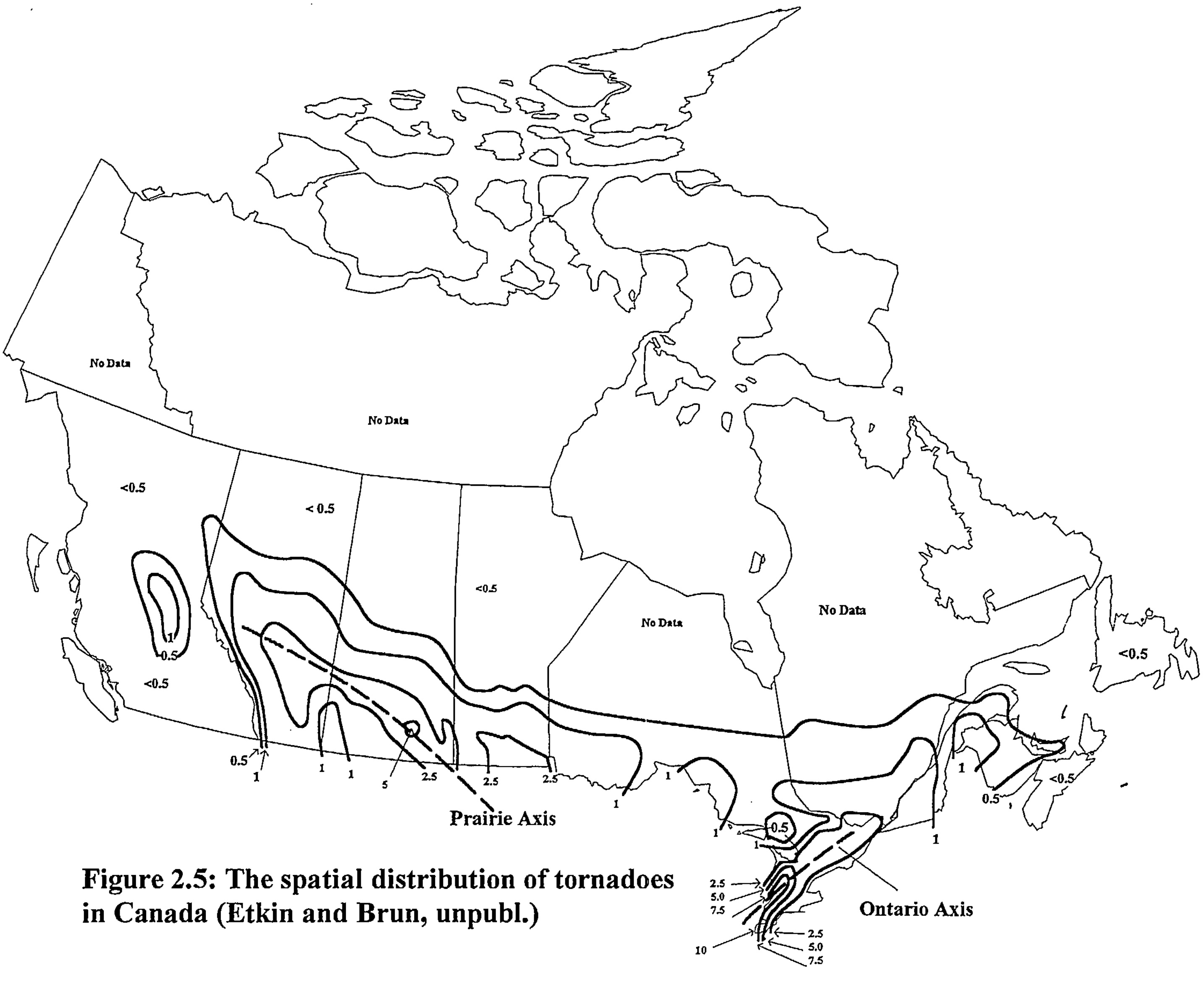


**Figure 2.5: The spatial distribution of tornadoes in Canada (Etkin and Brun, unpubl.)**

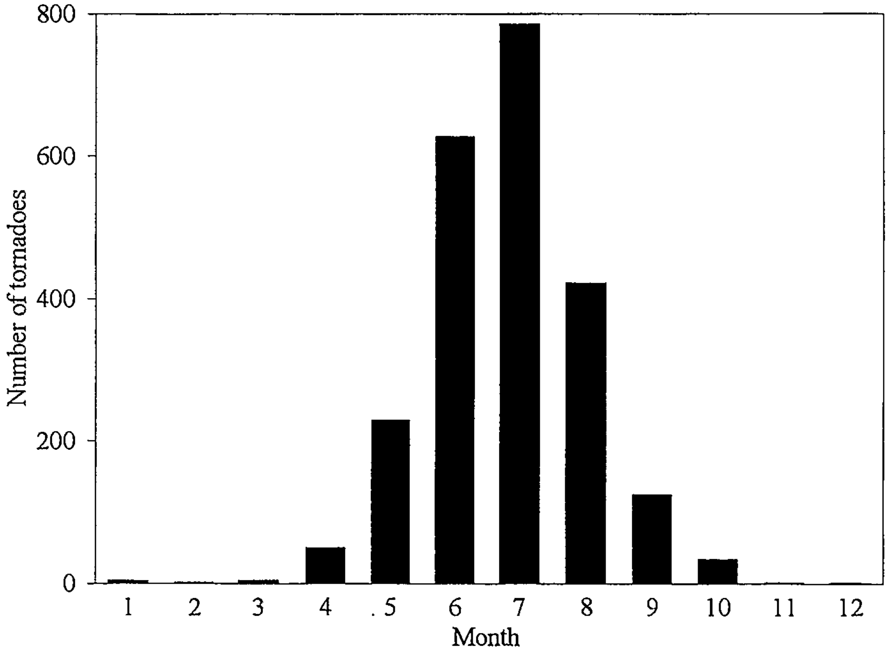


Figure 2.6 Monthly patterns of Canadian tornadoes (1918 - 1992)

Source: Etkin and Brun (unpublished)

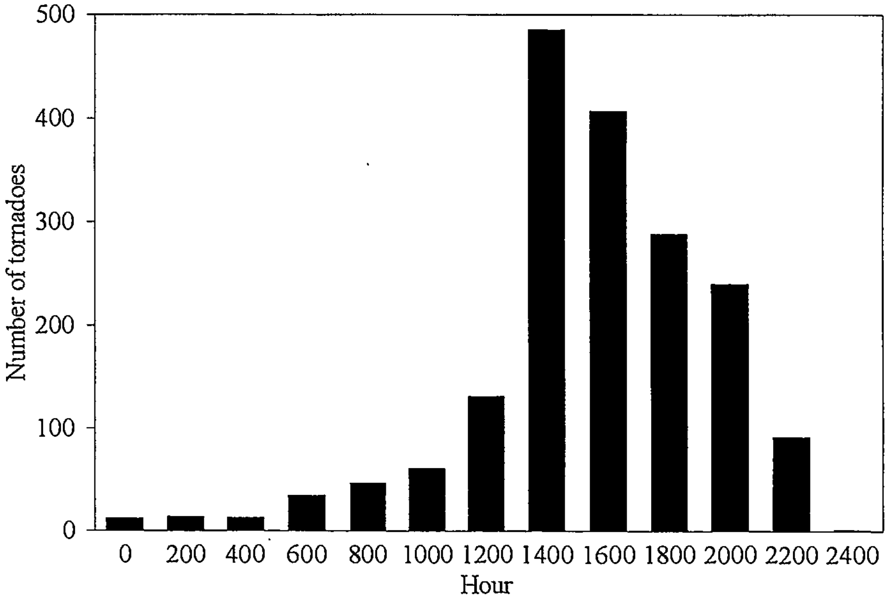


Figure 2.7 Diurnal patterns of Canadian tornadoes (1918 - 1992)

Source: Etkin and Brun (unpublished).

rapidly forced upward. They are more frequent where cold polar air comes in contact with warm moist air from the Gulf of Mexico. This is the main reason why eastern Canada receives more thunderstorms and tornadoes than western Canada.

Normally, colliding air masses simply generate numerous thunderheads on the leading edge of the cold front, with the atmospheric energy dispersed among them. Formation of thunderheads severe enough to spawn tornadoes is enhanced by the presence of an inversion layer, which limits the number of thunderheads formed and thus provides more energy to individual thunderstorms. This layer is usually located around 5000 ft. It acts initially to cap convection. However, with daytime solar heating, the air under the inversion layer becomes warmer and thus more unstable. Once it reaches a critical state, the warm air will punch through the inversion layer in isolated locations. This air, laden with moisture and extremely unstable, rises through the inversion layer and produces very severe thunderstorms.

For a thunderhead to spawn a tornado, it must begin to rotate. Under normal atmospheric conditions, wind directions and magnitudes change with increasing height (vertical wind shear), and this process can, under certain circumstances, initiate thunderhead rotation. Once this occurs, the conditions necessary to spawn tornadoes exist. However, it must be noted that even though these conditions exist, it does not necessarily imply a tornado will form. There are many other factors involved regarding the formation of tornadoes which are, as of yet, unknown.

### *2.2.3 Hail*

**Hailstorms pose a significant threat to Canada.** Severe hailstorms can cause extensive losses to property and crops in minutes. Though there have only been two recorded fatalities in North America caused by hail this century (Ahrens, 1994), these storms have caused widespread and heavy economic losses to crops, cars, homes and livestock. For instance, the worst Canadian hailstorm – Calgary, Alberta on Sept. 7, 1991 – caused $450 million in damages (Canadian National Report - IDNDR, 1994; IBC, 1996). The most costly hailstorm in the U.S., and possibly the world – in May 1995 in Texas – caused an estimated $1.125 billion (US dollars) in damage. Charlton et al. (1995), in a detailed study of urban hail incidences, found that they were among Canada's most costly natural disasters.

Damage swaths are typically between 3-20 km wide and 50-150 km long (Paul, 1991). Paul (1991) showed that a high proportion of damage caused by hail was done by long-lived storms (at least 3h) with long, narrow tracks. On average roughly three per cent of the prairie crops are wiped out by hail each year, mostly by severe storms on a relatively few number of days. Like tornadoes, hailstorms have a relatively rapid speed of onset; however, since the conditions under which they occur and their life-cycle are relatively well understood (Paul, 1991), unlike those for tornadoes, strategies (such as cloud seeding) have been developed to help reduce the hazards involved. Various hail suppression programs have been attempted in the past. A Russian program claimed success, while other programs in the U.S., Switzerland, Canada and South Africa were inconclusive (Cotton and Pielke, 1995), though some recent research reported in a conference on

'Hail Damage Mitigation and Science' reported some significant hail reduction due to cloud seeding (North Dakota Atmospheric Resource Board, 1996). As a result of studies such as the one in North Dakota, the Canadian insurance industry began, in 1996, a hail suppression program in Alberta in order to reduce losses due to hailstorms. Press releases from the industry have indicated that the program is believed to be successful.

Average hailstones range in size from small peàs to golfballs. The largest hailstone on record for Canada was 290 grams (0.6 lbs), falling on Cedoux, Saskatchewan, in August, 1973. In comparison, the largest hailstone in the U.S. weighed in at 757 grams (1.67 lbs) (Ahrens, 1994). Hailstorms generally occur in warm months, from late spring to early fall. Figure 2.8 gives the average annual number of days with hail for Canada for the period 1951-1980. The peak occurs in western Canada, with more than five days per year – the reverse of the situation for thunderstorms (see Figure 2.2). Thirteen significant hailstorm events are listed in Table 2.5.

*Hailstone Formation*

Hailstones are generated only within cumulonimbus clouds. They form when supercooled liquid from within the clouds is repeatedly accreted onto precipitation embryos, creating concentric rings of ice. The embryos can be large frozen raindrops, dust or even insects. As they travel upwards, they pass through layers of the cloud with varying liquid water contents and temperatures. Normally, the lower portions of cumulonimbus clouds are above freezing, and the higher portions, below freezing. As the embryo travels upward, it passes through the zero-degree isotherm, usually located midway throughout the cloud. Above this level, there exists supercooled liquid water which cannot readily freeze unless an object (such as dust) is present to allow for condensation or deposition. These rising embryos allow the supercooled liquid to freeze.

Therefore, as the embryo travels upward, a ring of ice will freeze onto it. As it continues upward, it passes into a region where the updraft is weaker. The updraft can no longer support its weight and the hailstone falls back to the lower portions of the cloud. From there, it can take two paths. Those that fall toward the aft end of the thunderhead usually fall into the downdraft and exit the cloud. Those that fall forward will return to the updraft in the base of the cloud. They then recirculate back to the upper portions of the cloud via the stronger updraft. As they do, more liquid water freezes onto them, forming another layer of ice.

The size of hailstones depends on the speed of the updraft, the height of the zero-degree isotherm, and the number of hailstone embryos. First, as the updraft provides the circulation mechanism, the stronger the updraft, the larger the hailstones. Second, the zero-degree isotherm's altitude determines the amount of freezing time. If it occurs at a lower altitude, then there is more time for water to freeze onto the surface of the hailstones. Furthermore, since the strength of the updraft decreases with height, if the zero degree isotherm is too high, then there is less time for freezing to occur, and the updraft is too weak to support the formation of large hailstones. Third, if there are too many hailstones, they compete for the existing supercooled liquid water. This reduces the potential size of the hailstones, regardless of the strength of the updraft. Accordingly, hail-suppression techniques

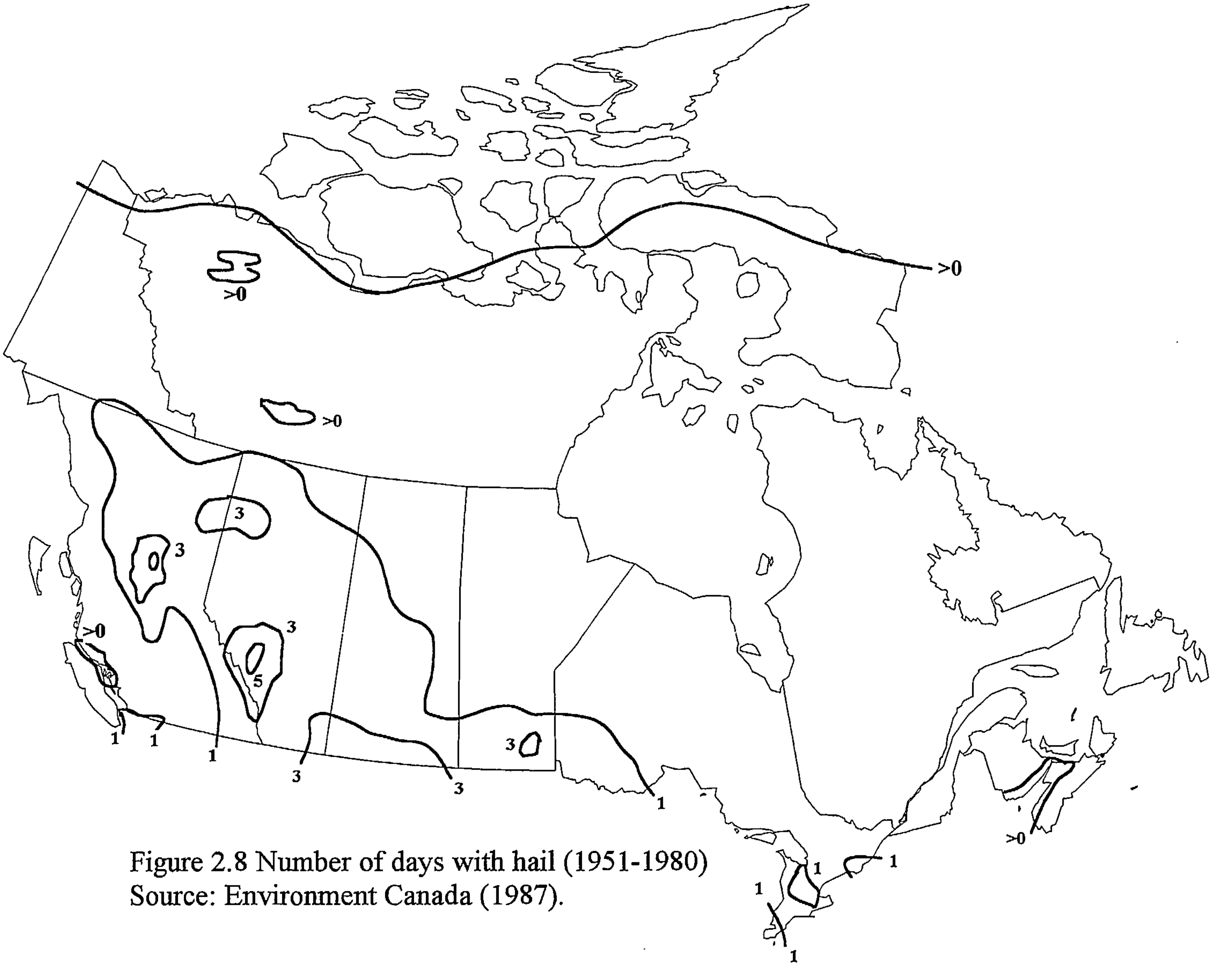


Figure 2.8 Number of days with hail (1951-1980)
Source: Environment Canada (1987).

Table 2.5 Major Canadian hailstorms.

| Location | Date | Damages ($) |
|---|---|---|
| Calgary | 7 Sept., 1991 | 450 million |
| Calgary | 16 July, 1996 | 150 million |
| Winnipeg | 16 July, 1996 | 105 million |
| Calgary | 28 July, 1981 | 100 million |
| Montreal | 29 May, 1986 | 65 million |
| Calgary | 24 July, 1996 | 40 million |
| Windsor–Leamington, Ontario | 30 May, 1985 | 30–40 million |
| Western prairies | 23 July, 1971 | 20 million |
| Edmonton | 4 Aug., 1969 | 17 million |
| Cedoux, Sask. | 27 Aug., 1973 | 10 million |
| Okanagan Valley | 29 July, 1946 | 2 million |
| Edmonton | 10 July, 1901 | extensive damage |
| Lambeth, Ont. | 19 Aug., 1968 | extensive crop and property damage |
| Montreal | 5 June, 1979 | extensive property damage |
| Central Alberta | 14 July, 1953 | unknown |

Source: Phillips, (1990).

seed clouds with hail embryos (e.g. Silver Iodide) to induce production of more, hence smaller hailstones.

Hailstones are produced more frequently by convective thunderstorms than by those associated with cold fronts (Smith, 1996). Cold fronts push warm air aloft, often producing a zero-degree isotherm at a very high altitude. In convective storms, however, which result from strong surface heating, the zero-degree isotherm is more often at an optimal altitude within the cloud.

### *2.2.4 Lightning*

**The major threat posed by lightning is its ability to initiate forest fires.** It can also damage buildings, trees, physical infrastructure, and power supplies. Approximately seven deaths per year in Canada are caused by lightning strikes (Etkin and Maarouf, 1995). Even though only 35 % of Canada's wildfires are the result of lightning strikes, they account for 85 % of the total area burned (Stocks, 1991). Lightning starts approximately 10,000 forest fires per year in the U.S. (Ahrens, 1994) destroying thousands of acres of valuable resources and ecological habitats. In the worst documented major disaster caused by lightning, on the St. Lawrence River, a freighter exploded, killing 30 crewmen (Canadian National Report - IDNDR, 1994).

Lightning is an atmospheric electrical phenomena associated exclusively with thunderstorms. The temporal and spatial distribution of lightning in Canada are given in Figure 2.9. A lightning flash climatology for the southern Great Lakes region (Clodman and Chrisholm, 1994) shows the greatest density along Ontario's tornado axis. LaDochy and Annett (1983) produced a lightning climatology that reports effects of strikes on many types of physical infrastructure.

*Electrification of Clouds*

Lightning, or any electrical discharge, requires the existence of a charge separation – a usual condition in cumulonimbus clouds. The base of the cloud is negatively charged; the upper portions, positively. The most popular theory explains the separation as a direct result of collisions between hailstones and ice crystals within the clouds (Ahrens, 1994). As hailstones collide with liquid water, the water freezes onto the hailstone. This freezing releases energy and keeps the outer portion of the hailstone slightly warmer than the inner. Then, when a hailstone comes in contact with a colder ice crystal, positive ions are transferred to the colder ice crystal, as energy is transferred from warmer objects to cooler ones. Thus, over time, the hailstones become negatively charged and the ice crystals become positively charged. Similarly, larger liquid water drops will also tend to develop negative charges.

Larger, heavier hailstones and water droplets, with the negative charge, will sink towards the lower portions of the clouds; the lighter ice crystals, with the positive charge, migrate to the upper portion of the cloud. The resulting charge separation explains cloud-to-cloud (CC) lightning. Since the base of the cloud and the ground are both negatively charged, cloud-to-ground lightning (CG lightning) requires a charge separation, which emerges naturally as the negative base of the cloud moves over the surface. The negative charges in the base of the cloud repel those of the surface and force the positive surface charges to concentrate in the highest surface objects (e.g. trees, utility poles,...,etc.). Charge separation results, with lightning always striking the highest objects in an area.

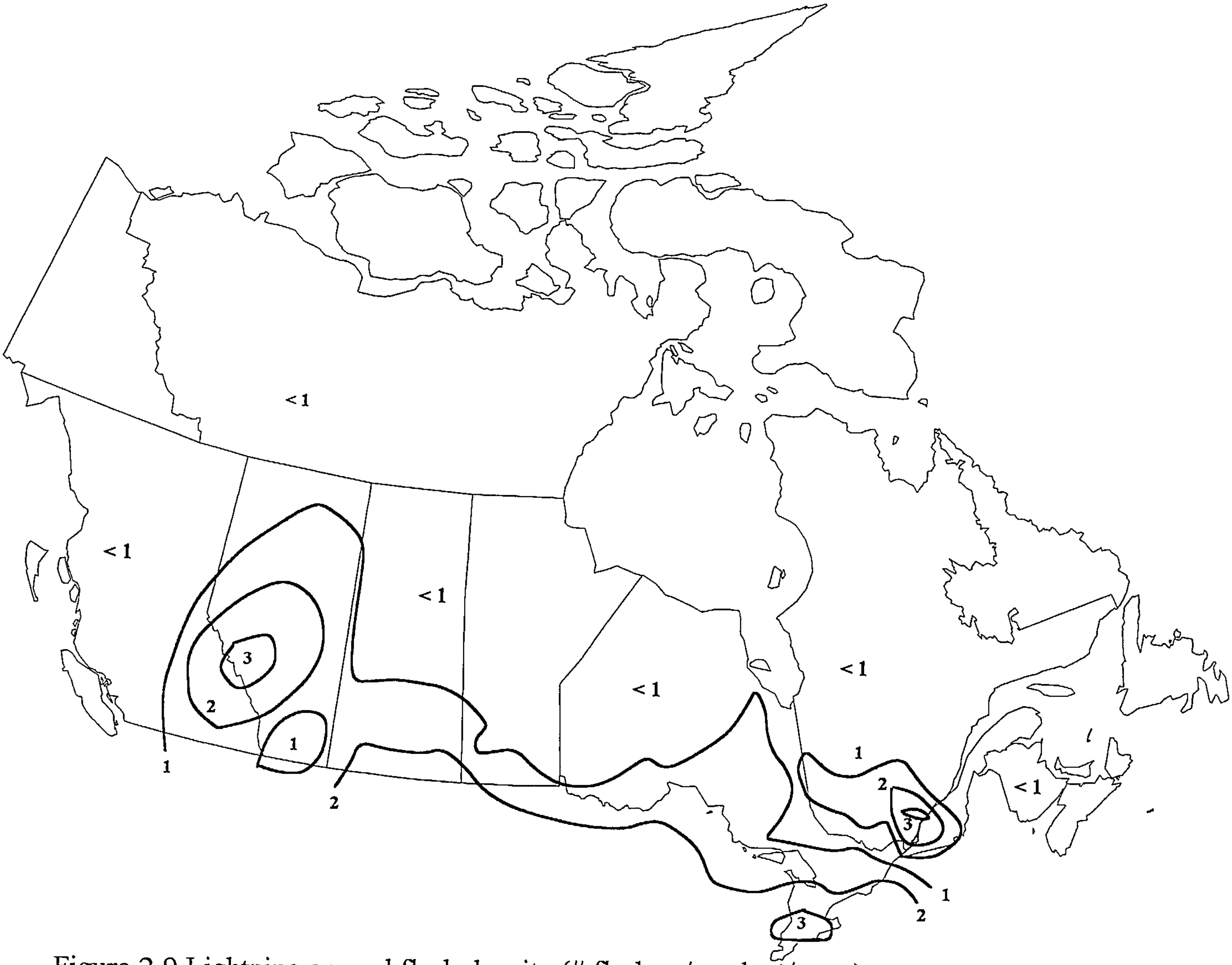


Figure 2.9 Lightning ground flash density (# flashes / sq. km / year).
Source: Janischewskyj and Chisholm, 1992.

## *2.2.5 Tropical Cyclones and Hurricanes*

**Tropical cyclones are storms that originate in the world's tropical oceans (Smith, 1996). The most significant are those that reach hurricane status, and they are probably one of the greatest natural threats to humanity** – they possess awesome power, strike densely populated and vulnerable coastal regions (e.g. Bangladesh), and are relatively frequent. The risk associated with them is steadily increasing as large coastal cities continue to develop (e.g. Miami).

Though high wind speeds are associated with tropical cyclones, most of the damage results from coastal flooding caused by intense rainfall and high storm surges (Ahrens, 1994). Even though hurricanes decay rapidly over land, they can still trigger severe thunderstorms, which often produce high winds, tornadoes and flash floods. Tropical cyclones, however, develop relatively slowly and can be detected by satellite technology, and so there is usually adequate warning for areas at risk.

The severity of tropical cyclones and hurricanes is classified on the Saffir–Simpson scale (see Table 2.6), which assess wind speed, height of the storm surge, and barometric pressure. A storm can be, in ascending order of severity, a tropical disturbance (an unorganised mass of thunderstorms); a tropical depression (a large intense low pressure cell with thunderstorms); or a tropical storm (slightly more organised than the simple depression). It becomes a hurricane once the wind speeds reach 64 knots (~120 kph), the storm surge height reaches 1.5m and the central low pressure cell falls below 980 mb. There are five classes of hurricanes. Table 2.6 gives the amount of expected damage from each category.

Since Canada is in the mid-latitudes, far from sites where tropical cyclones initiate (usually between 5 and 10 degrees north or south of the equator), its exposure to hurricanes is minimal. However, many downgraded hurricanes (i.e. tropical storms or depressions) have struck the eastern seaboard causing damage to the Maritime provinces. In rare instances (e.g. Hurricane Hazel - 1954), hurricanes can reintensify over land due to the influence of the jet stream, inundating inland regions with hurricane-force storms. Figure 2.10 depicts the vulnerable regions and common hurricane paths of North and Central America.

### *Hurricane Movement and Developmental Stages*

Atlantic hurricanes usually begin as a simple tropical disturbance, sometimes called easterly waves, off the coast of western Africa in the equatorial Atlantic (between 5 and 10 degrees north and south of the equator). At this stage, it does not have a well defined low pressure cell or characteristic circulating pattern. It is in effect a mass of thunderstorms moving westward in the tropical oceans under the influence of the trade winds. Continuing westward, it may develop into a well defined low pressure cell. As it does, under the influence of the Coriolis force, it will begin to rotate counterclockwise in the northern hemisphere (opposite in the southern hemisphere). This rotation may cause the low pressure cell to intensify, creating a steeper pressure gradient, which increases the wind speeds. When the wind speeds reach 20 to 34 knots, it is called a tropical depression.

Table 2.6 The Saffir-Simpson scale of hurricane classification.

| Stage | Pressure (mb) | Wind (knots) | Storm surge (m) | Type of damage |
|---|---|---|---|---|
| Tropical disturbance | | >20 | | |
| Tropical depression | | 20–34 | | |
| Tropical storm | | 35–64 | | |
| Hurricane 1 | >980 | 65–82 | ~1.5 | Damage to trees and unanchored mobile homes |
| Hurricane 2 | 965–979 | 83–95 | ~2–2.5 | Damage to roofs, some uprooted trees |
| Hurricane 3 | 945–964 | 96–113 | ~2.5–4 | Large trees blown down, some structural damage to small buildings |
| Hurricane 4 | 920–944 | 114–135 | ~4–5.5 | Extensive damage to roofs, windows, and doors; inland flooding as far as 10 km |
| Hurricane 5 | <920 | >135 | >5.5 | Extensive damage to buildings, small buildings overturned and blown away; major damage to lower floors of all structures less than 4.5 m less than 500 m from shore |

Source: Ahrens (1994).

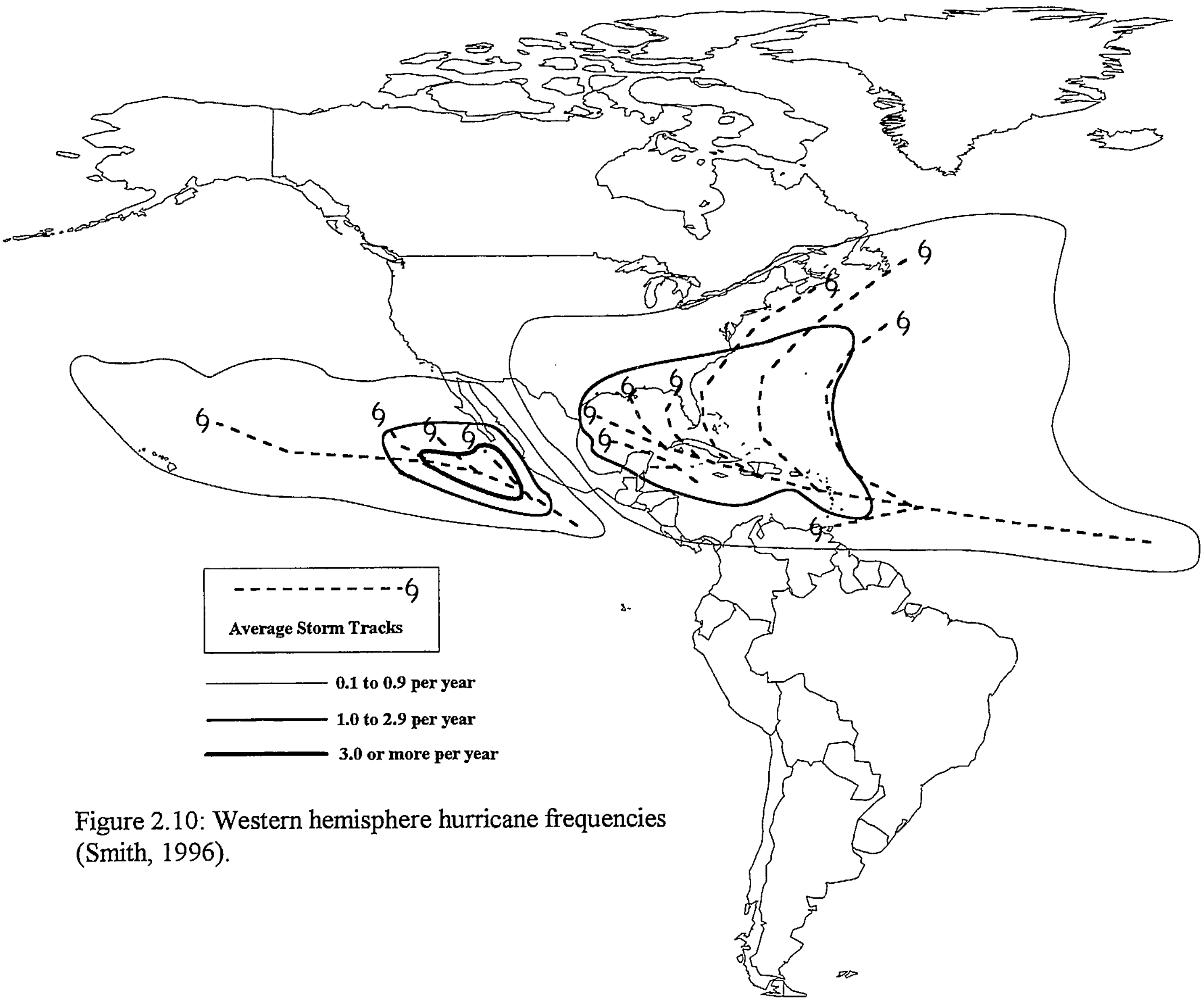


Figure 2.10: Western hemisphere hurricane frequencies (Smith, 1996).

As the storm moves westward, it slowly comes under the influence of the southern edges of the subtropical high-pressure belt. Since the pressure cells in this region rotate clockwise (i.e. the opposite of low-pressure cells) in the northern hemisphere, they will pull the storm out of the tropics and into the lower mid-latitudes (~30°N). The storm begins to move northward into the Caribbean. If the low-pressure cell further intensifies and the wind speeds increase to between 35 and 64 knots, it becomes a tropical storm. Further reduction in pressure and increases in wind speed result in hurricane status (see Table 2.6).

Pushed northward by the subtropical high-pressure cells, the storm enters the mid-latitudes (between 30 and 60°N). There, the mid-latitude westerly winds move the storm back, eastward, into the Atlantic, resulting in the characteristic U-shaped path of Atlantic hurricanes (see Figure 2.10).

*Conditions Necessary for Hurricane Development and Longevity*

Tropical storms derive their energy from the tropical oceans. As water evaporates from the ocean surface and is pulled into the storms, it rises, cools, and condenses to form clouds. Condensation releases energy and fuels the storms. For tropical cyclones to emerge, which requires extraordinary amounts of energy, temperatures at the ocean's surface must exceed 26°C (Ahrens, 1994) – one of the reasons why they only form near the equator. Unlike tornadoes and severe thunderstorms, hurricanes cannot form in the presence of strong vertical wind shears as this will shear off the top of the storm.

Moisture is crucial for hurricanes. When a hurricane reaches land, it loses its moisture supply and hence its energy source. If it moves into regions with cooler water temperatures (e.g. the North Atlantic), there is no longer sufficient energy to sustain itself. In either case, the storm will begin to decay rapidly into a mass of unorganised thunderstorms.

### *2.2.6 Mid-latitude Cyclones (Extra-Tropical Storms)*

Mid-latitude cyclones can be present over Canada at any time of the year, but they are more severe in winter. These large-scale storms are responsible for a variety of severe summer and winter weather. In winter, they are the major cause of blizzards, freezing rain (i.e. glitter storms), and heavy snowfall. During summer, they cause intense rainfall activity over widespread areas, spawn tornado families and produce numerous hailstorms.

The life-cycle of an extra-tropical cyclone is shown in Figure 2.11. Initially, two air masses form a stationary front between them (see Figure 2.11a). If a disturbance forms along the stationary front, the warm air east of the disturbance begins to advance northward, and the cold air west of it, southward. This counterclockwise motion produces a low pressure cell along the frontal boundary (see Figure 2.11b). The northward-advancing, warm air on the east side of the low forms a warm front; the southward-heading, cold air on the west side forms a cold front (see Figure 2.11c). This is the mature stage of development. Since cold fronts move faster than warm fronts, the cold front on the west side swings around and catches up to the eastward, warm front (see Figure 2.11d & e). An occluded front forms when the cold front overtakes the warm front and lifts the warm air aloft. Eventually, the entire system occludes, and the low

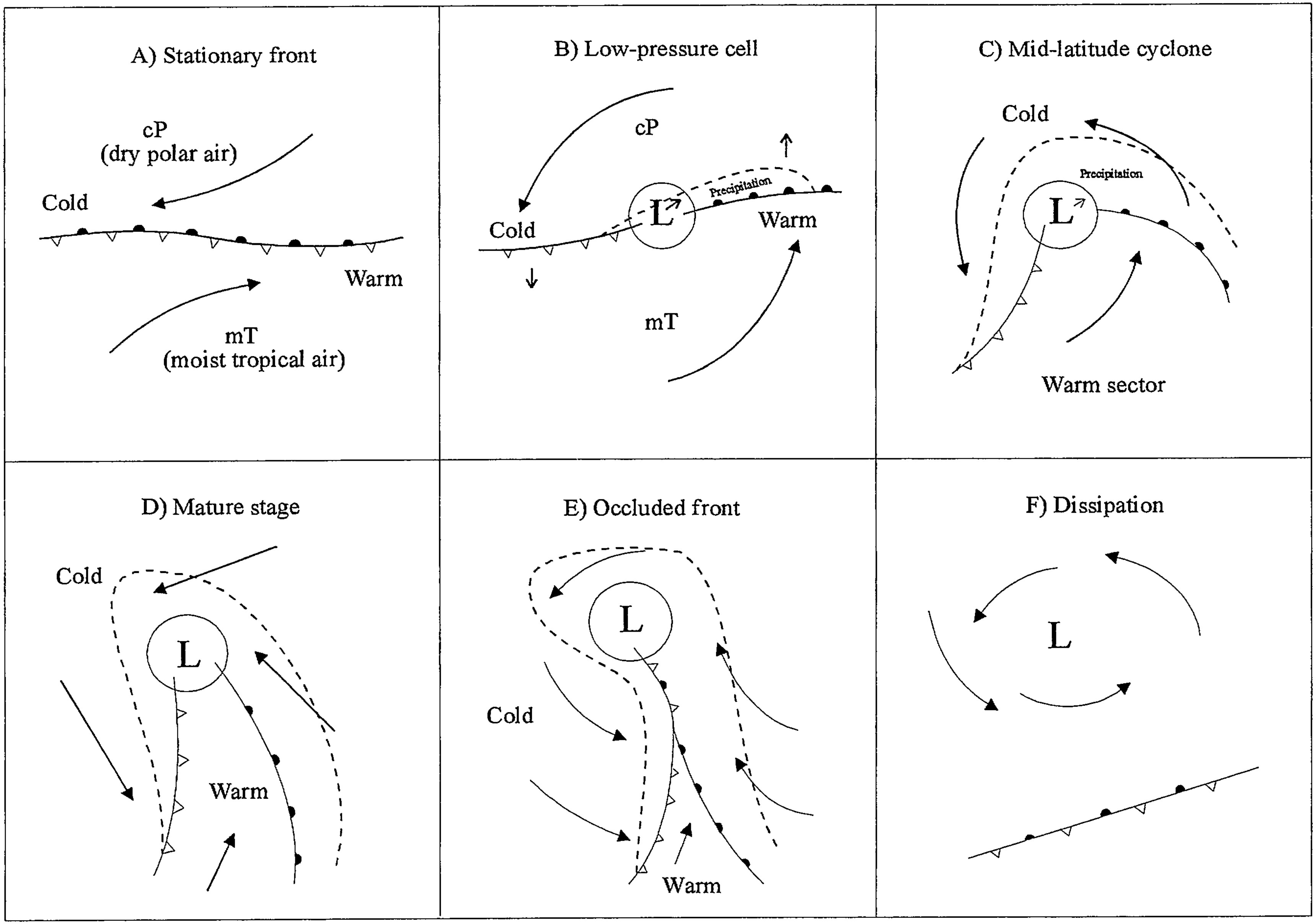


Figure 2.11 Development of a mid-latitude cyclone.

pressure cell breaks away from the front (see Figure 2.11f). At this stage, the low is called a cold low.

Storms that affect Canada usually follow one of five patterns of genesis and movement: they may originate

1. off the Pacific coast and move eastward through the lower Canadian prairies towards the Great Lakes;
2. east of the Colorado Rockies and move north-eastward through Ontario, Quebec and Newfoundland;
3. to the east of the Canadian Rockies and then pass eastward through the prairies to the Great Lakes;
4. over the Arctic regions and move south-east, through the Northwest Territories, Manitoba, Ontario and Quebec; or
5. off the southern U.S. Atlantic coast and move north-eastward along the coast to the maritime provinces.

The various types of severe summer or winter weather are a direct result of conditions associated with each portion of a mature, mid-latitude cyclone (see Figure 2.12). In winter, the strong winds and cold air behind a cold front can produce severe wind-chill. Blowing snow and high wind-chill factors are the main ingredients for blizzard conditions. Heavy precipitation over widespread areas, in the form of snow, sleet and/or freezing rain, is found along and north of the warm front to the east of the low-pressure cell. These storms usually move relatively slowly, often depositing large amounts of precipitation in their wake.

In summer, flooding is a major threat. These storms produce both widespread, heavy precipitation ahead of the warm front and intense, localised rainfall (from thunderstorm activity) in front of and on the leading edge of the cold front. Another major threat is posed by thunderstorm activity. If these thunderstorms are severe enough, they can produce multiple hailstorms and families of tornadoes dispersed over large areas.

## *2.2.7 Severe Winter Storms*

Severe winter storms may involve a number of potentially threatening events, including snow squalls and blizzards, freezing rain, severe cold snaps and heavy snowfall (Stewart et al., 1995). Canada's northern location greatly increases exposure to these cold-weather events.

The most common cause of severe winter weather in Canada is the extra-tropical cyclone (see Section 2.2.6), which can produce

1. heavy snowfall and blowing snow (i.e. blizzards);
2. freezing rain;
3. severe cold snaps; and
4. severe Atlantic and Pacific coastal storms (Stewart et al., 1995).

Furthermore, the extra-tropical cyclone and its associated weather conditions usually affect large areas, occur relatively frequently, and can cause considerable property damage and large death tolls. For instance, in March of 1993, a mid-latitude cyclone migrated up the east coast of the U.S. and Canada, producing a severe blizzard and killing more than 240 people – three times as many victims as hurricane Hugo and Andrew combined. At one point during the storm over 3 million people were left without electricity because of high wind speeds and falling trees (Smith, 1996).

### *Coastal Storms*

Intense weather systems (e.g. extra-tropical cyclones) frequently affect the Great Lakes and the Atlantic and Pacific coasts of Canada. Though these storms are associated

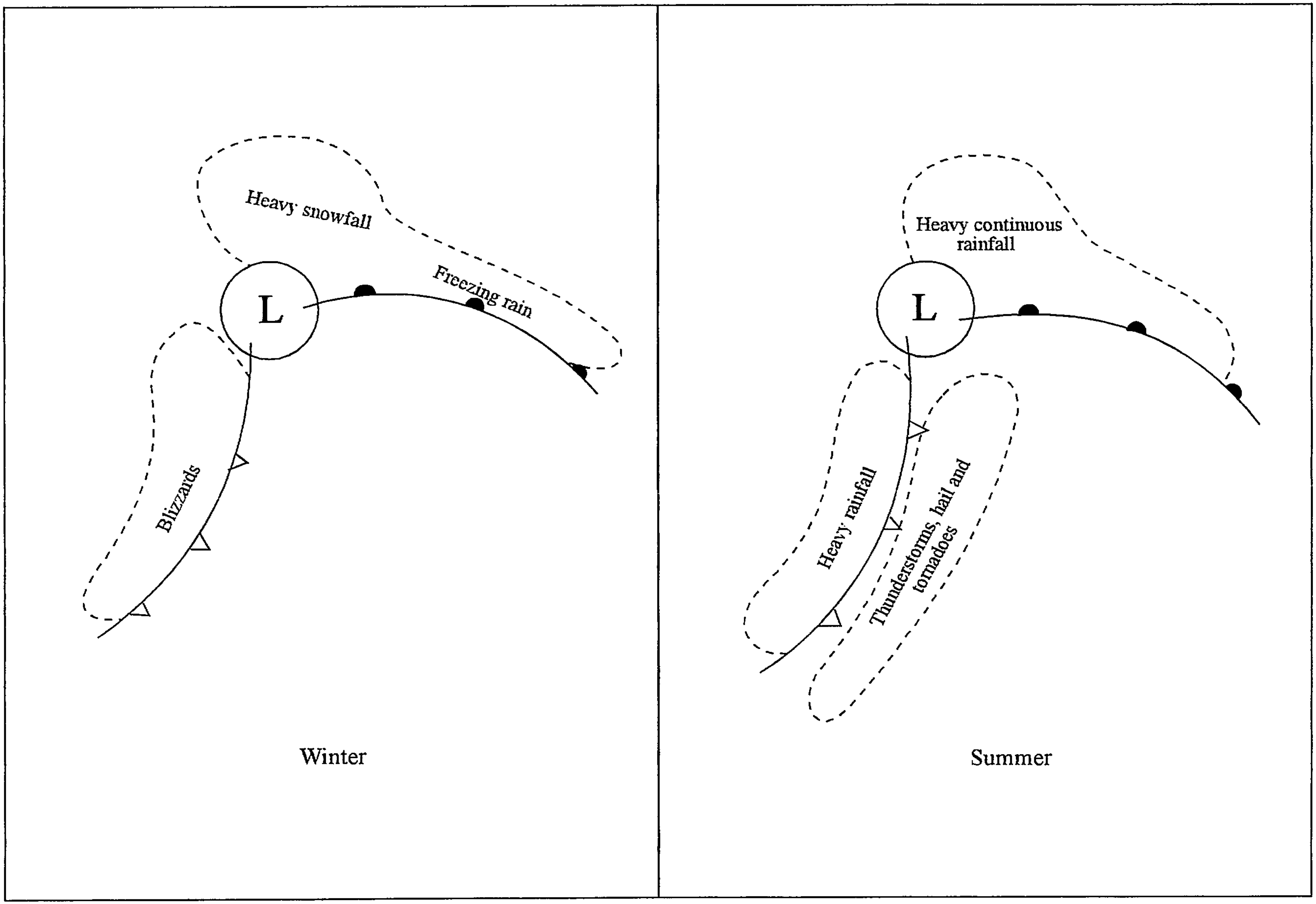


Figure 2.12 Winter and summer severe weather associated with mid-latitude cyclones.

with heavy rainfall, most of the damage results when high waves impact shorelines or come in contact with marine infrastructure (oil rigs, sea vessels,...,etc.). On a global scale, coastal waves and storm surges are the most severe marine hazard. They have caused extensive damage to property and loss of life. For example, on March 15, 1993, a powerful extra-tropical cyclone produced waves in excess of 30 m and sank the *Gold Bond Conveyor* off the coast of Nova Scotia, killing 33 crew (Canadian National Report - IDNDR, 1994).

High storm waves have caused extensive coastal erosion, leading to the collapse of numerous buildings and structures. The height of the waves depends on the strength of the wind, the configuration of the shoreline, coastal topography, tidal activities and the fetch length of the coastal sea. For instance, high winds from a severe coastal storm system can cause a build-up of waves. The length of open water (i.e. the fetch length) over which the sustained winds act helps determine the initial wave heights (i.e. the greater the length, the higher the waves). When these waves hit land, the coastal configuration and topography (e.g. mountain ranges on the west coast or coastal inlets with steep cliffs on the east coast) can increase wind speeds and wave heights by channelling wind and waves inland. A significant hazard is produced if coastal waves and storm surges occur in conjunction with high tides.

*Blizzards*

Blizzards occur across all of Canada, but they are more common in the prairie regions (Stewart et al., 1995). Blizzards are defined as any winter storm systems with wind speeds in excess of 40 kph, a wind-chill greater than 1600 $Wm^{-2}$, visibility of less than 1 km in snow or blowing snow, duration in excess of 4 hours, and temperatures under -12°C (Etkin and Maarouf, 1995; Stewart et al., 1995). At least one or two people and much livestock perishes from exposure to blizzards each year (Stewart et al., 1995). Table 2.7 is a list of the 16 most severe Canadian blizzards between 1904 and 1986. To achieve an understanding of the frequency of these events, blizzards can be characterised by the number of days with blowing snow and the annual depth of snowfall. Figure 2.13 shows the average annual number of days in Canada with blowing snow. The Arctic has the most days with blowing snow. The maximum in western Canada occurs in the southern Saskatchewan and Manitoba. The eastern shore of Lake Huron receives the highest incidence in eastern Canada, mainly because of lake effect snow from the Great Lakes (see below). The maximum average annual snowfall (Figure 2.14) occurs in the Rocky and Coastal Mountain ranges. Peaks in eastern Canada occur along an axis extending from north of the Great Lakes to the coast of Newfoundland.

*Freezing Rain*

One of the most ominous winter weather types is freezing rain, which affects nearly all of Canada (Etkin and Maarouf, 1995). In extreme cases it is quite capable of causing severe damage, especially to power transmission lines, telecommunications infrastructure, buildings, and trees, as well as massive traffic disruptions. These events can wreak havoc over large areas and last for several days. As an example, Table 2.8 lists five major freezing rain events in Canada. Figure 2.15 presents the spatial distribution of the average number of days with freezing precipitation. The largest incidences occur east of the Great Lakes and in the Maritimes.

Table 2.7 Major Canadian blizzards.

| Location | Date | Duration | Conditions |
|---|---|---|---|
| Regina | 30 Jan., 1947 | 10 days | 8 m high snow drifts |
| Regina | 6 Feb., 1978 | 4 days | |
| Winnipeg | 4 Mar., 1966 | 2 days | 35 cm of snow and 120 kph winds |
| Montreal | 4 Mar., 1971 | 2–7 days | 47 cm snow and 110 kph winds |
| Prince Edward Island | 22 Feb., 1982 | 5 days | 60 cm of snow, and 80 kph winds |
| London, Ont. | 9 Dec., 1977 | 3 days | 100 cm of snow |
| Southern prairies | 15 Dec., 1964 | | -34°C, 90 kph winds, and 3 fatalities. Called the "The Great Blizzard" |
| Newfoundland | 16 Feb., 1959 | | 5 m drifts and 70,000 people without power |
| Toronto | 11 Dec., 1944 | 2 days | 57 cm of snow |
| Southern prairies | 24 mar., 1904 | 3 days | 30 cm of snow and 100 kph winds |
| Southwestern BC | 4 Dec., 1980 | | 20–30 cm of snow. Record low temps. |
| Iqaluit, NWT | 8 Feb., 1979 | 10 days | 100 kph winds and -40°C temperatures |
| Southern Alberta | 14 May, 1986 | 2 days | Knee-deep snow and 80 kph winds |
| Montreal | 7 Nov., 1969 | 60 hours | 70 cm of snow and 15 fatalities |
| Manitoba | 7 Nov., 1986 | | 30 cm of snow and 90 kph winds |
| Ottawa | 7 Dec., 1983 | | 30 cm of snow and 48 kph winds |

Source: Phillips (1990).

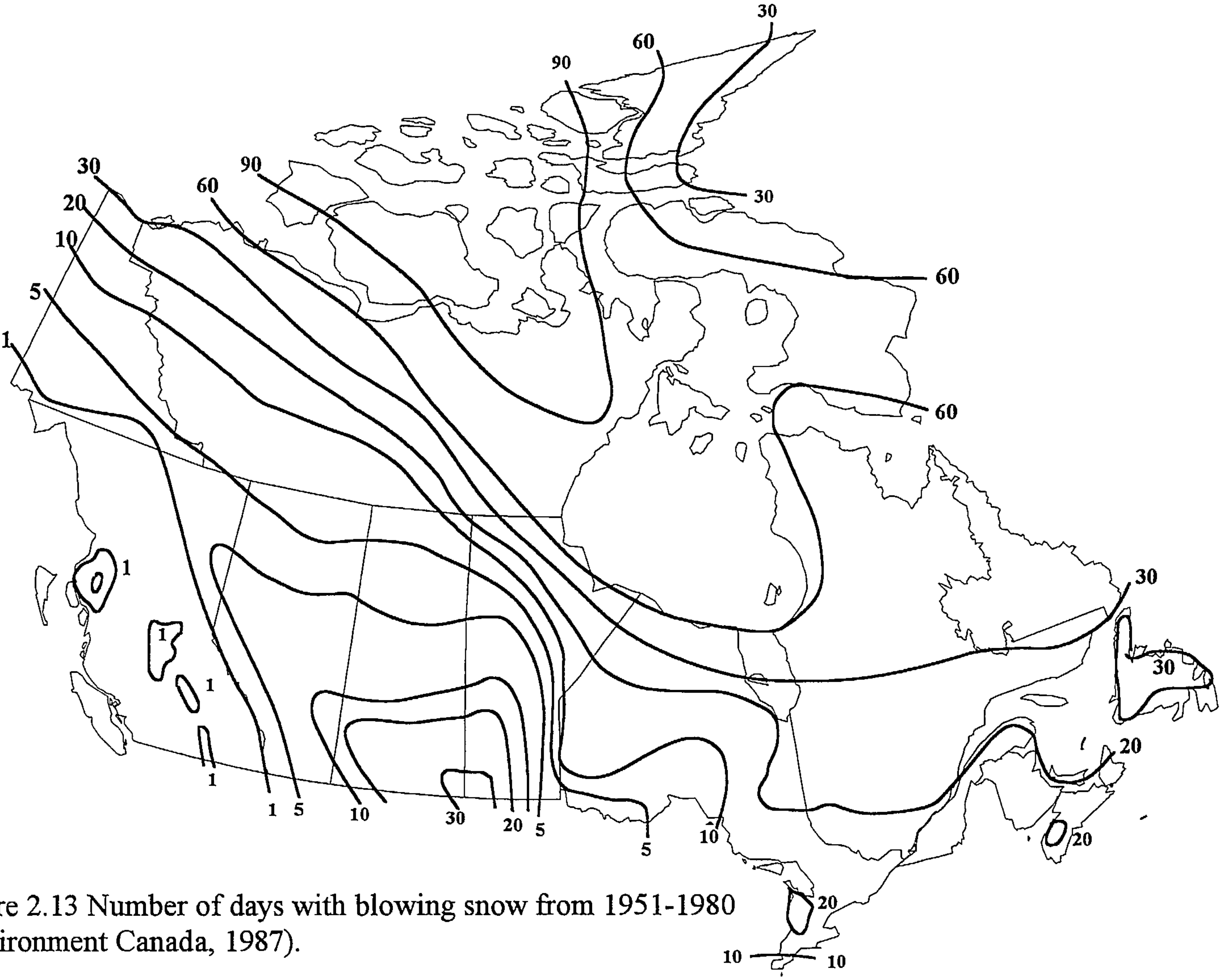


Figure 2.13 Number of days with blowing snow from 1951-1980 (Environment Canada, 1987).

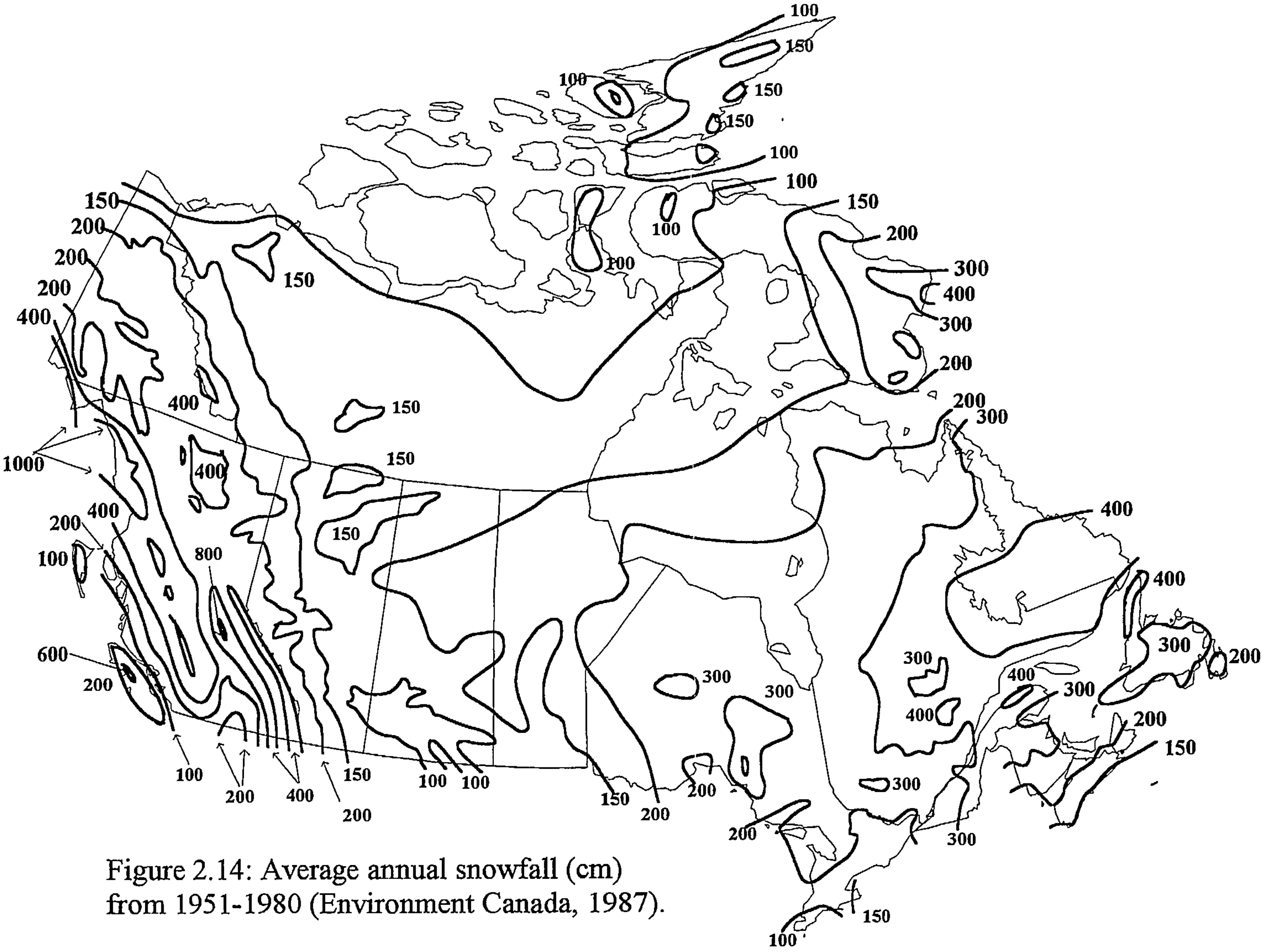


Figure 2.14: Average annual snowfall (cm) from 1951-1980 (Environment Canada, 1987).

Table 2.8 Significant freezing rain events.

| Date | Location | Conditions |
|---|---|---|
| Mar. 1953 | St. Johns, Nova Scotia | 43 hours of continuous freezing rain |
| 25 Feb., 1961 | Montreal | Ice storm heavily loaded utility wires, causing them to snap. Some areas were without electricity for a week. |
| Jan. 1968 | Southern Ontario | 3 days of on-and-off freezing rain and wet snow caused widespread power failures, closed schools, cancelled food deliveries, disrupted mail and fire services, collapsed buildings and antennae, isolated hospitals, and blocked highways |
| 11 April, 1984 | St. Johns, Nova Scotia | 200,000 residents were left without power after an ice storm blanketed transmission lines with 15 cm of ice, causing them to snap |
| 24 Dec., 1986 | Ottawa | 14 hours of freezing rain left one in four homes without electricity |

Source: Phillips (1990).

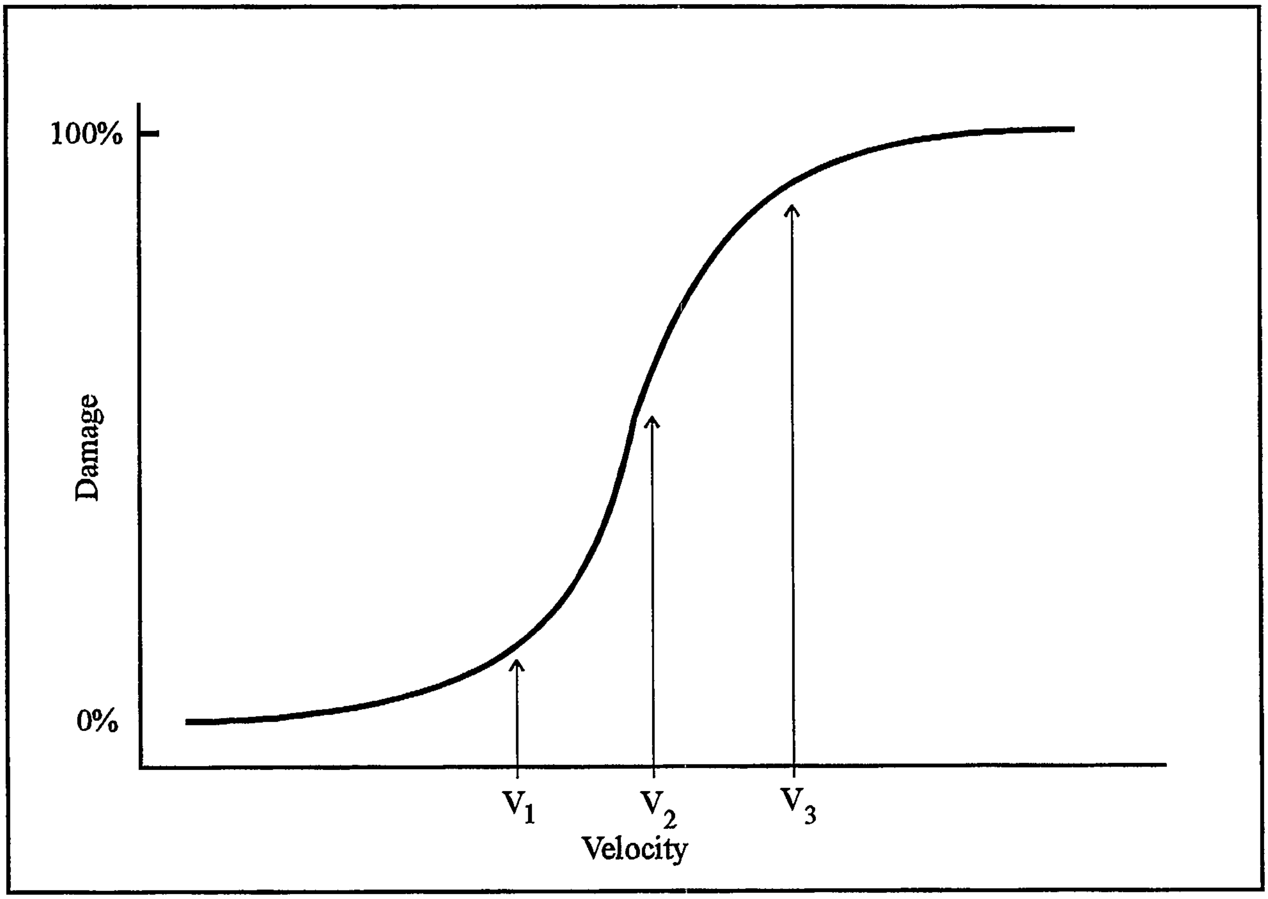


Figure 2.15 Hypothetical curve for wind damage. Source: Davenport (1994).

### *Physical Processes of Sleet and Freezing Rain*

The formation of sleet and freezing rain is a result of frozen precipitation falling through an irregular vertical temperature profile. Normally, the air through which snow falls in winter is warmer – though still below freezing – closer to the ground, and hence snowflakes remain frozen. Occasionally, instead of this characteristic temperature profile, a layer of warm temperatures hovers, on the order of 100's of metres, above the surface (i.e. an inversion layer). In winter, inversion layers are common just ahead of warm fronts and over large cities, though the main cause of freezing rain is due to inversion layers associated with warm fronts. Cold air trapped in valleys as warmer air advances into a region can also contribute to this phenomenon. In cases where this inversion layer is present, as snow falls towards the surface, it will pass through a layer of warmer air. Depending on the thickness of this layer, snowflakes falling through it will melt either partially or completely. When they pass into the lower, colder layer, they may completely refreeze or remain as supercooled liquid drops. If they refreeze, the original snow flakes are transformed into solid pellets of ice, normally called ice pellets in Canada or sleet in the US. If they become supercooled liquid drops, they produce freezing rain. The drops freeze instantaneously onto surface objects, forming a thin coating of ice. In extreme events, tonnes of ice may form on a single tree or power transmission lines, causing extensive damage.

### *Severe Cold Snaps*

Extreme cold temperatures are associated with continental Arctic air masses. All regions in Canada have experienced temperatures below -40°C, except for Prince Edward Island (Phillips, 1990). The actual temperatures reached depend specifically on the nature of the cold air mass and where it originated. In general, those from the Arctic regions are the coldest. Though cold temperatures are dangerous in their own right, they become more so in conjunction with strong winds (Etkin and Maarouf, 1995). The combination produces a wind-chill factor – heat loss measured in Watts per metre squared ($Wm^{-2}$). A wind-chill factor of 1400 $Wm^{-2}$ is equivalent to a temperature of -18°C. At 2700 $Wm^{-2}$, exposed flesh freezes within a half minute.

Exposure to extreme cold claims more lives, directly, in Canada than any other atmospheric extreme (Etkin and Maarouf, 1995) though indirect deaths, for example, due to weather related car accidents and air pollution are much larger. Prolonged exposure causes numerous injuries to people and animals, including hypothermia and frostbite. Sub-zero temperatures lead to many other problems, including frozen water pipes and the disruption of transportation and businesses. Table 2.9 lists some significant extreme cold events for Canada.

### *Lake-Effect Snows*

Lake-effect snows are frequent events in any part of Canada situated near large bodies of water such as the Great Lakes, the Gulf of St. Lawrence, the Arctic Ocean, and the Manitoba lakes. These local weather systems can account for much of the annual snowfall in these regions (Stewart et al., 1995).

Lake-effect snows are produced as cold air passes over relatively warmer water. The temperature difference between the air and the water, which can be as great as 25°C, profoundly affects the severity of the storm. Lake-effect snows are most common in late autumn and early winter, when the

Table 2.9 Significant Canadian extreme cold events.

| Location | Date | Conditions |
|---|---|---|
| Snag, Yukon | 3 Feb., 1947 | Lowest recorded Canadian temperature, -63°C |
| Winnipeg | 24 Jan. 1966 | Longest skin-freezing windchill (170 hours) |
| Edmonton | 7 Jan. – 2 Feb., 1969 | Temperatures below -18°C for 26 days |
| Pelly Bay, NWT | 13 Jan., 1975 | Coldest recorded windchill (equivalent to -97°C) |
| Saskatoon | 28 Dec., 1978 | Longest windchill event (215 hours) |
| Most of Canada | Jan. 1982 | Coldest winter month on record, most provinces below -40°C |
| British Columbia | 30 Jan., 1989 | Freezing caused $2.5 million in damage |

Source: Etkin and Maarouf (1995).

temperature difference is greatest. Extensive cumulus clouds form as cold air passes over warmer water, and the warm, moist air overlying the water rises through the cold air.

To form cumulus clouds large enough to produce heavy snowfall, the cold air must pass over at least 80 km of open water, which requires a large body of water. When these clouds move onshore, they produce heavy snowfall over localised regions (usually less than 50 km inland) to the lee of the lakes. These storms are so localised that one portion of a city may be inundated by 20-30 centimetres of snow per day, while other parts may receive none at all (Ahrens, 1994).

### *2.2.8 Geomagnetic Storms*

**Geomagnetic storms are probably one of the least-known atmospheric hazards.** They have wreaked considerable havoc in the high northern mid-latitudes. For instance, on the morning of March 13 1989, a powerful geomagnetic storm occurred causing a major power failure from northern Quebec to Montreal. The storm tripped a voltage regulator and shut down one of the main lines stemming from the La Grande hydroelectric complex in northern Quebec. During the next 60 seconds, voltage levels became increasingly erratic within the grid. Within 90 seconds, the entire 9,500 Megawatt power complex was isolated from the rest of the system. In all, this storm cost Hydro Quebec $10 million and its customers between $10 and $100 million (Lerner, 1995). This same storm was responsible for the failure of three 'fault-tolerant' disc drives at the Toronto Stock Exchange, halting trading for three hours (Dayton, 1989).

Geomagnetic storms result as high energy particles emanating from the Sun reach the Earth's atmosphere. Within the Sun, extremely high temperatures cause violent collisions between gases, stripping them of electrons. The ionised gases and electrons then rapidly make their way to the surface of the Sun. The Sun's magnetic energy is capable of containing most of them, allowing only relatively few to fly out into space. This stream of high energy protons and electrons, called plasma or solar wind, travels through space and may come in contact with the Earth (Bone, 1991; Ahrens, 1994).

A magnetic shield, called the magnetosphere, protects the Earth's surface and its inhabitants from this constant bombardment. The magnetosphere, hypothesised to be the result of the Earth's iron core, deflects the solar wind around the Earth, forming the equivalent of an electrical generator. It deflects solar protons to the dawn side of the Earth, and solar electrons, to the dusk side (Lerner, 1995). Some of these particles are, however, caught in the magnetosphere and funnelled into the upper atmosphere at the magnetic north and south poles. There, gases in the atmosphere provide a ring circuit for the solar wind. The solar particles flow into the upper atmosphere and westward around the planet to the opposite side, where they are flung back into outer space. As these high energy particles flow around the upper atmosphere, however, they collide with and transfer energy to the gases there. This causes the gases to glow, producing the aurora borealis and aurora australis (Bone, 1991).

Under normal circumstances, these interactions are minor and can only be seen in the high latitudes, near the magnetic poles. However, dramatic solar flares, which occur during intense sunspot activity, cause massive pulses of high-energy plasma to be ejected into space. When these strike the Earth, far more electrons and protons are funnelled into the magnetic poles than can be handled by the gaseous circuit. A surge of energy builds up in the atmosphere and pushes the aurora towards the mid-latitudes. During sunspot episodes, which have an eleven-year cycle, the aurora borealis has been sighted as far south as the U.S. state of Georgia (Bone, 1991).

Geomagnetic storms take place during times of intense solar flare activity. The high-energy particles racing around the upper atmosphere, trying to complete the circuit and return to outer space, are too numerous for the natural atmospheric circuit to handle. Excess particles move down into the lower atmosphere, towards the Earth's surface, in order to build a circuit. In areas where the ground is not a good conductor (e.g. the Canadian Shield), they seek out other possibilities. Prime targets are north-south-oriented power transmission lines. Even high-tension power lines cannot handle this amount of energy – ~500,000 Megawatts (Lerner, 1995) – hence, power surges and eventual power failure can ensue.

*Influence of Geomagnetic Storms on Human Infrastructure*

Geomagnetic storms can also produce satellite drag, disruption of ground and satellite communication, ship navigation systems, and failure of orbiting satellites (Bone, 1991). Satellite drag results from the thickening of the Earth's atmosphere following the heating caused by increased numbers of high energy particles. Artificial satellites may decay out of orbit earlier than expected (e.g. SkyLab, July 1979). The electrical signature of the high energy plasma can also cause orbiting satellites to execute phantom commands, causing major malfunctions of on-board computer systems. In 1994, a $250 million Canadian communications satellite went off line for nearly six-months (Lerner, 1995).

### *2.2.9 Windstorms*

**Cumulatively, strong wind events cause the most insurance losses in Canada** (Davenport, 1994) and can be caused by tornadoes, tropical cyclones, extra-tropical cyclones, downburst and microbursts, gust fronts of thunderstorms, and general atmospheric turbulence. Wind itself occurs on a variety of scales and is a function of numerous factors, including atmospheric stability, topography and surface roughness (Etkin and Maarouf, 1995). Wind can directly exert powerful pressures on structures in its path and can produce many other hazardous events such as storm surges and waves, flying debris during tornadic events, falling trees, wind-driven rain, sleet and hail, ice jams along coasts, and drifting icebergs (Davenport, 1988). Wheaton (1992) described dust storms, which are wind related, as a significant hazard common during summer and winter drought periods.

Prevention of damage from wind-related events requires proper building design and thorough enforcement of building codes (Yip et al., 1995). The majority of the insurance losses stem from structural damage caused, either directly or indirectly, by the force of the wind (Davenport, 1994). Figure 2.16 shows a hypothetical curve between wind speed and the loss or damage quotient (Davenport, 1994); as wind speed increases linearly, resulting damage increases at a faster rate until – at a maximum, structure specific, wind speed – total destruction follows.

The National Building Code of Canada (NBCC) for 1990 uses the 10-year, 30-year and 100-year return-period wind

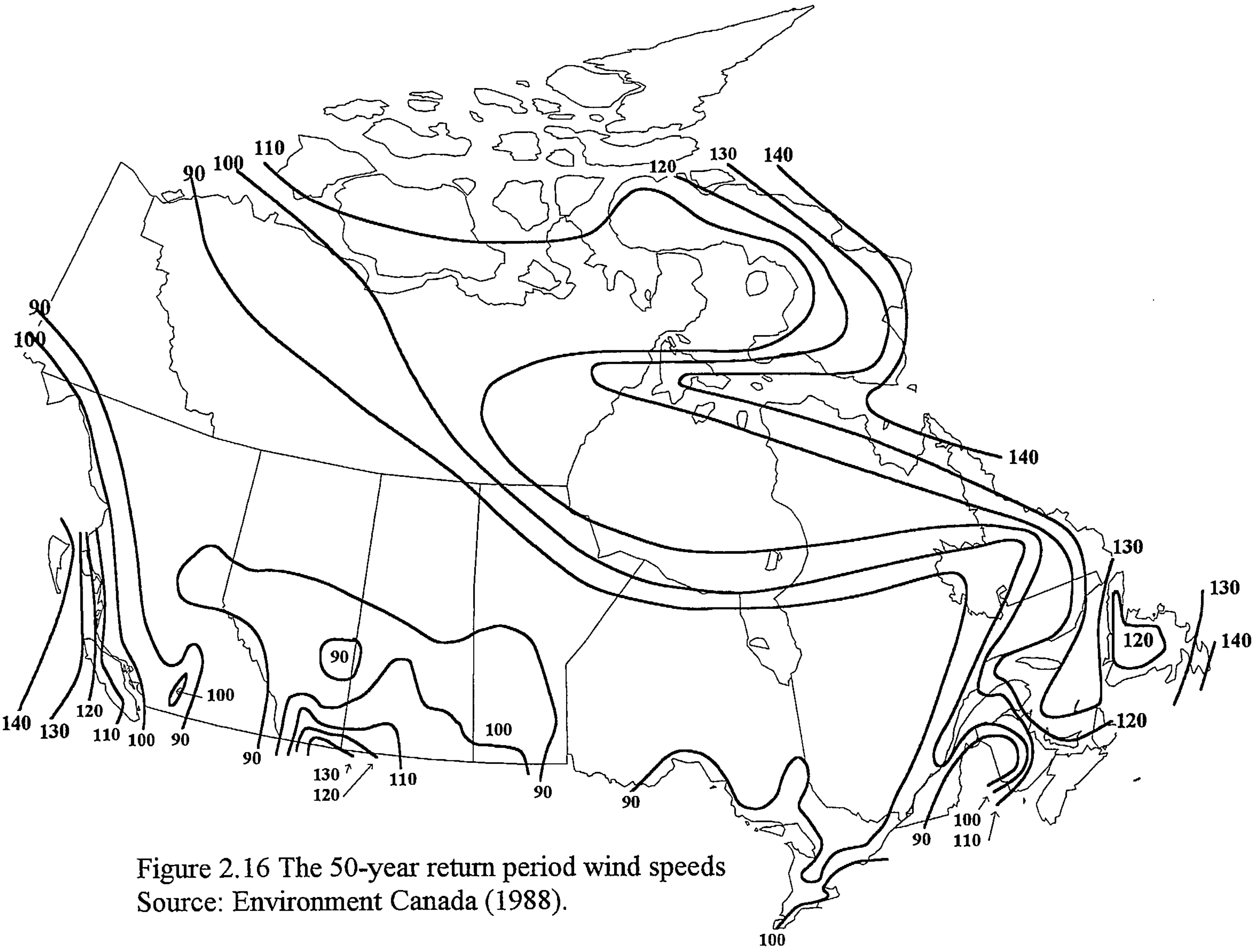


Figure 2.16 The 50-year return period wind speeds
Source: Environment Canada (1988).

pressures. The highest 50-year return period winds (140 kph) are located along the coast of British Columbia and in the eastern provinces and result from low surface roughness (low friction) associated with water surfaces (Etkin and Maarouf, 1995). Furthermore, the high eastern maximum also results from higher incidences of tropical and extra-tropical cyclones (Etkin and Maarouf, 1995). The peak speeds for the Great Lakes region are between 90-100 kph.

*Processes of Windstorm Damage*
It is the pressure exerted by wind which causes the damage, not the wind speed itself (Insurance Institute, 1994). There are three types of wind pressure: positive, negative and internal. As Figure 2.17a shows, positive pressure sets up a dynamic force that acts to push over an object. However, as air rushes past the object, it produces negative pressure on the leeward side. This negative pressure then acts on the leeward side to pull over an object. The two pressures work in tandem. If a structure loses a door or window, the interior pressure is dramatically altered (see Figure 2.17b,c,d). Figure 2.17b shows how an opening on the windward side can increase the internal pressure and the chance of roof lift-off. Figure 2.17c illustrates how suction forces are generated by an opening on the leeward side. If two or more windows are open on opposite sides, then the windward and leeward pressure are equalised and the internal pressure is not altered (see Figure 2.17d).

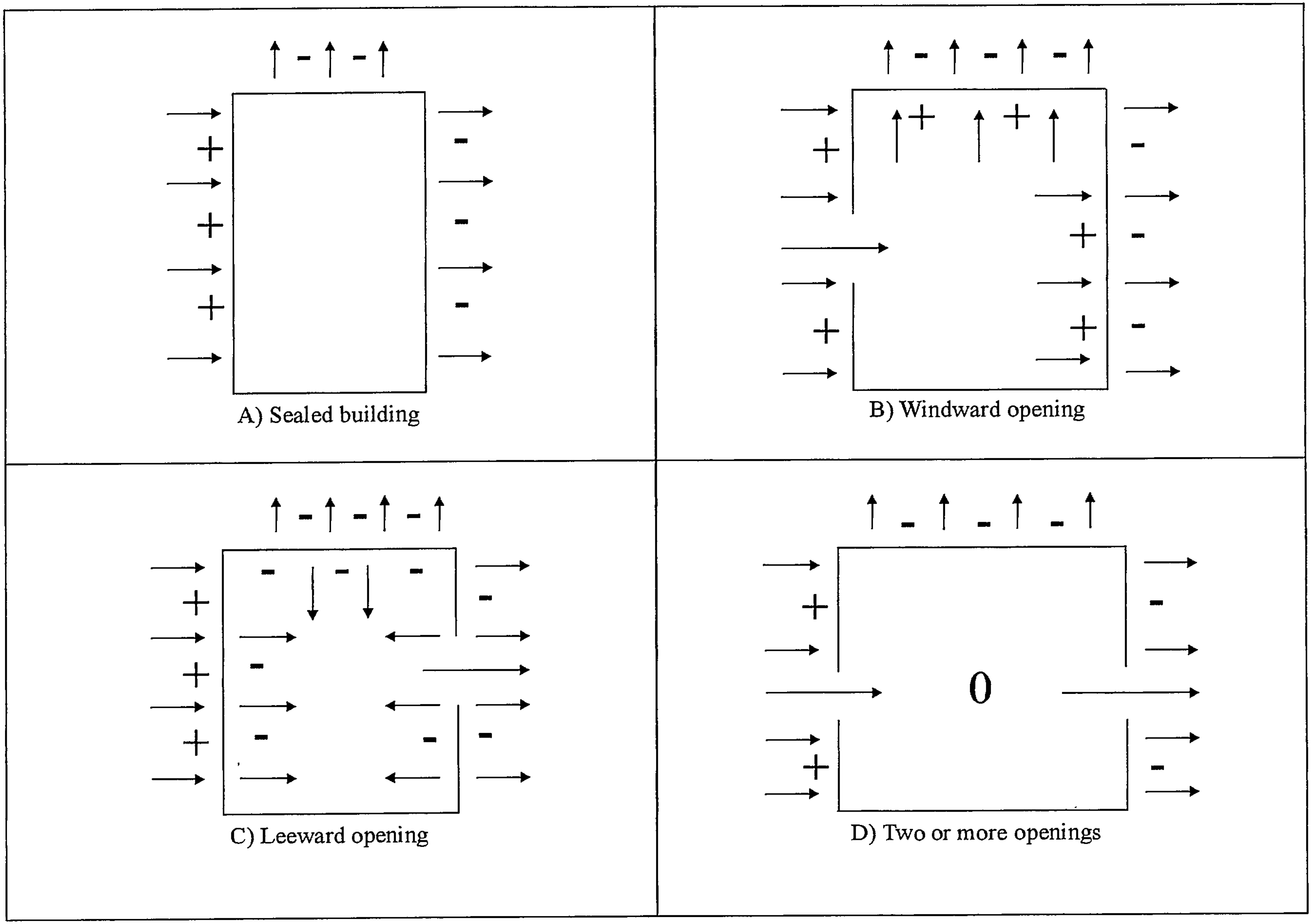
## 2.3 Hydrologic Hazards

**Hydrologic hazards are severe events caused by an excess or a lack of water: flooding and drought, respectively.** On a global scale, flooding is the most common of all environmental hazards, claiming over 20,000 lives and affecting 75 million people annually. Long-term droughts, on the order of years, can significantly degrade the environment, and lead to malnutrition and starvation on a large scale. Each year, famine kills an average of roughly 200,000 people and affects 1 billion world-wide. Furthermore, no country in the world is immune to either of these hazards (Smith, 1996).

### *2.3.1 Drought*

**Droughts are a major Canadian hazard**; they can affect areas in excess of 1 million km$^2$ and last weeks, months, or years (Newark, 1982). Around the world they cause many deaths, but their impact on Canada is mainly economic by comparison. Droughts principally affect agriculture, where losses to crops and livestock have reached billions of dollars (see Table 2.10). The drought of 1988 caused an estimated $1.8 billion in damage (1981 dollars). Droughts have also caused extensive environmental problems through increased degradation and erosion of soil, destruction of ecological habitats, and deterioration of lakes (Maybank, et al., 1995). In the past 200 years, 40 severe droughts have occurred in western Canada; the 1930's and 1980's were especially bad (Koshida, 1992). The worst recorded drought in Canada was the drought of 1988 which caused extensive damage to agriculture, wildlife, water resources, forestry and other economic sectors of western Canada (Wheaton, 1992; Lawford, 1992; Wheaton et al., 1992; Wheaton and Arthur, 1992; Maybank et al., 1995).

Droughts are caused by anomalous weather patterns (Koshida, 1992) when shifts in the jet stream block storm systems


A) Sealed building

B) Windward opening

C) Leeward opening

D) Two or more openings

Figure 2.17 Differences in internal building pressure as a result of blowing wind.

Table 2.10 Recent Canadian droughts.

| Date | Location |
|---|---|
| 1973 | Ontario |
| 1977 | Southern Alberta and western Saskatchewan |
| 1978 | Ontario |
| 1979–80 | Prairies, $2.5 billion in losses |
| 1983 | Southern Ontario and Quebec |
| 1984–85 | Southern prairies and Nova Scotia |
| 1985 | British Columbia, one of the worst fire seasons |
| 1987 | British Columbia, winter drought in Atlantic provinces |
| 1988 | Extensive drought across the prairies, Ontario, and Quebec, worst drought in interior Bristish Columbia |

Source: Phillips (1990); Koshida (1992); Etkin and Maarouf (1995).

from reaching an area. As a result, large, stationary high-pressure cells may dominate a region for prolonged periods, reducing precipitation and increasing temperatures. Higher temperatures cause evaporation rates to increase and moisture to be drawn out of soil, lakes and rivers. During prolonged droughts, moisture in the soil and levels of lakes, ground water, and rivers decline – sometimes sufficiently to harm crop and livestock production, forestry, ecological habitats, and water resources, with spin-off effects on other parts of the economy and the environment.

There are three different definitions of droughts – meteorologic, hydrologic, and agriculture – all fundamentally controlled by lack of precipitation. The meteorological drought – lack of precipitation over prolonged periods – is the most common and occurs when precipitation amounts are 50 per cent or more below normal for at least 30 days. This lack of precipitation ultimately determines the degree of moisture shortage for the other two types of drought (Koshida, 1992).

Hydrologic droughts occur when the hydrological cycle of a region is disrupted, because of a prolonged lack of precipitation or excess water mining. The usual cause is a combination of high temperatures and prolonged, below-normal precipitation. When evaporation exceeds precipitation, levels of ground water and lakes and river discharges eventually decline (Koshida, 1992).

Agricultural droughts occur when there is not enough soil moisture for crop and livestock production. During lengthy periods of below-normal precipitation and high temperatures, evaporation draws more moisture out of the soil, with little replenishment. If the soil moisture levels fall below the wilting point, which is plant specific, the vegetation cover begins to die. Cereal drought can kill annual agricultural crops, such as wheat; forage drought affects livestock pastures and rangelands (Koshida, 1992). These two types of agricultural drought need not be simultaneous.

Droughts are more frequent in the prairies (Koshida, 1992) and are caused by variable or highly seasonal precipitation (Maybank et al., 1995). Annual precipitation in these semi-arid and sub-humid regions is naturally limited (usually between 290 mm to 470 mm), and, therefore, even short periods of below-normal precipitation can initiate a drought. The most drought prone region in Canada, the Palliser Triangle – the southern portions of Alberta, Saskatchewan, and Manitoba – has had major multi-year droughts in the 1890's, 1930's, and 1980's. In contrast, though all areas in Canada can experience drought, most other parts of the country receive more than 600 mm of annual rainfall (Canadian National Report - IDNDR, 1994). Therefore, droughts that may occur outside of the prairies are usually brief, spatially limited and less frequent (Koshida, 1992).

The end of a drought is not easily defined (Koshida, 1992). A few days with precipitation is not sufficient to terminate a severe drought. To bring the levels of soil moisture, ground water, lakes and rivers back to normal, prolonged, above-average precipitation is necessary. Environmental and socio-economic sectors hurt by the drought may take longer to recover.

## *2.3.2 Floods*

**Floods are one of the most significant natural hazards for Canada; they are frequent, have relatively rapid speeds of onset, can affect large areas, and can cause extensive losses to property and life.** The worst flood disaster in world history occurred in August, 1931 along the Huang He River in China and killed an estimated 3.7 million people. The world's death toll from floods between 1966 and 1990 was 117,000 – an average of 4,680 persons per year (Lawford, et al., 1995).

The worst Canadian flood occurred in the summer of 1996 (see Table 2.11). The Saguenay River valley in Quebec received roughly 290 mm of rainfall in approximately 36 hours. Though few people died, more than $1 billion in damages resulted. In October, 1954, hurricane Hazel struck the Toronto region, causing extensive flooding, 79 deaths, and $133.3 million in damages (Andrews, 1993).

Although the economic and social impacts of floods can be quite staggering, far more money is spent on flood prevention. For instance, roughly $600 million per year is expended on construction of drainage systems in the Toronto area. Extrapolating this figure across Canada, this suggests nearly $3-5 billion per year is spent on storm sewers and other drainage networks (Canadian National Report - IDNDR, 1994; Hogg, 1994; Etkin and Maarouf, 1995). Because of the economic losses caused by flooding and the cost of prevention, flooding is considered a significant hazard in Canada (Lawford et al., 1995).

Floods result when natural drainage channels, or human-made facsimiles, cannot convey all the water supplied to them; excess water spills over the banks and inundates the surrounding areas. The characteristics of the drainage basin also contributes to the hazard (Lawford et al., 1995). Flooding is usually caused by intense localised rainfall, prolonged rainfall on saturated surfaces, ice jams, snowmelt, or any combination of these.

A drainage basin's size, shape, topography, vegetation cover and degree of development may determine whether a basin will flood or not. For instance, heavy rain may not cause flooding in a natural area as infiltration, vegetation or gentle slope gradients may reduce the amount of runoff and keep it from reaching the drainage channel. However, this same event may cause extensive flooding in urban areas because of the large areas of impenetrable surfaces (e.g. pavement, roofs and heavily compacted soils). Impermeable surfaces render urban areas highly vulnerable to flooding (Lawford et al., 1995), by promoting rapid rates of runoff that result in large quantities of water inundating urban drainage networks (e.g. sewer and canals). Many cities, whether they are located in river valleys or not, are thus prone to flooding (e.g. by sewer back-up or runoff), especially if their drainage systems are inadequate.

It is difficult to provide a spatial representation of flood-prone areas in Canada due to the numerous causes of flooding. The most susceptible regions include all of southern Ontario and Quebec, the southern half of British Columbia, isolated regions of southern Saskatchewan and Manitoba and most of the Maritimes.

The main causes of flooding in Canada are spring ice jams and snowmelt, and heavy summer rainfall (Lawford et al., 1995; Etkin and Maarouf, 1995; Hogg, 1994; Phillips, 1990). Flooding in Canada peaks in April and is at a minimum in

Table 2.11: Significant Canadian floods.

| Date | Location | Conditions |
|---|---|---|
| 1798 | Montreal and Trois-Rivieres, Quebec | Described as "worst in living memory" |
| 1826 | Red River, Manitoba | Flood waters crested to 12 m above normal |
| 1865 | Sorel and Trois Rivieres, Quebec | St. Lawrence rose 3–4 m, 45 fatalities |
| 1883 | London, Ontario | Wall of water on the Thames River, 18 fatalities |
| 1928 | Rideau, Chaudiere and Quyon Rivers, Que | Several fatalities |
| 1937 | London, Ontario | 4000 people left homeless |
| 1948 | Fraser River, BC | Worst flood on record, 9000 people left homeless |
| 1950 | Red River, Manitoba | Flood waters crested to 10 m above normal, 100,000 people evacuated |
| 1954 | Etobicoke Creek and Toronto, Ontario | Hurricane Hazel caused extensive flooding, 79 fatalities, and $133.3 million in damage |
| 1973 | Saint John River, New Brunswick | $12 million in damage |
| 1974 | Grand River and Cambridge, Ontario | $7 million in damage |
| 1974 | Prairies | Extensive flooding |
| 1979 | Red River, Manitoba | Flood waters rose higher than 12 m above normal |
| 1979 | Dawson, Yukon | 80% of town flooded by Yukon River |
| 1980 | Squamish River, BC | $13 million in damage |
| 1986 | North Saskatchewan River, Edmonton | Flood waters crested to 7.6 m above normal, 900 people evacuated |
| 1987 | Montreal | Flash flood: >100 mm of rain in one hour, $40 million in damage |
| 1989 | Essex County, Ontario | 450 mm of rain fell in 30 hours in Harrow, Ontario |
| 1993 | Parts of US and Canadian Midwest | Extensive damage; $175 million in Winnipeg |
| 1996 | Saguenay River, Quebec | 290 mm of rain fell in two days, $1 billion in damage |

Sources: Phillips (1990); Andrews (1993); Lawford et al. (1995); Etkin and Maarouf (1995).

September. During winter and early spring, winter precipitation causes floods on the west coast. In May, delayed snowmelt and ice jams lead to flooding in the north. Between May and September, the major cause of frequent flooding is heavy, convective rainfall (Lawford et al., 1995). In June, flooding can occur in mountainous regions as a result of high mountain snow and glacier melt. Other minor forms of flooding are due to wind driven waves and storm surges along the coastal regions of Canada, especially the Maritimes (Phillips, 1990).

*Rainstorm Floods*

Rainstorm floods are controlled by the nature of the rain event and the characteristics of the land on which it falls. Intense, localised thunderstorms can produce major flooding in small catchments and minor flooding in urban areas. Rainstorm floods can be caused by larger, mesoscale thunderstorm complexes, which can inundate medium-sized areas, small to medium sized waterways and most urban environments with vast quantities of water. The most damaging events come form the large-scale frontal cyclones, or mid-latitude cyclones, which can easily cause flooding in Canada's major waterways.

*Icejam Floods*

The magnitude of ice jam floods are partly a function of the discharge flowing through a river and the size of the ice jam obstruction. The location of these floods is controlled by the morphology of the waterway; the shape of the river controls the location of the build-up of ice pack. Ice jams occur during freeze-up of rivers in winter or the break-up of winter ice cover in early spring. During the cold months, a layer of ice develops on river surfaces, leaving water to flow beneath. This ice cover can be thin, because of spring melting or insufficient winter freezing. If enough water is supplied to the river (e.g. from snowmelt or rainfall), pressure exerted from underneath may be sufficient to break the ice cover. If so, the ice pack then flows downstream – a common event along many Canadian waterways.

These chunks of ice may then become lodged where the flow is constricted, obstructed or slowed. They may converge at channel bends and bridge piers, where rivers bifurcate around islands, or become more shallow and have gentle gradients. When significant amounts of ice build-up, they may block the flow of water. As water collects in the newly formed reservoir behind the jam, areas upstream may begin to flood. If the icejam breaks under the pressure of the upstream water, large volumes of water may inundate downstream locations (Lawford et al., 1995).

*Snowmelt Floods*

Though snowmelt causes most spring flooding in Canada, its very gradualness means that it results in few large floods. However, in northern and mountainous regions with heavy winter snowfall, snow melt combined with abnormally high temperatures, or when snow melt is combined with major rainfall, serious hazards can develop. Snow melt also supplies much of the water that produces many ice-jam floods (Lawford et al., 1995).

## 2.4 Geophysical Hazards

Geophysical hazards include earthquakes, tsunamis, mass movements and volcanic eruptions. Though mass movements are frequent, they do not pose as significant a threat as other geophysical hazards. **Although no major earthquakes, tsunamis and volcanic eruptions have occurred recently in Canada, their potential threat is quite significant.**

### *2.4.1 Earthquakes and Tsunamis*

Globally, significant earthquake activity is known to occur in 35 countries and is responsible for staggering losses of life and property. The worst earthquake in history killed 800,000 people in Shensi, China in 1556 (Smith, 1996). Earthquakes in urban areas can be even more lethal, often because of fires caused by ruptured gas (and water) mains. Perhaps 80 % of the damage in the 1906 San Francisco earthquake resulted from fires caused by the quake (Smith, 1996).

**Most earthquakes that cause extensive loss of life and property occur along the boundaries between major tectonic plates (Smith, 1996). The entire west coast of Canada lies on a major boundary between the Pacific and North American plates.** Other major areas at risk from earthquakes are those that lie near tectonic rift systems (e.g. the St. Lawrence Rift), where tectonic plates split apart. Table 2.12 lists significant Canadian earthquakes from 1870 to 1988.

The primary earthquake hazard is caused by ground movement following abrupt shifting of the tectonic plates. This leads to structural damage and the possible collapse of buildings. Secondary hazards are fires following the event, landslides, rock and snow avalanches, soil liquefaction and tsunamis. These events, especially fire following, can be just as devastating as the earthquake itself.

Though seismic activity occurs all over Canada, Vancouver and Montreal have the highest risk. Low- to moderate-magnitude earthquakes have occurred in these regions, and a high-magnitude one is expected. These regions are also heavily populated urban centres. Vancouver Island has had more than 100 magnitude-5 or greater earthquakes in the past 70 years (Basham et al., 1995). East of the Canadian Cordillera, the risk of seismic activity is substantially lower. However, there are a few “hot spots”, such as the St. Lawrence rift valley system, the Grand Banks and the Arctic Islands (Basham et al., 1995).

*Tectonics and Earthquakes*

Tectonic plates form as the earth’s mantle is extruded at spreading centres such as mid-oceanic ridges. These areas are called zones of divergence. As the plates move apart and over the earth’s surface they encounter resistance from other plates, and one of two types of response follows. At zones of transcursion, the two plates slide past each other along a series of slip faults – for example, the San Andreas fault in California. At zones of convergence, they collide, resulting in one of three scenarios. If both are continental plates, orogeny, or mountain-building, often follows. If both are oceanic, the lighter plate subducts the denser. If one is continental and the other oceanic, the thicker and less dense continental plate floats over the oceanic, which is subducted and reabsorbed into the mantle. As the oceanic plate is thrust downward to pass beneath the continental plate, there develops a dipping, planar region (20-55) of seismic activity, called the *Wadati-Benioff* zone (Briggs, 1989; Summerfield, 1991; Rogers, 1994; Smith, 1996).

Earthquakes are concentrated in narrow bands along the margins of the

Table 2.12 Siginificant Canadian earthquakes.

| Date: | Location | Magnitude (Richter scale) |
|---|---|---|
| 20 Oct., 1870 | Charlevoix–Kamouraska region | 6.5 |
| 15 Dec., 1872 | Washington–BC border | 7.4 |
| 4 Sept., 1899 | Yukon–Alaska border | 7.9 |
| 6 Dec., 1918 | Vancouver Island | 6.9 |
| 1 Mar., 1925 | Charlevoix–Kamouraska region | 6.7 |
| 6 May, 1929 | South of Queen Charlotte Islands | 7.0 |
| 8 Nov., 1929 | Atlantic Ocean | 7.2 |
| 20 Nov., 1933 | Baffin Bay | 7.3 |
| 1 Nov., 1935 | Quebec–Ontario border | 6.2 |
| 5 Sept., 1944 | Eastern Ontario–New York | 5.6 |
| 23 June, 1946 | Vancouver Island | 7.3 |
| 22 Aug., 1949 | Off Queen Charlotte Islands | 8.1 |
| 10 July, 1958 | Alaska–BC border | 7.9 |
| 24 June, 1970 | South of Queen Charlotte Islands | 7.4 |
| 20 Dec., 1976 | West of Vancouver Island | 6.7 |
| 28 Feb., 1979 | Yukon-Alaska border | 7.2 |
| 17 Dec., 1980 | West of Vancouver Island | 6.8 |
| 23 Dec., 1985 | Mackenzie District, NWT | 6.9 |
| 12 Nov., 1988 | Saguenay region, Quebec | 6.0 |

Source: Geologic Survey of Canada (1994).

tectonic plates. Intermediate-depth (70-300 km) and deep (>300 km) earthquakes are associated mainly with areas of subduction (Briggs, 1989). However, shallow events (< 70 km) cause the greatest damage and are the most difficult to predict (Rogers, 1994).

*Mechanics of Earthquakes*

Occurring less than 700 km below the earth's surface, an *earthquake* is the sudden movement and fracturing of rock along a zone of weakness known as a fault. For example, the seismic process in a convergence zone begins as a subducting oceanic plate applies tectonic strain to a continental plate. In response to this strain, the elastic properties of the continental crust enable the margin to deform, which can be seen at the surface as a shortening or bulging of the coastline. The energy from this deformation is stored and builds as elastic energy in the rock. When the stress of the elastic energy exceeds the strength of the rock, the fault ruptures. The sudden movement and fracturing of rock along the fault releases the pent-up elastic energy, which propagates as seismic waves. These waves radiate outward in widening, concentric rings around the fault, much like the rings from a rock thrown into a lake. The fracturing and elastic rebounding of the rock on either side of the rupture cause the ground to shake. The point of rupture, where seismic waves originate, is known as the *hypocenter,* or *focus*. The position directly above the hypocenter, at the earth's surface, is the *epicenter*. The epicenter is the source point for earthquake measurements (Briggs, 1989; Smith, 1996).

*Seismic Waves*

Elastic energy is released during an earthquake as seismic waves, or shock waves. Originating at the hypocenter, shock waves radiate outward through the earth. Deep earthquakes do not always surface at the epicenter, but may be confined to the interior of the earth. However, most earthquakes are shallow such that the seismic waves erupt at the epicenter and propagate as one of three types of waves: P, S, or L waves (Briggs, 1989; Summerfield, 1991; Smith, 1996).

*P waves* are the primary, compression waves, which move rapidly at depth. Energy is transmitted to adjacent particles in a compression-expansion motion. That is, the particles are initially pushed forward, then pulled back in the same direction as wave propagation away from the focus. Like sound waves, P waves vibrate particles and can pass through all mediums (Briggs, 1989; Summerfield, 1991; Smith, 1996).

*S waves* are the secondary, shear waves, which move up to 40 % more slowly through the ground than P waves. Energy is transmitted by shaking particles up and down, perpendicular to the wave propagation. Unlike P waves, which can pass through all mediums, S waves can only pass through solid materials (Briggs, 1989; Summerfield, 1991; Smith, 1996).

*L waves* are the longer, Love or Rayleigh waves, which shake the ground horizontally at right angles to the direction of wave propagation. Though the slowest seismic waves, L waves can travel the furthest, since they are not interrupted by discontinuities in the earth. During an earthquake, L waves are also responsible for most of the damage to surface structures located more than a few kilometres beyond the epicenter (Smith, 1996).

The *attenuation* of a seismic wave – the rate at which the wave dissipates or decays – depends on the density and elastic properties of the material through which the wave passes. For instance, S waves can only travel as long as there is solid material, such as rock, to pass through. Though P waves can be transmitted through any material, some substrates, like unconsolidated fill, amplify its propagation, while others, such as rock, dampen its movement. As well, if the hypocenter is deep within the mantle, shock waves experience discontinuities in velocity at depth as they travel through the mantle-crust boundary (called the *Moho*) (Briggs, 1989; Summerfield, 1991; Smith, 1996).

During most earthquakes, several initial foreshocks occur, which are related to the fracturing of obstructions and bonds along the fault. This is followed by a more severe principal shock of the main displacement, which can last from a few seconds to a few minutes. The longer the event, the more extensive the damage at the surface. Finally, rebounding of the rock after the principal movement produces aftershocks, which can range from minor tremors to significant motions (Briggs, 1989; Summerfield, 1991; Smith, 1996).

### *2.4.2 Tsunamis*

Tsunamis result from tectonic displacement of the ocean floor caused by large, shallow oceanic crust earthquakes or by volcanic island explosions (Smith, 1996). When the oceans are disturbed by tectonic or volcanic activity, large volumes of water (many hundreds of cubic kilometres) can be thrust upward by rapid, vertical sea-floor displacement. Water builds up and spreads in all directions at speeds of 140 $ms^{-1}$ or more. Tsunamis can travel great distances, even across the Pacific ocean. In deep ocean waters, the wave heights are shallow (~0.5 m), but as the mass of water rushes towards shallower waters, the wave heights increase (up to 30 m) (Smith, 1996). As these waves strike the shore, their buoyancy and drag forces can scour away virtually any object in their path.

**The threat of large tsunamis in Canada is mainly on the west coast.** Furthermore, since attenuation of distant earthquakes does not produce appreciable wave heights, the major concern is with tsunamis produced locally (Murty and Stronach, 1989).

### *2.4.3 Mass Movements*

A wide variety of mass movements (such as landslides, earthflows, mudflows, rockfalls, rock avalanches, ground ice slips, snow avalanches) occur throughout Canada, especially along river valleys and in permafrost, coastal, and mountainous regions. **Though the majority of these events do not significantly affect Canadian population, every year mass movements cause serious problems on major transportation corridors (such as the Trans-Canada Highway).** Since 1840, nine major events have caused a total of 262 deaths. The worst landslide disaster occurred in Alberta, 1903, and caused 76 fatalities. Each year, Canadians spend millions of dollars to repair damage to infrastructure and for landslide prevention (Basham et al., 1995).

Mass movements are displacements of the earth *en masse* under the forces of gravity. Such activity is usually facilitated by water, lack of vegetation, and the underlying geology. Mass movements can be both rapid or slow. Slow mass movements (e.g. solifluction and soil creep) are movements of the earth's surface which are imperceptible to the human eye. They occur on all hillslopes, but are much more pronounced on steeper slopes. Although these types of movements are not responsible for significant losses of life, they can cause major amounts of property damage (Smith, 1996).

Rapid mass movements are much more costly and deadly. They can occur almost instantaneously, move downslope extremely rapidly, and displace large volumes of material. These events usually involve failure of a slope along a preferred failure plane (e.g. cracks, water tables, bedding planes), where the material is weaker. If the stress produced by the slope material (e.g. it's weight) exceeds the strength along the failure plane, the mass movement is eminent. Such events are strongly enhanced by excess water, which increases the material's weight and decreases its strength. Vegetation, slope angle and geology also influence the stability.

Serious landsliding occurs in the sensitive sediments of the St. Lawrence Lowlands, the clay shales of the prairie provinces, the ice-rich sediments of the permafrost regions, and the Canadian Rockies and Coastal Mountains (Basham et al., 1995). Large scale events, in excess of 5 million cubic metres, have occurred along the St. Lawrence River and in the Canadian Rockies and Coastal mountains.

### *2.3.4 Volcanic Eruptions*

Most Canadian volcanic activity is confined to British Columbia and the Yukon. In the past 2 million years, roughly 100 volcanoes and volcanic fields have formed (Canadian National Report-IDNDR, 1994) (see Figure 2.18). While eruptions in Canada have not occurred recently, the forces that produce them are still active. Since volcanic ash plumes can travel significant distances (see Figure 2.18), active volcanoes in the U.S. (e.g. Mt. St. Helens) can affect Canada. As such, **the potential for major volcanic activity exists for much of western Canada**.

The hazard posed by volcanic eruptions is related to the type of extruded material. Volcanoes eject a range from molten lava to pyroclastics (i.e. ash and particulates). Shield volcanoes, which extrude molten lava, are relatively gentle, non-explosive, and rarely eject material into the atmosphere. The principle damage they cause is to infrastructure in the path of flowing molten lava. Since some erupt frequently (sometimes daily events in the case of the Hawaiian Islands), advanced warnings can allow for evacuation.

In contrast, composite volcanoes eject molten lava and pyroclastic material in fragments ranging in size from fine ash to blocks the size of houses. They erupt explosively with little warning. The most powerful can spew ash and debris for thousands of kilometres, blanketing everything with metres of hot ash and debris. Since most buildings are not designed to carry such loads, collapse is likely. Ash plumes also pose a major threat to the aviation industry. If jet aircraft fly through these events, the pyroclastics can fuse to the turbines, causing engine failure. As well, ash plumes can combine with precipitation (e.g. Mt. Pinatubo, Phillipines), or hot ash with snow cover (e.g. Mt. St. Helens), causing massive mudflows, which inundate surrounding regions.

The volcanoes in and near western Canada are all composite in nature, and, hence, the potential for extensive, widespread damage exists. For example, roughly 1200 years ago, Mt. Churchill near the Alaska–Yukon border, erupted, devastating almost 300,000 km$^2$ of the

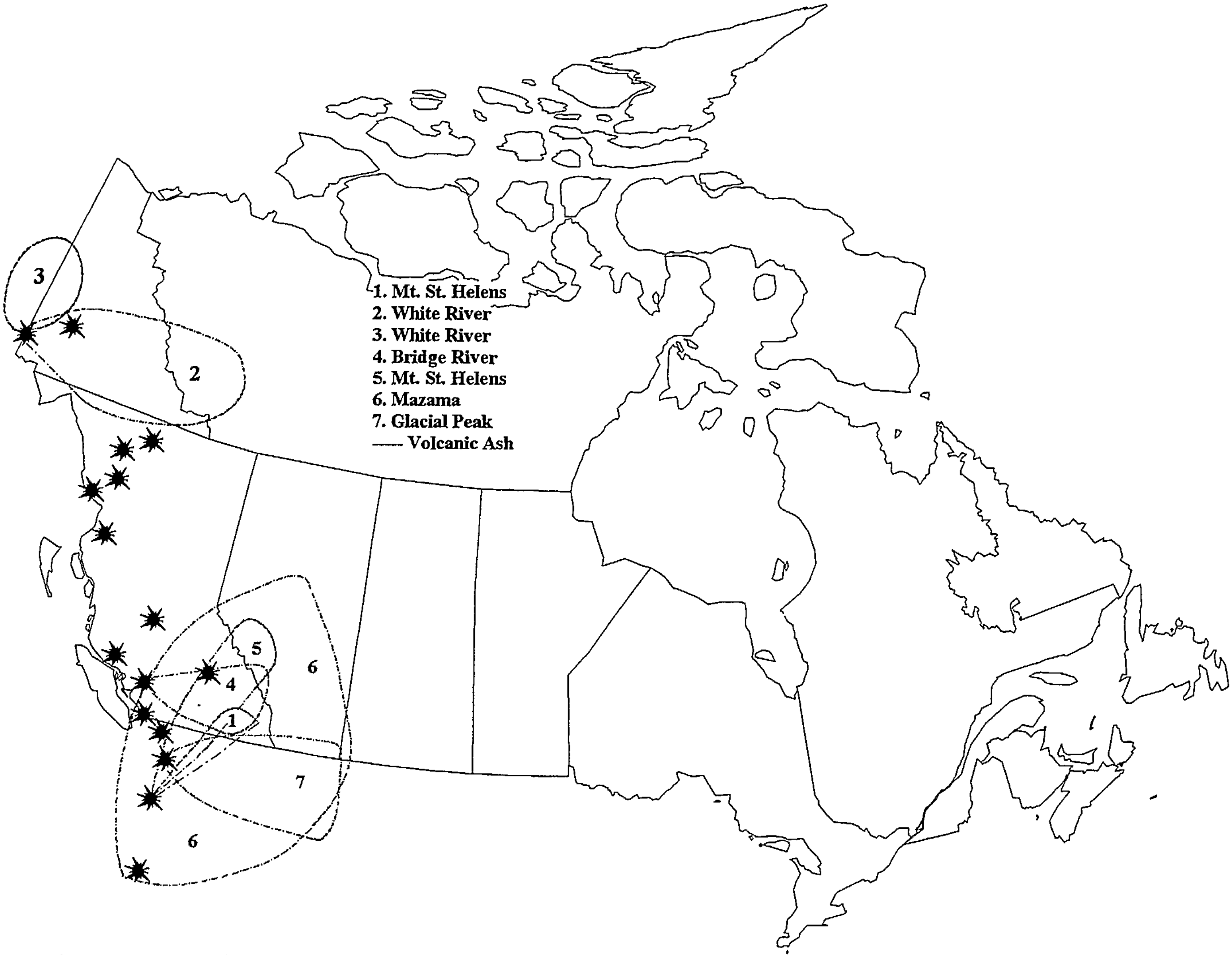


Figure 2.18: Distribution of Canadian volcanoes and significant ashfalls.
Source: Emergency Preparedness Canada, 1996.

Yukon. The 1980 eruption of Mt. St. Helens affected residents and aviators in British Columbia, Alberta and Saskatchewan (Canadian National Report - IDNDR, 1994). Similar eruptions in either Canada or the U.S. could significantly impact the aviation industry and western Canadians and incur major economic costs.

## 2.5 Summary

Canada is subject to a wide variety of natural hazards which can occur throughout the year. **Summer probably represents the most vulnerable period as this is when the four most devastating weather related hazards can occur: floods, drought, hail and tornadoes.**

The most significant hazards, based on past and potential socio-economic effects, are earthquakes, floods, droughts, tornadoes, hail, severe winter storms, and windstorms. These seven hazards require more detailed risk analyses in order to determine the vulnerability of Canadian society. Even with these investigations, prediction of future impacts will be a daunting task; without them, it will be well nigh impossible.

## References

Ahrens, C. D. (1994). *Meteorology Today, An Introduction to Weather, Climate and the Environment* (5th ed.). West Publishing Company, St. Paul, MN, 592 p.

Andrews, J. (1993). *Flooding, Canada Water Book.* Ministry of Supply and Services, Cat. No. EN 37-96/1993E.

Basham, P. W., Clague, J. J., Evenas, S. G., Grieve, R. A. F., Heginbottom, J. A., Hickson, C. J. and Moran, K. (1995). Overview of geological and geophysical hazards in Canada. **In:** *Proceedings of a Tri-lateral Workshop on Natural Hazards.* Etkin, D. (ed.). Merrickville, Canada, February 11-14. pp. 1-1 to 1-25.

Bone, N. (1991). *The Aurora: Sun-Earth Interactions.* Ellis Horwood, New York, 156 p.

CEA data (1990-1994)

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

Charlton, R. B., Kachman, B. M., Wojtiw, L. (1995). Urban Hailstorms: a view from Alberta. *Natural Hazards* 12: 29-75.

Church, C., Burgess, D., Doswell, C., Davies-Jones, R. (eds.), (1993). *Geophysical Monograph vol 79. The tornado: its structure, dynamics, prediction, and hazards.* American Geophysical Union, 637 p.

Clodman, S. and Chrisholm, W. (1994). Lightning flash climatology in the southern Great Lakes region. Submitted to *Atmospheric-Ocean.*

Cotton, W. R. and Pielke, R. A. (1995). *Human Impacts on Weather and Climate.* Cambridge University Press, Cambridge, 288 p.

Davenport, A. G. (1988). The reduction of windstorm hazard through the IDNDR. *Natural Hazards* 1: 235-243.

Davenport, A. G. (1994). Atmospheric extremes, insurance and construction. In: *Proceedings of a workshop on improving responses to atmospheric extremes: the role of insurance and compensation.* McCulloch, J. and Etkin, D. (eds.). Toronto, Ontario, Canada, October 3-4. pp. 2-38 to 2-48.

Dayton, L. (1989). Solar storms halt stock market as computers crash. *New Scientist* 9: 35.

Emergency Preparedness Canada (EPC) (1996). *Natural Hazards.* National Atlas of Canada.

Environment Canada (1987). *Climate Atlas of Canada, map series 3: pressure, humidity, cloud, visibility, and days with thunderstorms,* *hail, smoke and haze, fog, freezing precipitation, blowing snow, frost, snow on the ground.* Ministry of Supply and Services, Cat. No. EN56-63/3-1986.

Environment Canada (1988). *Climate Atlas of Canada, map series 5, wind.* Ministry of Supply and Services, Cat No. EN56-63/5-1988.

Etkin, D. A. and Maarouf, A. (1995). An overview of atmospheric natural hazards in Canada. In: *Proceedings of a Tri-lateral Workshop on Natural Hazards.* Etkin, D. (ed.). Merrickville, Canada, Feb. 11-14. pp. 1-63 to 1-92.

Etkin, D. A., Brun, S. E. (unpublished). *A revised risk analysis of tornadoes in Canada.* Manuscript.

Fujita, T. T. (1973). Tornadoes around the world. *Weatherwise* 26: 58-60.

Hogg, W. D. (1994). Heavy rainfall and floods. In: *Proceedings of a workshop on improving responses to atmospheric extremes: the role of insurance and compensation.* McCulloch, J. and Etkin, D. (eds.). Toronto, Ontario, Canada, October 3,4. pp. 3-44 to 3-50.

Insurance Bureau of Canada (IBC) (1996). Environmental Scan: Analysis of IBC's External Environment (January, 1996). Toronto.

Insurance Institute (1994). *Understanding the Wind Peril.* Insurance Institute for Property Loss Reduction, 109 p.

Janischewskyi, W. and Chisholm, W.H. (1992). Lightening Ground Flash Density Measurements in Canada. 1 March, 1984 - 31 Dec, 1991. University of Toronto, Department of Electrical Engineering, Report #179T382.

Geological Survey of Canada (1994). *Canadian Geophysical Atlas - Map 15*, 5th ed.

Grazulis, T. P., Schaefer, J. T. and Abbey, R. F. (1993). Advances in tornado climatology, hazards and risk assessments since tornado symposium II. *Geophysical Monograph* 79: 409-426.

Klemp, J. B. (1987). Dynamics of tornadic thunderstorms. *Annual Review of Fluid Mechanics* 19: 369-402.

Koshida, G. (1992). *About Drought in Canada.* Canadian Climate Program, Atmosphere Environment Services, Canada, CLI-1-92.

LaDochey, S., Annett, C. H. (1983). A damage-based climatology of lightning in Manitoba. *Climatological Bulletin* 17: 3-21.

Lawford, R. G. (1992). Research implications of the 1988 Canadian Prairie provinces drought. *Natural Hazards* 6: 109-129.

Lawford, S., Prowse, T. D., Hogg, W., Warkentin, A. A. and Pilon., P. J. (1995). Hydrometeorological aspects of the flood hazard. *Atmosphere-Ocean* 33: 303-328.

Lerner, E. J. (1995). Space Weather. *Discove,r August 1995*: 54-61.

Maybank, J., Bonsal, B., Jones, K., Lawford, R., O'Brien, E. G., Ripley, E. A. and Wheaton, E. (1995). Drought as a natural disaster. *Atmosphere-Ocean* 33: 195-222.

Murty, T. S. and Stronach, J. A. (1989). State of tide and tsunami threat to the Pacific coast of Canada. *Natural Hazards* 2: 83-86.

Newark, M. J. (1982). Meteorological hazards. *Chinook* 4: 42-44.

Newark, M. J. (1988). Tornado Hazard in Canada. In: *Natural and Man-Made Hazards*, El-Sabh, M. I. and Nurty T. S. (eds.). D. Reidel Publishing Company, p. 743-748.

Paul, A. (1991). Studies of long-lived hailstorms in Saskatchewan, Canada from crop insurance data. *Natural Hazards* 4: 345-352.

Phillips. D., (1990). *The Climates of Canada.* Environment Canada, Supply and Services Canada Publishing Centre, Catalogue No. EN56-1/1990E, 176 p.

Rogers, G. C. (1994). Earthquakes in the Vancouver area. *Geological Survey of Canada Bulletin* 481: 221-229.

Smith, K.. (1996). *Environmental Hazards, Assessing Risk and Reducing Disaster.* Routledge Publishers, London, 389 p.

Stewart, R. E., Bachand, D., Dunkley, R. R., Giles, A. C., Lawson, B., Legal, L., Miller, S. T., Murphy, B. P., Parker, M. N., Paruk, B. and Yau, M. K. (1995). Winter Storms over Canada. *Atmospheric-Ocean* 33: 223-247.

Stocks, B. J. (1991). The extent and impact of forest fires in northern circumpolar countries. In: *Global Biomass Burning, Atmospheric, Climatic and Biospheric Implication.* Levine, J. S. (ed.). pp. 197-202.

Wheaton, E. E. (1992). Prairie dust storms - a neglected hazard. *Natural Hazards* 5: 53-63.

Wheaton, E. E., Arthur, L. M., Chorney, B., Shewchuk, S., Thorpe, J., Whiting, J. and Wittock, V. (1992). The Prairie drought of 1988. *Climatological Bulletin* 26: 188-203.

Wheaton, E. E. and Aurthur, L. M. (1992). *Some Environmental and Economic Impacts of the 1988 Drought: With Emphasis on Saskatchewan and Manitoba, Vol I.* SRC Pub. No. E-2330-4-E-89.

Yip, T-C and Auld, H., Dnes, W. (1995). *Recommendations for Updating the 1995 National Building Code of Canada Wind Pressures.* Atmospheric Environment Service, Downsview. Unpublished document, 6 p.

# 3.0 Climate Change and Atmospheric Hazards

*by David Etkin and Søren E. Brun*

## 3.1 Introduction

*In a future altered climate, it may be changes in the frequency of hazards or extreme events, not changes in means, that has the greatest impact. This section addresses the question "How might extreme events change due to enhanced greenhouse warming?", by reviewing and summarising current literature on that issue. In some cases, prediction can reasonably be made regarding the consequences of climate change, while in other cases the jury is still out.*

Although the world climates have changed quite dramatically and sometimes very rapidly in the past as evidenced, in part, by glacial epochs (within each of these long-term cycles there existed natural short-term fluctuations in global and regional climatologies -e.g. the Little Ice Age and Little Optimum), these changes were the result of natural climate variability due to factors such as changes in the earth's orbital parameters.

Since the onset of the industrial revolution, humans have been steadily increasing the output of greenhouse gases (e.g. Carbon Dioxide and Methane) mainly through the burning of fossil fuels. As well, through deforestation, humans have also altered the earth's natural ability to absorb these gases. In this way, humans have caused the concentration of greenhouse gases to build up in the atmosphere. Since these gases readily absorb infrared radiation, they retain energy which would have otherwise escaped back into space. Current models and theories suggest that the earth's climate will be altered (if it already hasn't been) by increases in anthropogenic greenhouse gases.

Though global changes in temperatures or precipitation can be hazardous in their own right, in that they represent changes from what societies have adapted themselves to, it is generally thought that the greatest impact of climate change will be due to increases or decreases in the magnitude and frequency of extreme events (Downing et al., 1996; Mitchell and Ericksen, 1992). This is especially true for societies that do not have the capacity to adapt to potential increases in extreme events. **Therefore, if increases in extreme events as a result of climate change become a reality, they will undoubtedly lead to a greater number of natural disasters.** The following sections discuss current views regarding the incidences of extreme events as a result of climate change.

**Model Predictions**

The results of most numerical climate models predict that over the next half century a doubling in $CO_2$ will lead to:

- an average overall warming of the earth's global climate by between 1.5°C and 4.5°C, and
- to a proportional increase in global average precipitation (Ahrens, 1994; Mitchell et al., 1995, IPCC, 1995).
- The results of various theoretical and empirical studies strongly suggest an increase in certain types of extreme events.

## 3.2 Tropical Cyclones

It has been suggested that tropical cyclones and hurricanes might become more frequent or intense in a warmer climate. This argument is based on the fact that sea surface temperatures (SST), the major energy supply for tropical storms, will increase as the climate warms. However, since the mid-1970s there has been a general decrease in the number of intense North Atlantic hurricanes (Landsea et al., 1996). The years 1995 and 1996 suggest a return to a more active Atlantic hurricane pattern. This more active pattern has been correlated with more favourable phases of the Quasi-Biennial Oscillation (QBO), increased west African rainfall prior to and during the hurricane season and below normal temperatures in the equatorial eastern Pacific ocean, which are used as predictors of coming hurricane seasons (Gray et al., 1994).

Broccoli and Manabe (1990) examined tropical cyclone frequency in an equilibrium 2 x $CO_2$ Global Climate Model (GCM), and found a large increase in storms with prescribed cloudiness, but a lower frequency of storms when cloud feedback is allowed. Interestingly, SST increases were larger in the cloud feedback case, which points to the importance of factors other than SST in cyclone development. Haarsma et al. (1993), using a GCM simulation, found a 50% increase in the number of cyclones, with relatively more intense ones.

Lighthill et al. (1994) concluded through an examination of observational data that *"though the possibility of some minor indirect effects of global warming on tropical cyclone frequency and intensity cannot be excluded, they must effectively be "swamped" by large natural variability"*, and that the use of climate models to assess changes in cyclone frequency was not at a useful stage.

There is no strong evidence to support the hypothesis that hurricanes will become more frequent or severe, though some support this theory.

## 3.3 Extra-Tropical Storms (Mid-latitude cyclones)

It has commonly been argued that since polar latitudes are expected to warm more than mid or tropical latitudes, then the decreased north-south temperature gradient will result in weaker mid-latitude storms. However, the effect of atmospheric moisture complicates this issue. A warmer climate should increase the amount of latent heat release providing more energy and thus strengthening storms. Lambert (1995) hypothesised that the latent heat effect is responsible for a greater number of intense storms. **It is not clear therefore, whether mid-latitude cyclones will become stronger or weaker** (Held, 1993).

**Changes in the atmospheric circulation pattern may well alter storm tracks.** Balling and Lawson (1982) found a shift in winter circulation patterns over North America in the early 1950s, from predominantly zonal to meridional, a change that would have major impacts on storm tracks. They also noted that the interior plains and north-east quarter of the U.S. appear to be most sensitive to the change in circulation. Hall et al. (1994) and Carnell et al. (1996) found an intensification and northward shift of storm tracks. Prediction of storm tracks in a warmer climate remains a major challenge (Held, 1993).

Agee (1991) examined storm frequencies during periods of warming and cooling, and found statistically significant linear relationships between the two. During periods of warming, cyclone frequency increases, while during periods of cooling, it decreases. In the 1950 to 1975 cooling period, storm frequencies dropped by 30%, while in the 1905 to 1940 warming period, they increased by around 19%. Lambert (1995), using the Canadian Climate Centre (CCC) GCM, found a 4% decrease in extra-tropical cyclones in the northern hemisphere though the frequency of intense cyclones increased in the north Atlantic and north Pacific, particularly near the Aleution and Icelandic lows (Lambert, 1996).

It is unclear how extra-tropical storm frequencies will change in the future, though there is evidence that some areas will receive more frequent, or more intense, storms.

## 3.4 Thunderstorms

Convective storms (severe thunderstorms producing hail, lightning, tornadoes, heavy rain and strong winds) remain a particularly difficult issue for GCM's because of their small scale. Intuitively, one would expect more frequent and more intense convective activity since a warming surface and a cooling stratosphere in mid-latitudes will create greater instability in the lower atmosphere. **A number of studies have suggested more frequent intense convective rainfall in a warmer climate** (Mitchell and Ingram, 1990; Noda and Tokioka, 1989). Griffiths et al. (1993) discuss the difficulties in assessing convective changes.

Price and Rind (1993), using GCM output, suggested that a doubling of $CO_2$ with a 4.2°C warming in global temperature would increase cloud-to-ground lightning strokes by 72% over continental regions. Etkin (1995) in an empirical examination of tornado occurrence in the prairies of western Canada found that tornado frequency is greater in warmer springs and summers. This implies that the number of tornadoes may increase there as a result of climate change.

Evidence supports the hypothesis of more frequent and severe thunderstorms in the future.

## 3.5 Extreme Temperature Events

In a warmer climate, heat waves would become more frequent, while cold waves would become less so. **Evidence suggests that even small amounts of warming can have major impacts on this hazard due to non-linearities in the system.**

The frequency with which extreme temperature events occur has been analysed by Mearns et al (1984), Wigley (1988) and Katz and Brown (1992). Mearns et al. (1984) note the strong non-linear relationship between changes in the mean and changes in the probability of extremes, which may be the principal way in which climate change is felt. They found large changes in the likelihood of heat waves at Des Moines, Iowa (by a factor of 3), with relatively small changes in mean temperature (1.7°C). Hennessy and Pittock (1995) using a global warming scenario of 0.5°C found 25% more days over 35°C in summer and spring at Victoria, Australia, and 50-100% more in a 1.5°C warming scenario.

Wigley (1988) found that risk is extremely sensitive to changes in the mean (assuming that the extreme events come from the same parent population). He found, for example, that for an event with a 10% risk of occurring in 100 years, the risk is increased to 90% if the mean were increased by 0.02 standard deviations per year (assuming a normal distribution).

Katz and Brown (1992) analysed the sensitivity of extreme events to changes in the mean and standard deviation (for a normal distribution), and found that extreme events are more sensitive to variability than to its average, and that this sensitivity becomes greater the more extreme the event. This conclusion was also noted by Barrow and Hulme (1995). In an analysis of temperature extremes, a 0.5°C change in the mean results in a 35% increase in probability of daily exceedence of 38°C, while the same change in standard deviation results in a 71% increase. This occurs because the sensitivity to mean increases linearly while the sensitivity to standard deviation increases quadratically. Recent, but as yet unpublished, research at the University of Toronto suggest that increases in hot summer temperatures have historically been correlated with increases in variance over much of Canada.

If GCM models are correct, then rare heat wave events will become much more common before the middle of the next century, and cold waves less frequent.

## 3.6 Floods

Concern about increased flooding in a $2xCO_2$ world result from the fact that warmer atmospheres can hold more moisture, and precipitation is expected to increase as a result. As well, the precipitation is expected to become more convective (i.e. from thunderstorms) in nature (Mitchell and Ingram, 1990), and therefore more intense over smaller areas - suggesting greater flooding problems.

Gordon et al. (1992), while noting that GCMs cannot provide meaningful quantitative estimates of how extreme rainfall events may change, note that their GCM shows a marked increase in convective rainfall events and a mid-latitude decline of non-convective events. The frequency of large rainfall events increased (with return periods decreasing by around a factor of two for the central U.S. but by up to five elsewhere); while the frequency of light rainfall days decreased for all regions, especially in mid-latitudes. These results are similar to Noda and Tokiaoka (1989) and Hansen et al. (1988).

**This increase in variability (resulting from more favoured convection) suggests potentially large changes in the probability of extreme events**, as discussed by Katz and Brown (1992). In one example by Smith (1993), a 25% increase in half hour rainfall intensities for Sydney changed the 1 in 100 year event into a 1 in 17 year event. While noting the severe limitations of estimating changes to flood probabilities, Smith (1993) notes that for Australia, there is a consensus that the frequency of extreme floods will increase.

Rind et al. (1989), Wilson and Mitchell (1987) and Parry (1994), contrary to other results, did not find evidence of increased heavy rainfall in GCM simulations. Lawford et al. (1995) found no clear evidence of historical trends that indicate changes to extreme flood events in Canada, though the data is suggestive that Alberta may have been experiencing more heavy rainfall storms since the 1960s.

In the future, more local flooding is likely, due to more intense and more frequent thunderstorms.

## 3.7 Drought

The concern is that if precipitation becomes more convective with an increase in heavier events, then the number of dry days will increase and drought will become more severe (IPCC, 1995). This could be exacerbated by increases in potential evapotranspiration due to higher temperatures.

An interesting paper by Hughes and Brown (1992) indicates that central California has had fewer droughts in the period from 1850 to 1950 than at any time in the last 2000 years. This suggests that the current climate is anomalously benign, and that increased drought frequency in the future is not unlikely for that region.

Vance (1991) found that drought on the northern Great Plains is not cyclical, but rather that intervals of intense drought are interspersed between longer periods when drought is rare. Oladipo (1993) analysed drought in northern Nigeria and found a statistically significant abrupt transition towards lower precipitation in the Sahel region beginning in 1968. Some GCM studies show reduced summer soil moisture values over the mid North American continent, suggesting more frequent droughts, though Maybank et al. (1995) indicate that the trend is not clear. **Cubash et al. (1995) found a doubling from 1% to 2% in the frequency of 3 month droughts in central North America with a doubling of $CO_2$.**

More frequent drought is a likely consequence of climate warming. Since drought is the most costly hydrometeorological hazard in North America, this is of great concern.

## 3.8 Other Hazards

Various other hazards are tied to the more primary ones discussed above. For example, wildfires are a function of temperature, the precipitation regime and lightning. Street (1989) depicts a longer and more severe forest fire season in Ontario with climate warming, with a shift in timing towards later in the season for the most severe period. Storm surges and storm waves result from ocean or lake based storms. It is not clear how these hazards will evolve if the climate warms (Khandekar and Swail, 1995) due to uncertainty about storm intensities.

## 3.9 Summary

Conclusions on how climate change will affect the frequencies and intensities of extreme events in Canada are mixed. In a warmer climate, it seems likely that the number of convective events (e.g. thunderstorms with extreme rainfall, tornadoes and hail), heat waves, floods and drought will increase in many areas; while the frequencies of cold waves will become rarer. The relationship between the frequency and intensity of tropical cyclones and global warming is inconclusive. Table 3.1 is a summary of the current views on the future of extreme events as a result of climate warming.

## References

Agee, M. (1991). Trends in cyclone and anticyclone frequency and comparison with periods of warming and cooling over the northern hemisphere. *Journal of Climate* 4: 263-267.

Ahrens, C. D. (1994). *Meteorology Today, An Introduction to Weather, Climate and the Environment* (5th ed.). West Publishing Company, St. Paul, MN, 592 p.

Balling, R. C. and Lawson, M. P. (1982). Twentieth century changes in winter climatic regions. *Climatic Change* 4: 57-69.

Barrow, E. M. and Hulme, M. (1996). Changing probabilities of daily temperature extremes in the UK related to future global warming and changes in climate variability. *Climate Research* 6: 21-31.

Broccoli, A. J. and Manabe, S. (1990). Can existing climate models be used to study anthropogenic changes in tropical cyclone climate. *Geophysical Research Letters* 17: 1917-1920.

Carnell, R. E., Senior, C. A. and Mitchell, J. F. B. (1996). An assessment of measure of storminess: Simulated changes in northern hemisphere winter due to increasing $CO_2$. *Climate Dynamics* 12: 467-476.

Cubash, U., Waszkewitz, J., Hegerl, G. and Perlwitz, J. (1995). Regional climate changes as simulated in time slice experiments. MPI Report 153. *Climate Change* 31: 273-304.

Downing, T. E., Olsthoorn, T. E. and Tol, R. S. J. (1996). *Climate Change and Extreme Events, Altered risk, socio-economic impacts and policy responses.* European Commission, Amsterdam, The Netherlands, 309 p.

Etkin, K. A. (1995). Beyond the year 2000, more tornadoes in western Canada? Implications from the historical record. *Natural Hazards* 12: 19-27.

Gordon, H. B., Whetton, P. H., Piccock. A. B., Fowler, A.M. and Haylock, M. R. (1992). Simulated changes in daily rainfall intensity due to the enhanced greenhouse effect: Implications for extreme rainfall events. *Climate Dynamics* 8: 83-102

Gray, W., Lansea, C.W., Mielke, P.W. and Berry, K.J. (1994). Predicting Atlantic basin seasonal cycline activity by 1 June. Weather and Forecasting, vol. 9, pp. 103-115.

Griffiths, D. J., Colquhoun, J. R., Batt, K. L. and Casinadar, T. R. (1993). Severe thunderstorms in New South Wales: Climatology and means of assessing the impact of climate change. *Climatic Change* 25: 369-388.

Haarsma, R. J., Mitchell. J. F. B. and Senior, C. A. (1993). Tropical disturbances in a GCM. *Climate Dynamics* 8: 247-257.

Hall, N. M. J., Hoskins, B. J., Valdes, P. J. and Senior, C. A. (1994) Storm tracks in a high resolution GCM with doubled $CO_2$. *Quarterly Journal of the Royal Meteorological Society* 120: 1209-1230.

Hansen, J., Fung, I., Lacis, A., Rind, D., Lebedoff, S., Ruedy, R. and Russel, G. (1988). Global climate changes as forecast by GISS's three-dimensional model. *Journal of Geophysical Research* 93: 9341-9364.

Held, I. M. (1993). Large-scale dynamics and global warming. *BAMS* 74: 228-241.

Hennessy, K. J. and Pittock, A. B. (1995). Greenhouse warming and threshold temperature events in Victoria, Australia. *International Journal of Climatology* 15: 591-612.

Hughes, M. K and Brown, P. M. (1992). Drought frequency in central California since 101 B.C. Recorded in giant sequoia tree rings. *Climate Dynamics* 6: 161-167.

IPCC. (1995). *Climate Change 1995: The Science of Climate Change.* Houghton, J. T. , Meira Filho, L. G., Callander, B. A., Harris, N., Kattenberg, A. and Maskell, K. (eds.). Cambridge University Press.

Khandekar, M. L. and Swail, V. R. (1995). Storm waves in Canadian waters: A major marine hazard. *Atmosphere-Ocean* 33: 303-328.

Katz, R. W. and Brown, B. G. (1992). Extreme events in a changing climate: Variability is more important than averages. *Climatic Change* 21: 289-302.

Lambert, S. J. (1995). The effect of enhanced greenhouse warming on winter cyclone frequencies and strengths. *Journal of Climate* 8: 1447-1452.

Lambert, S. J., 1996. Intense extratropical northern hemisphere winter cyclone events: 1899-1991. *Journal of Geophysical Research D* 101: 21319-21325.

Landsea, C. W., Nicholls, N., Grucey, W. M. and Avila, L. A. (1996). Downward trends in the frequency of intense Atlantic hurricanes during the past five decades. *Geophysical Research Letters* 23: 1697-1700.

Lawford, R. G., Prowse, T. D., Hogg. W. D., Warkentin, A. A. and Pilon, P. J. (1995). Hydrometeorological aspects of flood hazards in Canada. *Atmosphere-Ocean* 33: 303-328.

Lighthill, J., Holland, G., Gray, W., Landsea, C., Craig, G., Evans, J., Kurihara, Y. and Guard, C. (1994). Global climate change and tropical cyclones. *Bulletin of the American Meteorological Society* 75: 2147-2157.

Maybank, J., Bonsal, B. Jones, K. Lawford, R., O'Brian, E. G., Ripley, E. A. and Wheaton, E. (1995). Drought as a natural disaster. *Atmosphere-Ocean* 33: 195-222.

Mearns, L. O., Katz, R. W. and Schneider, S. H. (1984). Extreme high-temperature events: changes in their probabilities with changes in mean temperature. *Journal of Climate and Applied Meteorology* 23: 1601-1613.

Mitchell, J.K. and Ericksen, N.J. (1992). Effects of climate change on weather-related disasters. In: Irving M. Mintzer (ed.): *Confronting Climate Change Risks, Implications and Responses.* Cambridge University Press, Cambridge pp. 141-151.

Mitchell, J. F. B. and Ingram, W. J. (1990). On $CO_2$ and climate. Mechanisms of changes in cloud. *Journal of Climate* 5: 5-21.

Noda, A. and Tokioka, T. (1989). The effect of doubling $CO_2$ concentration on convective and non-convective precipitation in a general circulation model coupled with a simple mixed layer ocean. *Journal of the Meteorological Society. Japan* 67: 95-110.

Oladipo, E. O. (1993). Drought in northern Nigeria: An indication of abrupt climatic change. *Weather and Climate* 13: 34-39.

Parey, S. (1994). Simulations de trente ans $1XCO_2$, $2XCO_2$, $3XCO_2$ avec le modele du LMD (64X50X11) premiers resultants. *EDF, Direction des Etudes et Recherches*, HE-33/94/008.

Price, C. and Rind, D. (1993). Lightning fires in a $2xCO_2$ world. In: *Proceedings of the 12th Conference on Fire and Forest Meteorology.* Jekyll Island, Georgia, October 26-28. pp. 77-84.

Rind, D., Goldberg, R., and Ruedy, R. (1989). Change in climate variability in the 21st century. *Climate Change* 14: 5-38.

Smith, D. I. (1993). Greenhouse climatic change and flood damages, the implications. *Climatic Change* 25: 319-333.

Street, R. B. (1989). Climate change and forest fires in Ontario. In: *Proceedings, 10th Conference on Fire and Forest Meteorology*, Ottawa, Ontario. pp. 177-181.

Vance, R. E. (1991). *A paleo-botanical study of holocene drought frequency in southern Alberta*. Ph.D. Thesis, University of British Columbia, 180 p.

Wigley, T. M. L. (1988). The effect of changing climate on the frequency of absolute extreme events. *Climate Monitor* 17: 44-55.

Wilson, C. A. and Mitchell, J. F. B. (1987). Simulated climate and $CO_2$ induced climate change over western Europe. *Climatic Change* 10: 11-42.

# 4.0 The Social and Economic Impact of Hydrometeorological Hazards and Disasters: a Preliminary Inventory

*by David Etkin*

*The social and economic costs to Canadians from natural hazards are substantial, not only as a result of damages when events occur, but also due to adaptation and recovery. In particular, drought, flood and hail have had significant economic impacts. Understanding the impact these hazards have had can help us can devise better policy tools to deal with them.*

## 4.1 Introduction

Canada is subject to a variety of natural hazards, both geophysical and hydrometeorological as described in Chapter 2. From time to time, these hazards have had significant social and economic impacts on Canadians, and they are sure to continue to do so in the future. Three recent examples occurred in July 1996, when damaging hailstorms occurred over Calgary and Winnipeg ,and severe flooding devastated the Saguenay region of Quebec. Coincidentally, all three of these events occurred during an international conference on natural hazards being held in Toronto (we shall not, however, infer any cause and effect relationship, though it is also noteworthy that during the 1990's – the International Decade of Natural Disaster Reduction - natural disasters world-wide increased dramatically).

Understanding the historical and potential costs resulting from natural hazards and disasters are important because:

1. People, if they are aware of their risks, are able to make more informed personal decisions regarding the purchase of insurance and other mitigative and adaptive options.
2. Governments at various levels can devise better policy tools to deal with hazards, in terms of prevention, response and recovery.
3. Industries (e.g. Insurance) can base their cost-benefit analyses on the best available data.

This paper will only inventory hydrometeorological events, though other natural hazards are certainly important (in fact the greatest risk Canadians face in the future from a natural hazard is probably due to an earthquake). The inventory upon which this paper is based is summarised, in part, in Figure 4.1, which shows the number of identified events by hazard for which cost estimates could or could not be made. The total of known costs are provided at the end of each bar, in 1995 dollars. Tornadoes are not included, since there are over 2,200 known Canadian events. Events are included if the information source suggested a 'significant' impact of some sort, either meteorological, social or economic. No precise definition of significant is used. The data collection was done primarily by undergraduate and graduate students during their work terms. For some categories, such as heat and cold, a number of events were identified, though no cost estimates were found. Further research in these categories may reveal some economic information. Some categories such as floods and storms have a number of estimates, though there are

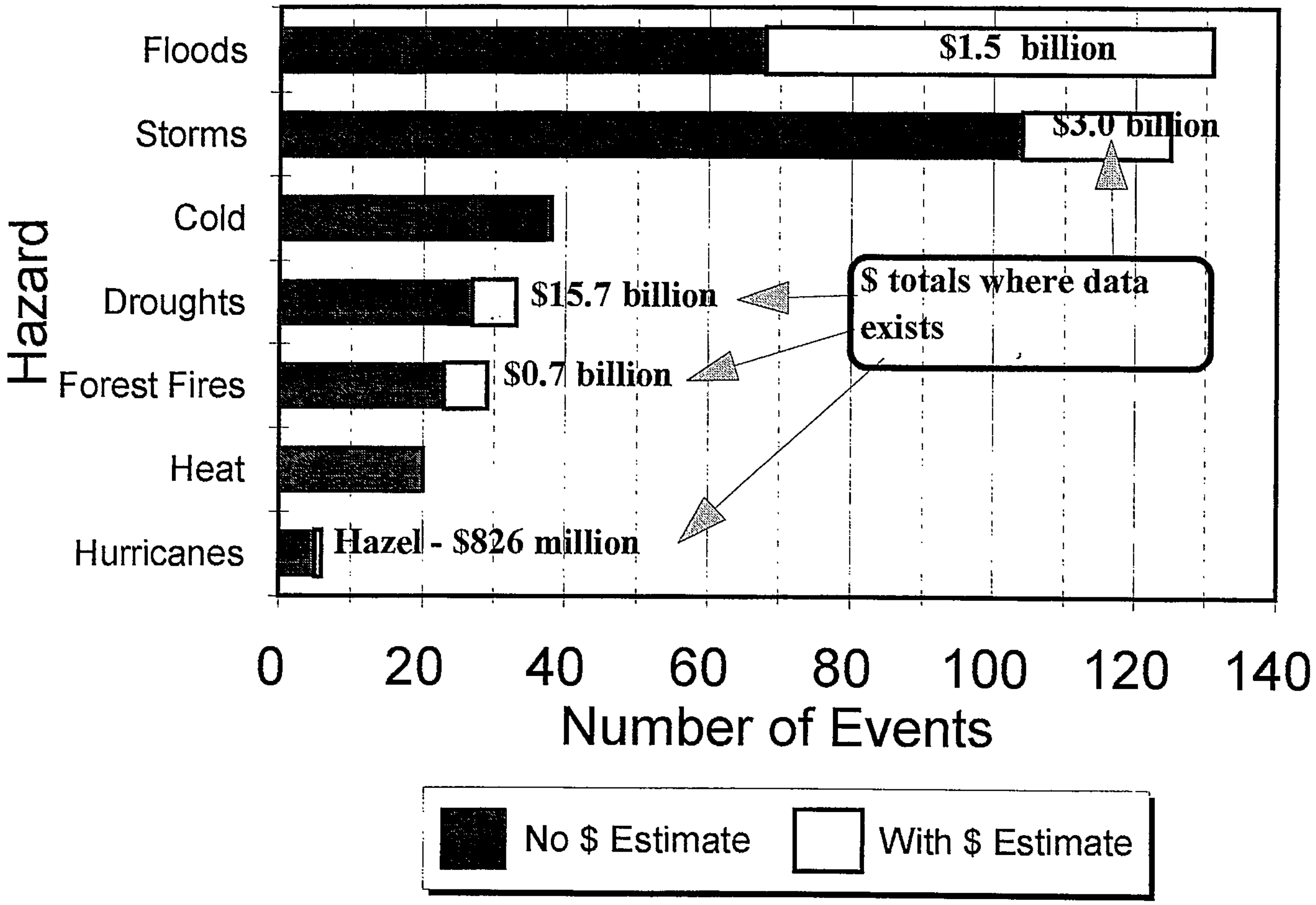


Figure 4.1 No. of Identified Events (tornadoes not included), 1961-1996
Totals in 1995 dollars.

still a large proportion of events with no estimate. Droughts, by far, are the most costly hazard, though they rank fourth on the list of frequency. It is worth noting that for hurricanes, only Hazel had an economic impact that was known.

An historical survey of Canadian disasters (Jones, 1991; Jones, 1995) shows that 44% of them were weather or climate related. Almost one-third of all disasters occur at sea, and 80% of those are weather related. A listing of these disasters follows in Table 4.1 and Table 4.2.

## 4.2 What Are Natural Disasters?

Natural disasters are the extreme of natural hazards, and occur when social vulnerability is triggered by an extreme event. A disaster is said to occur when recovery is not possible using local resources. There have been numerous recent examples, including Hurricane Andrew, the Northridge and Kobe earthquakes and the Saguenay flood. Blaike et al. (1994) emphasises the importance of understanding the social roots of disasters (while nature causes the event, man makes the disaster). The costs we incur from hazards are a function of our adaptive decisions. For example, if nobody lived in trailer parks or attended schools in portables, there would be many fewer deaths from tornadoes. Unsafe conditions result from a number of social forces which are rooted in limited access to power, economic resources and the nature of political and economic systems. Figure 4.2 (adapted from Blaike et al., 1994) illustrates this relationship.

## 4.3 Natural Hazards in Context

World-wide, people die from many causes, the dominant ones being civil strife and famine. Figure 4.3 shows the number of disasters world-wide from 1967-1991, including numbers injured and killed. Note that floods are the most frequent disaster, though drought claims the most victims. Most natural hazards cause relatively few deaths directly, especially in developed countries though their economic impact can be large. The one possible exception is famine, which is often drought or flood related, though some would argue that the number of fatalities are more related to social issues than the physical hazard itself.

The numbers in Figure 4.3 vary greatly from country to country for obvious reasons. Numbers for countries that are not at war and that are wealthy enough to support good health care systems and infrastructures that reduce vulnerability would be quite different from those for countries which suffer from a variety of social and economic woes. Costs incurred in Canada are summarised below.

## 4.4 Social Costs in Canada

### *4.4.1 Transportation*

*Aircraft Accidents*

Figure 4.4 shows aircraft and helicopter accidents in Canada from 1985 to 1994. The filled-in icons illustrate weather related events while human-environmental interactions are shown from 1991 onward by the empty circles and squares. The values were adjusted to the number of hours flown in 1994. Note the downward trend in weather related aircraft accidents from more than 60 in 1985 to less than 20 in 1994.

Table 4.1 Canadian weather-related disasters (single-event) with a death toll greater than 20.

| | Disaster | Year | Deaths |
|---|---|---|---|
| 1. | wreck of *Delight* off Sable Island, N.S. | 1583 | 85 |
| 2. | fleet of ships aground in fog, Quebec City | 1711 | 884 |
| 3. | hurricane hits Grand Banks, Nfld | 1775 | 4000 |
| 4. | sloop *Ontario* sinks in Lake Ontario | 1783 | 190 |
| 5. | *Hamilton* and *Scourge* sink in Lake Ontario | 1813 | 53 |
| 6. | Miramichi, N.B. fire | 1825 | 200-500 |
| 7. | hurricane-force winds on Lakes Ontario and Erie | 1844 | 200 |
| 8. | hurricane hist Nfld. | 1847 | 300 |
| 9. | PEI gale sinks 70 US fishing vessels | 1851 | 150-300 |
| 10. | wreck of *Hungarion* off Sable Island | 1860 | 205 |
| 11. | wreck of *Anglo Saxon* on Cape Race, Nfld. | 1863 | 238 |
| 12. | St. Lawrence River floods (Sorel and Trois Rivieres) | 1865 | 45 |
| 13. | *City of Boston* disappears in storm off N.S. | 1870 | 191 |
| 14. | wreck of *Atlantic* if fog of Prospect, N.S. | 1873 | 535-585 |
| 15. | forest fires near Lake Huron | 1881 | 500 |
| 16. | *Asia* sinks in Georgian Bay gale | 1882 | 126 |
| 17. | *Algoma* sinks in Lake Superior | 1885 | 48 |
| 18. | great fire of Vancouver | 1886 | 30-40 |
| 19. | *La Bourgogne/Cromartyshire* collision off N.S. | 1898 | 549 |
| 20. | wreck of *Valencia* off Vancouver Island | 1906 | 126 |
| 21. | avalanche in Rogers Pass, BC | 1910 | 62 |
| 22. | forest fire, Porcupine, Ontario | 1911 | 73 |
| 23. | Regina tornado | 1912 | 29 |
| 24. | 34 ships sink in Great Lakes storm | 1913 | 270 |
| 25. | *Southern Cross* vanishes off Nfld. | 1914 | 173 |
| 26. | 4 seal ships caught in ice off Nfld. | 1914 | 77 |
| 27. | *Empress of Ireland/Storstad* collision off Rimouski, Que. | 1914 | 1014 |
| 28. | Britannia mine avalanche, Howe Sound, BC | 1915 | 57 |
| 29. | forest fire, Cochrane/Matheson, Ontario | 1916 | 233 |
| 30. | *Princess Sophia* runs aground, northern BC | 1918 | 343 |
| 31. | forest fire, Haileybury, Ontario | 1922 | 44 |
| 32. | *John B. King* hit by lightning | 1930 | 30 |
| 33. | 3 Great Lakes ships wrecked | 1940 | 69 |
| 34. | *Truxton* and *Pollux* aground off Nfld | 1942 | 204 |
| 35. | Hurricane Hazel | 1954 | 83 |
| 36. | TCA Northstar crash, Mt. Slesse, BC | 1956 | 62 |
| 37. | 22 fishing boats sink in storm, Escuminac, NB | 1959 | 35 |
| 38. | winter storm hits Maritimes | 1964 | 23 |
| 39. | Granduc Mt. avalanche, Stewart, BC | 1965 | 26 |
| 40. | *D.J. Morrell* sinks in Lake Huron | 1966 | 28 |
| 41. | crater opens in rainstorm, St. Jean-Vianney, Quebec | 1971 | 31 |
| 42. | wreck of Edmund Fitzgerald, Lake Superior | 1975 | 29 |
| 43. | PWA 737 crash, Cranbrook, BC | 1978 | 42 |
| 44. | Ocean Ranger sinks off Nfld | 1982 | 84 |
| 45. | Edmonton, Alberta tornado | 1987 | 27 |
| 46. | Air Ontario crash, Dryden, Ontario | 1989 | 24 |
| 47. | *Johanna B* and *Capitaine Torres* sink - Gulf of St. Lawrence | 1989 | 39 |
| 48. | Gold Bond Conveyor sinks off Yarmouth, N.S. | 1993 | 33 |

Table 4.2 Supplemental list: Weather-related disasters that occurred over more than a few days or possibly outside Canadian territory, or had a death toll less than 20.

| | Disaster | Year | Deaths |
|---|---|---|---|
| 1. | Two Quebec City fires | 1845 | 23 |
| 2. | loss of Franklin expedition, NWT | 1847-48 | 129 |
| 3. | Cape Breton hurricane sinks 1200 ships | 1873 | 'untold' |
| 4. | great fire of Saint John, NB | 1877 | 18-100 |
| 5. | *Titanic* hist iceberg south of Grand Banks | 1912 | 1513 |
| 6. | longest Canadian summer heat wave | 1936 | 780 |
| 7. | '*Dirty Thirties*' on Canadian Prairies | 1930-39 | ? |
| 8. | Lake St. Clair tornado | 1846 | 16 |
| 9. | Red River Flood, Manitoba | 1950 | 1 |
| 10. | freighter sinks in Lake Superior due to winds | 1953 | 17 |
| 11. | 60 hour snowstorm in Montreal with 70 cm snow | 1969 | 15 |
| 12. | Barrie, Ontario tornado | 1985 | 12 |
| 13. | trawler *Hosanna* sinks 400 km off Cape Race | 1987 | 34 |
| 14. | *Protektor* disappears 400 km east of Nfld. | 1991 | 33 |
| 15. | *Salvador Allende* sinks 900 km south of Nfld. | 1994 | 29 |

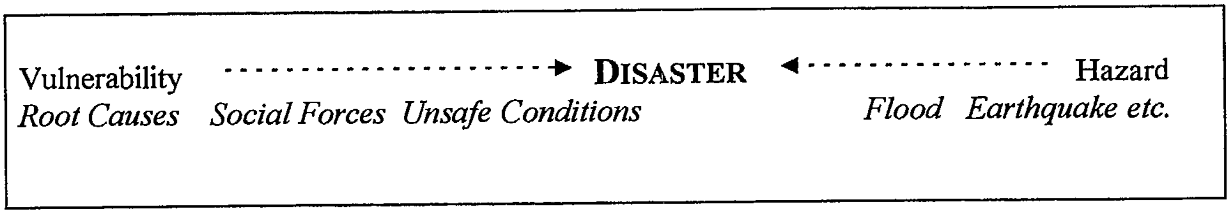


Figure 4.2 'Pressures' that Result in Disasters

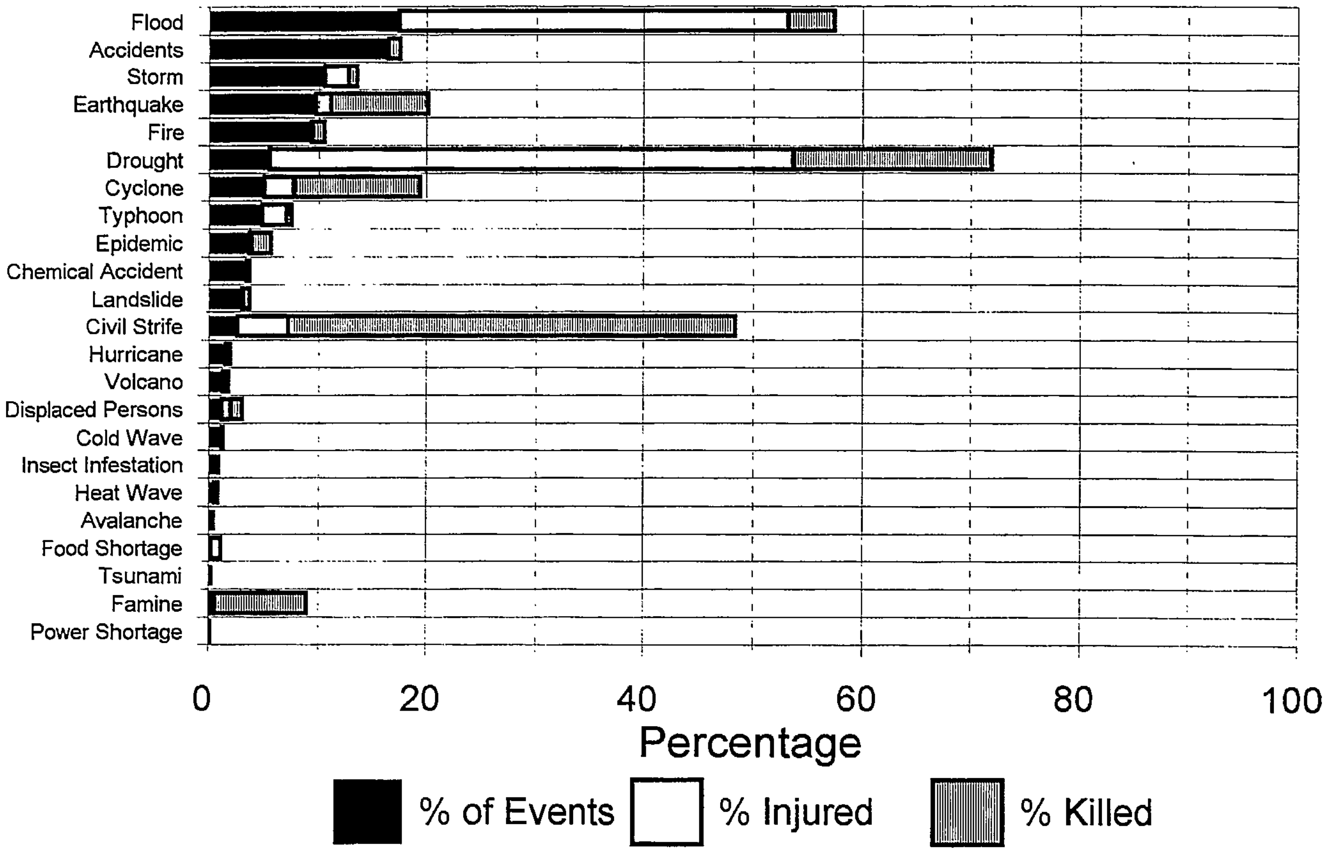


Figure 4.3 World Disasters, 1967 to 1991. As a result of 7,766 events, 3 billion people were injured and 7.5 million killed. Weather related hazards accounted for 47% of the events, 91% of the injuries and 36% of the deaths.
Source: World Disasters Report, Int'l. Red Cross

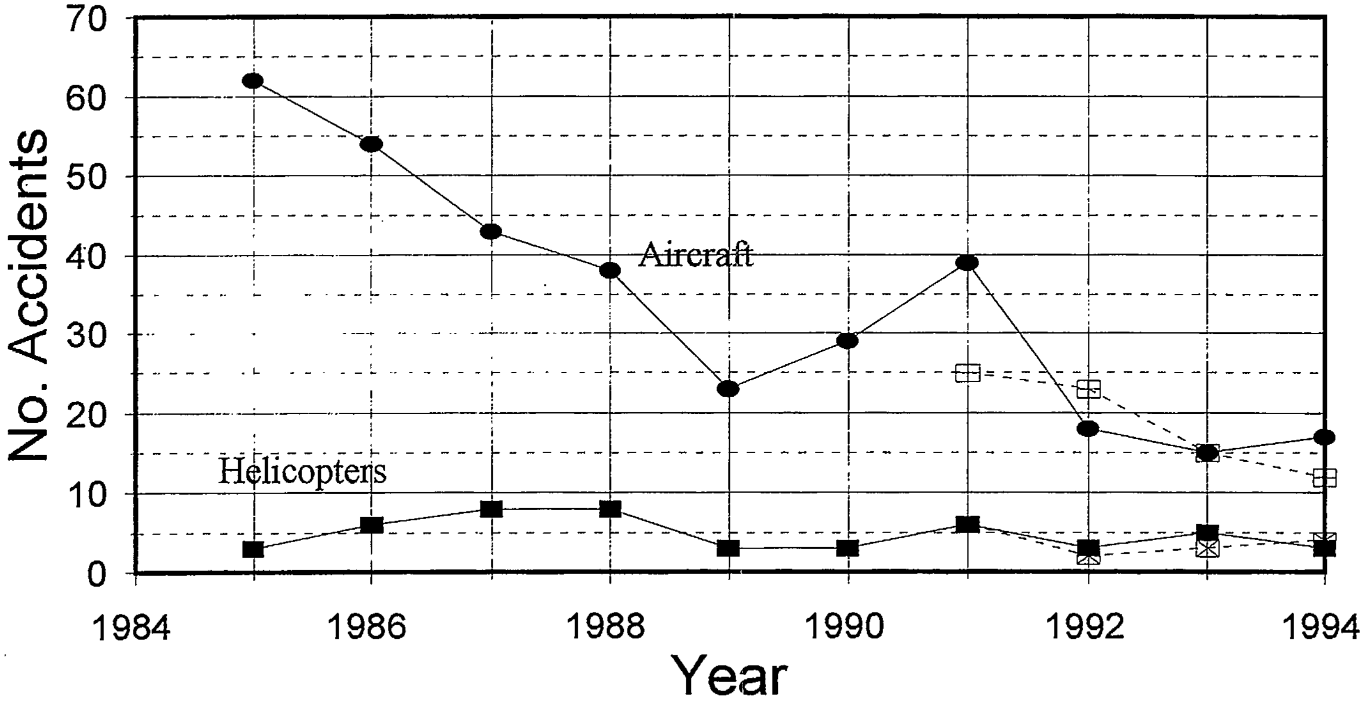


Figure 4.4 Weather Related Aircraft Accidents. Solid icons are weather related. Cross-haired icons represent Human-Environmental Interaction

Source: Transport Safety Board of Canada

Helicopter accidents have shown a much smaller trend.

*Railway Accidents*
Significant numbers of weather related railway accidents occur in Canada - over 120 in 1990 - though there are few fatalities (Figure 4.5). The number of accidents showed a sharp increase from 1988 to 1990, for an as yet undetermined reason, with a subsequent decrease after 1991, though not to the pre-1989 levels.

*Marine Accidents*
Historically, many of Canada's worst disasters have been ocean based (Jones, 1995). Figure 4.6 shows the number of weather related marine incidents from 1984 to 1993. The worst year was in 1990, as for railway accidents, with almost 500 incidents. Overall there has been a gradual decline of debatable significance. A history of weather related marine disasters is shown in Table 4.1.

*Ontario Road Accidents*
Figure 4.7 shows the 1992 statistics for weather-related Ontario road accidents, which accounts for about one-third of the cases. There were 298 fatalities, over 23,000 personal injuries and over 72,000 property damage cases. This does not include minor incidents not reported to the police. The majority of the accidents resulted from wet conditions, followed by ice, snow, slush and mud. Data from the other provinces is not currently available, but it is clear that weather related car accidents are of great significance.

### 4.4.2 *Number of Time Loss Injuries*

Weather related time loss injuries result mainly from cold, and are shown in Figure 4.8. Note the large increase after 1986, which is likely to be a function of non-climatic factors, such as policies in the Workers Compensation Board. In recent years, injuries have occurred at a rate of between 1,500 and 2,000 per year. Costs to employers from these injuries can be very large, and are worthy of further investigation. The largest number of injuries from 1990-94 was in Quebec (56%) followed by Nova Scotia (15%) and Alberta (9%).

### 4.4.3 *Time Lost at Work*

Figure 4.9 shows the number of hours lost at work due to bad weather from 1981 to 1994, adjusted to the number of employed Canadians in 1994. The curve shows a gradual decrease in time lost, in contrast from what one would expect as a result of the number of time loss injuries shown in Figure 4.8. Further investigation is required in order to understand this trend.

### 4.4.4 *Extreme Heat*

On average, 11 Canadians die annually from excessive heat and sun stroke (Etkin and Maarouf, 1995). The number who suffer heart attacks and other ailments as a result of hot weather discomfort is unknown. However, total mortality from all causes (i.e. heat and non-heat related) shows significant correlations with summer temperatures in Toronto and Montreal (Kalkstein and Smoyer, 1993). For both cities heat waves early in the season are considered more damaging than those late in the season.

Temperatures higher than 40°C have been experienced in all regions except the Maritimes and the Arctic. However, prolonged heat stress is unusual outside southwestern Ontario, southwestern Quebec and southeastern Manitoba. Heat waves in summer are much shorter than cold waves in winter. Most hot, humid spells break within

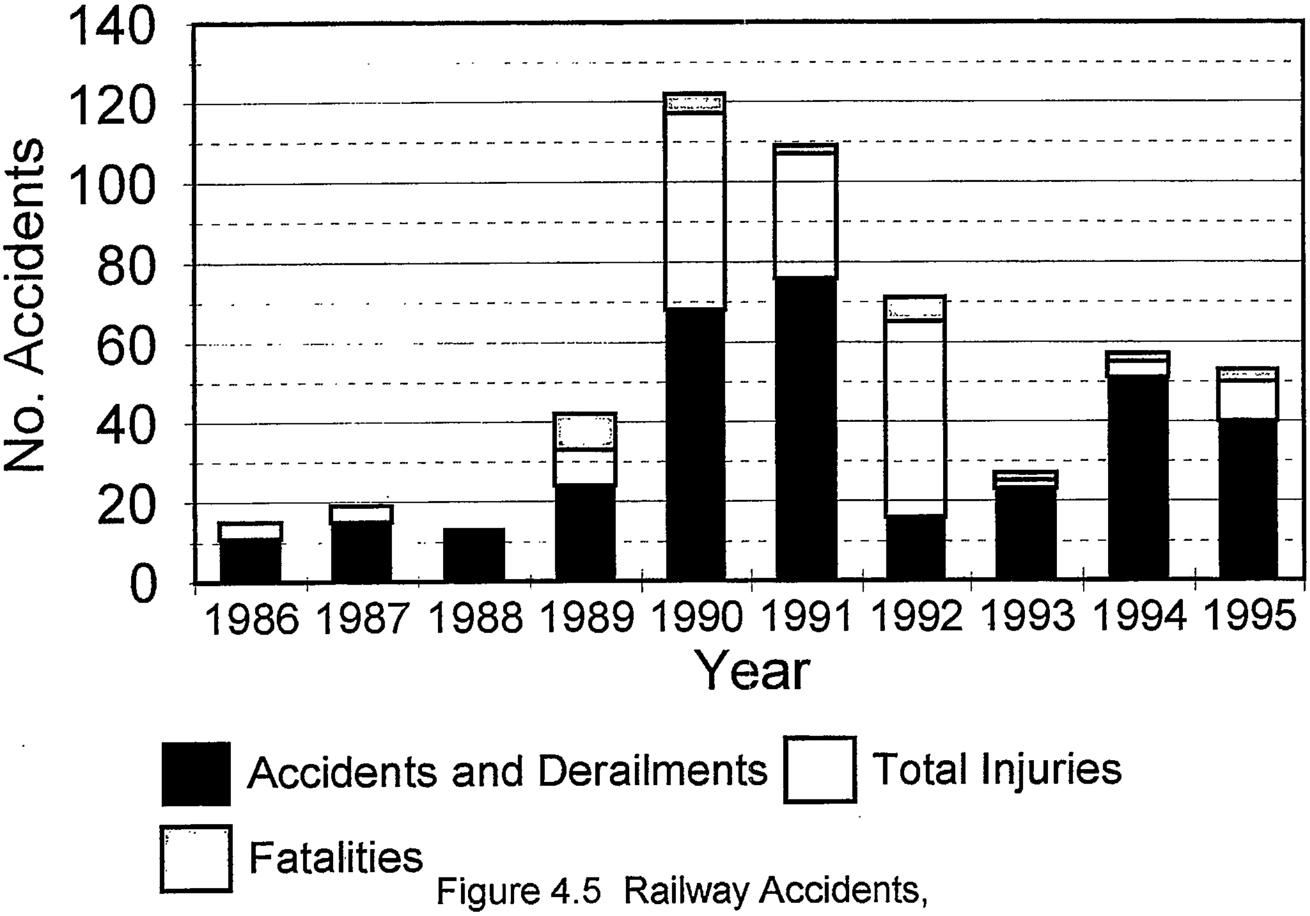


Figure 4.5 Railway Accidents,
Weather Related

Source: Transport Safety Board of Canada

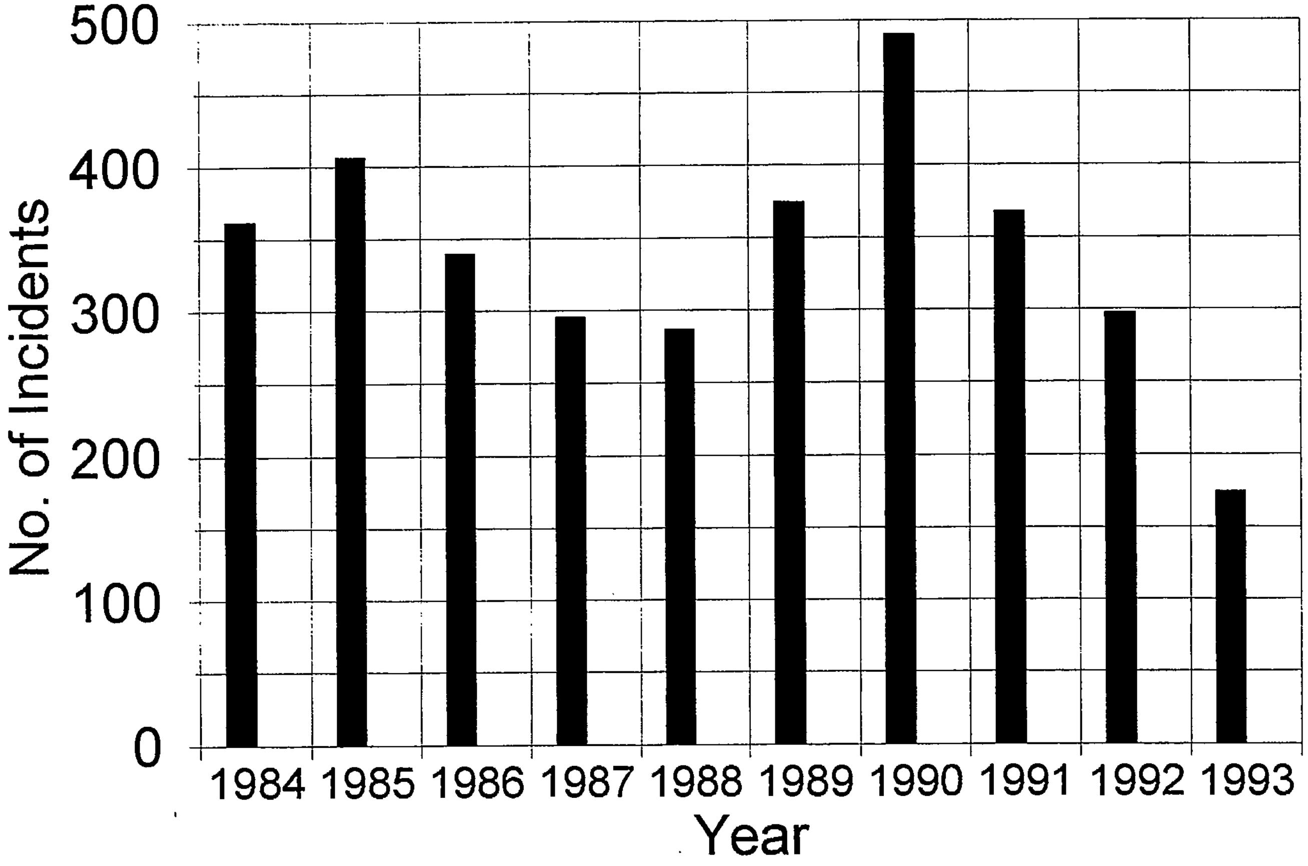


Figure 4.6 Marine Incidents,
Weather Related

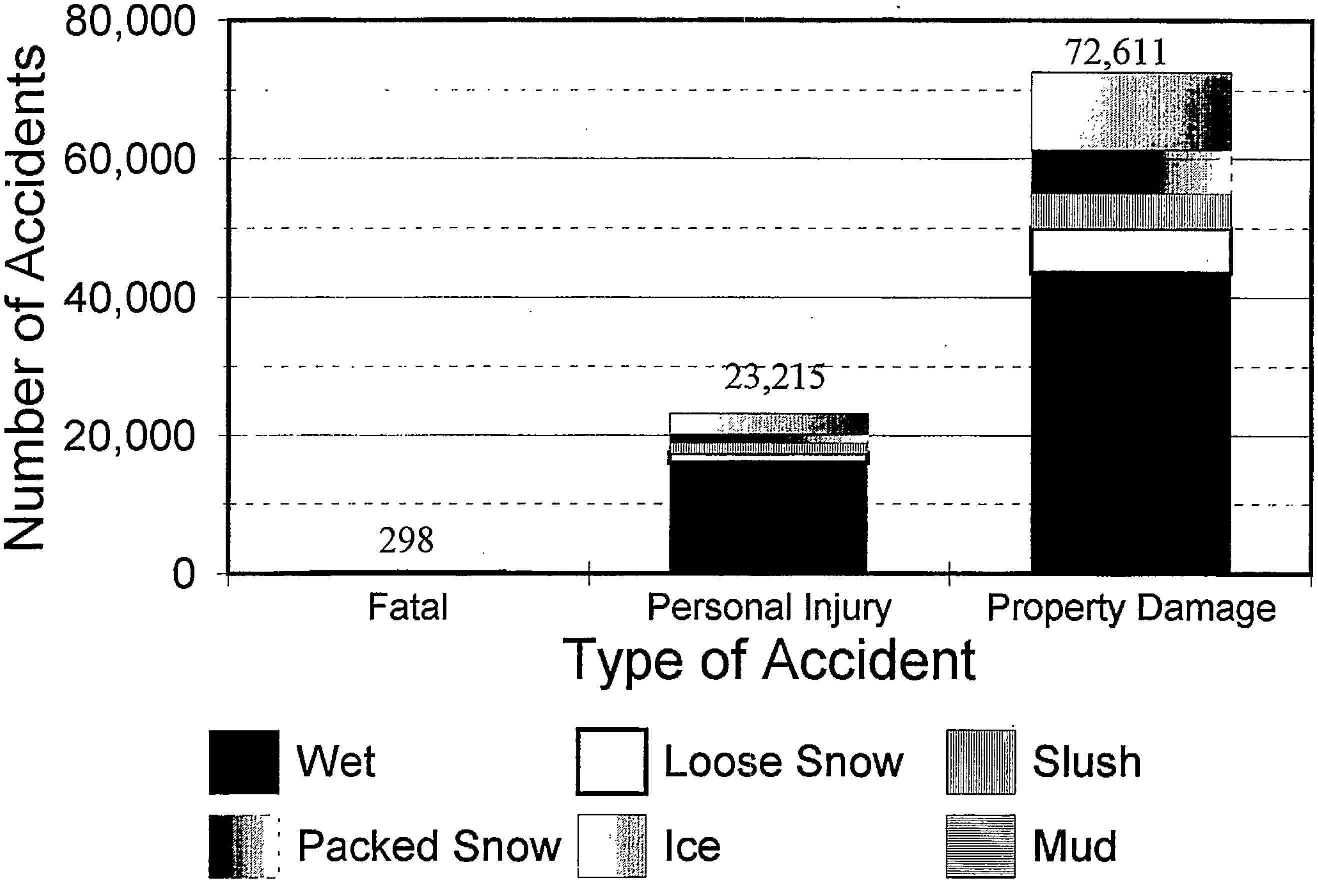


Figure 4.7 Weather Related Ontario Road Accidents, 1992
Source: Ontario Ministry of Transportation

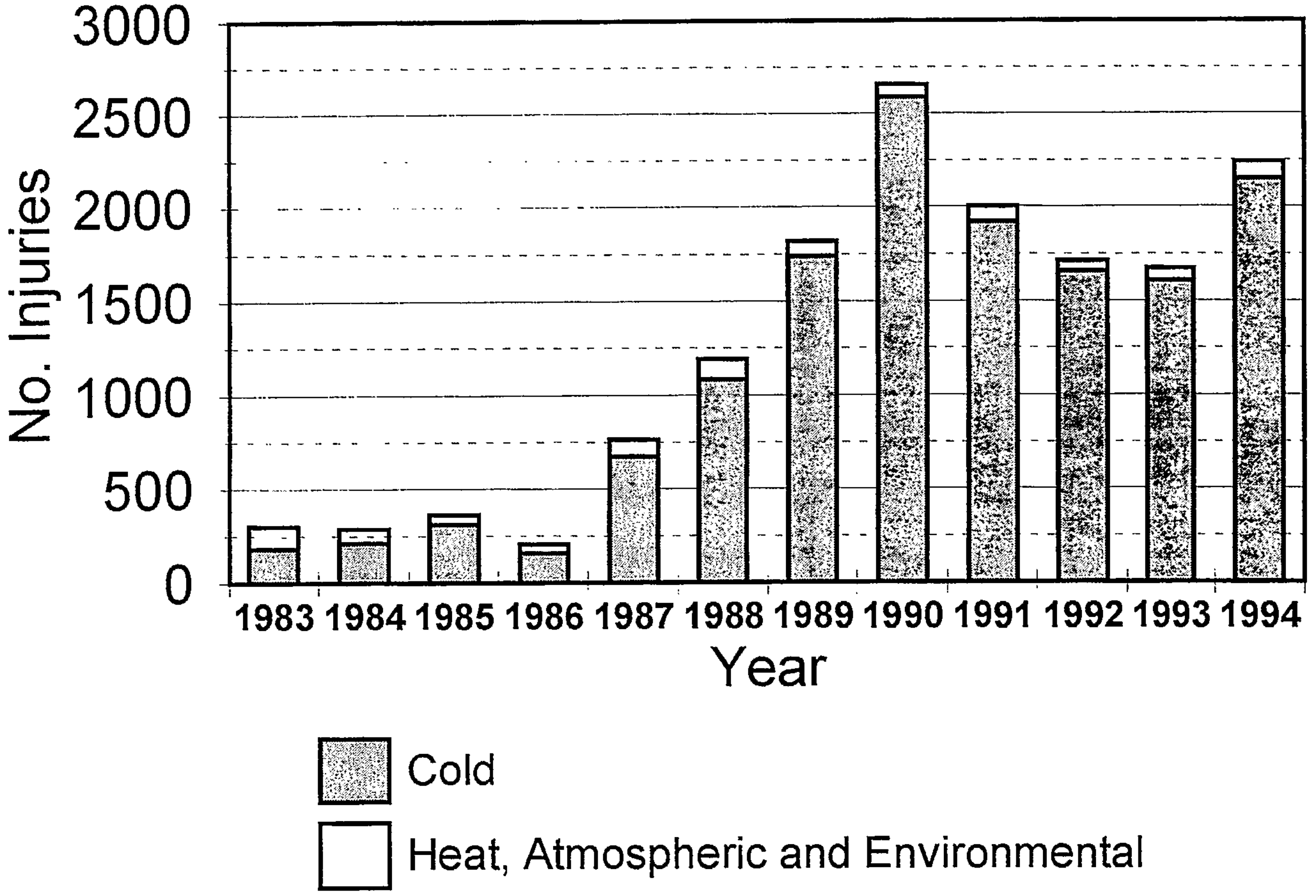


Figure 4.8 No. of Time Loss Injuries, Population Adjusted to 1995
Source: Stats Canada

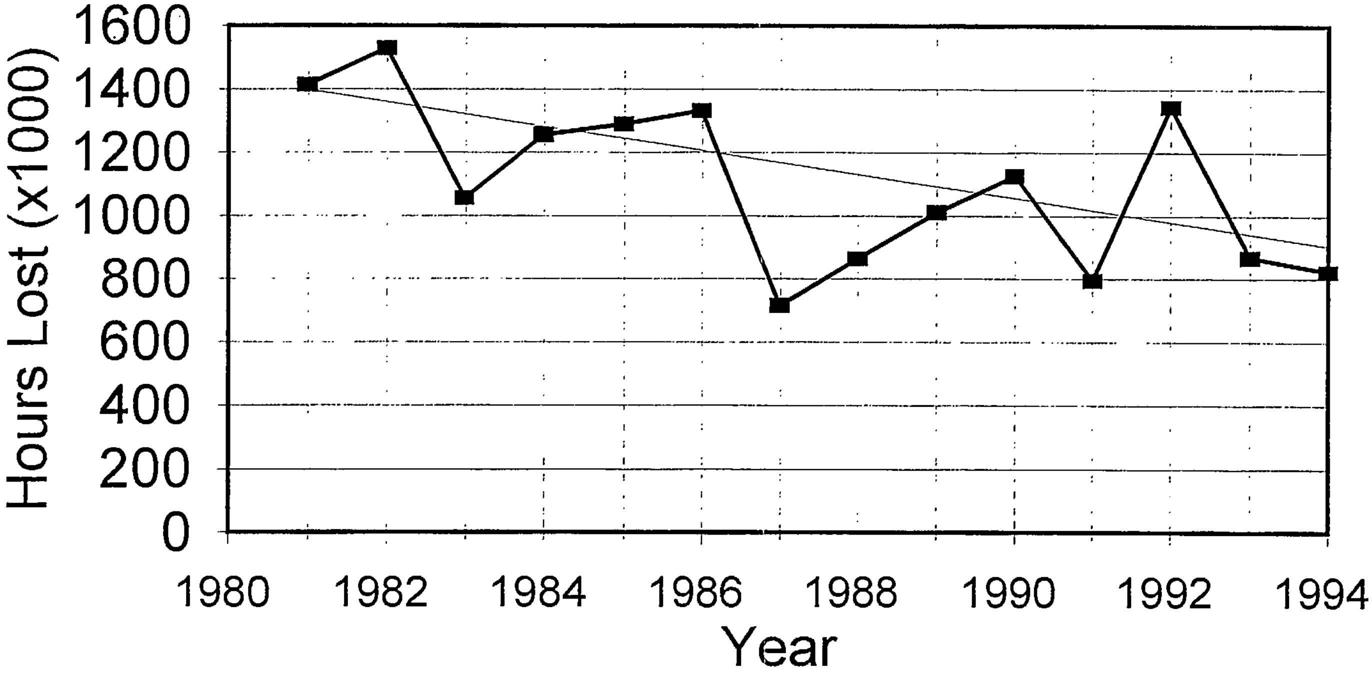


Figure 4.9 Time Lost at Work Due to Bad Weather, Adjusted to no. employed in 1995
Source: Stats Canada

5 or 6 days. One memorable exception, however, was Canada's worst heat wave in July, 1936. For a week and half, temperatures exceeding 32°C prevailed from southern Saskatchewan to the Ottawa Valley. High humidity added to the discomfort and 780 people died (Phillips, 1990). Forest fires consumed vast areas of tinder-dry bush in Ontario and the Prairies. The heat buckled highways and softened asphalt. Ground surface temperatures exceeded 65°C (Phillips, 1993).

Extreme Heat Events (Phillips, 1990, 1993):

1. Canada's worst heat wave in July, 1936; 780 people died and crops were blackened as a result of the extreme heat.
2. The highest temperature ever recorded in Canada was 45°C at Midale and Yellow Grass, Saskatchewan on July 5, 1937.
3. Starting on August 24, 1954, the longest consecutive string of hot days in Toronto (12 days) with a maximum temperature at or above 30°C.
4. June 1961 was a record hot, dry month on the Canadian Prairies.
5. The 1980s was the warmest decade in Canada (and globally) with several extreme heat events.

### *4.4.5 Deaths*

Canadians occasionally die from atmospheric hazards, as shown in Figure 4.10. Note that most deaths occur as a result of cold. By comparison, weather related fatalities due to car accidents in the province of Ontario alone are much larger (see Figure 4.7). In the past decade, the number of deaths from cold have shown a gradual decrease, while those resulting from other atmospheric causes have remained fairly constant. How Statistics Canada assigns attribution of cause requires further investigation.

## 4.5 Economic Costs

There are two fundamental costs associated with natural hazards:

1. **Adaptation costs** - the costs related to protecting ourselves from hazards (e.g. building codes or dams), and
2. **Impact, response and recovery costs** - the costs that society incurs when our protections fail.

### *4.5.1 Adaptation Costs*

Estimating adaptation costs is a difficult task, and little research has been devoted to it. One preliminary estimation of Canadian adaptation costs is provided in Table 4.3.

The total shown in this table is likely an underestimate.

### *4.5.2 Costs due to Impacts*

*Other Countries and World-wide*

Economically, natural hazards have shown some dramatic trends. Figure 4.11 (source, Munich Re) shows impact data world-wide - note the increase in recent decades. This increase is due to (1) increases in population, (2) the migration of population towards more hazardous areas such as coasts, (3) increases in wealth in many countries and (4) possibly an increase in the number of hazardous events.

The U.S. estimates that natural hazards cost them about $1 billion per week (Hooke, B, personal communication), and some of the more significant events such as Hurricane Andrew (which caused a number of insurance companies to go bankrupt) and the Northridge earthquake have had massive impacts. It is worth noting that Changnon et al. (1996), found that the 707 U.S. catastrophes in the $10-100 million range from 1949-1994 have shown a continual

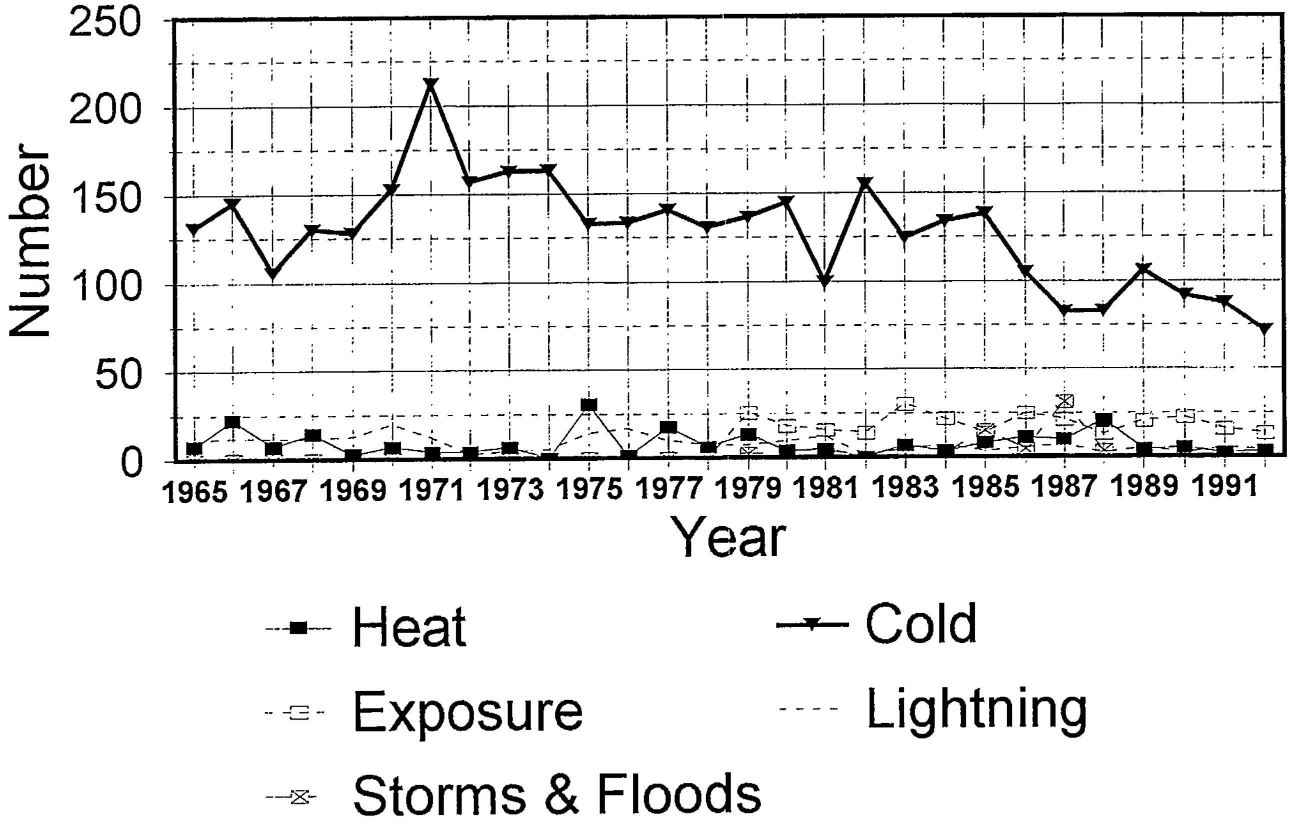


Figure 4.10 Deaths from Natural Hazards, Population Adjusted to 1995
Source: Stats Canada

Table 4.3 Annual climate adaptation expenditures in Canada by economic sector. Source: Burton, 1994.

| Sector | Annual Expenditure (billions $) |
|---|---|
| Transportation | 1.7 |
| Construction | 4.0 |
| Agriculture | 1.3 |
| Forestry | 0.4 |
| Water | 0.8 |
| Household | 5.3 |
| Emergency Preparedness | 0.01 |
| Weather Services | 0.2 |
| Total | 13.7 |

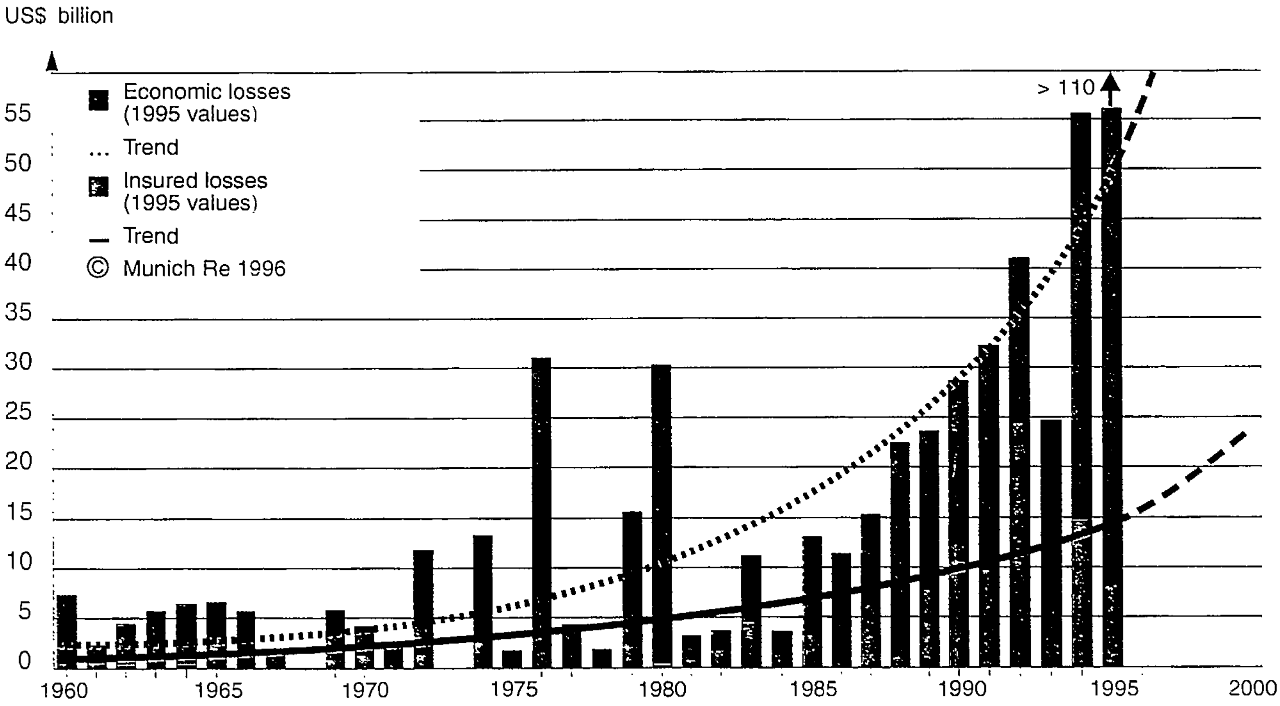


Figure 4.11 Economic and insured losses with trends. Source: Munich RE, 1995.

increasing trend, not related to weather fluctuations, but to changing populations or targets. Disasters costing more than $100 million have not shown the temporal increase, but correlate well with weather factors - not with population shifts. The Kobe earthquake in Japan set a new standard in the potential costs of natural hazards, with a price tag of around $100 billion (this number still varies quite a bit, depending upon the source). Table 4.4 shows a U.S. summary of recent costs due to natural hazards.

### *4.5.3 Economic Costs to Canada from Natural Hazards*

*Forest Fires*
Forest fires can have a direct impact due to the loss of a natural resource, though it is unclear how to account for them as they are now considered an essential part of the natural ecological cycle. Figure 4.12 shows the area of forests burned in Canada from 1986-95. Note that 1995 was by far the worst year with over 7 million hectares burnt, followed by 1989. The data supports an upward trend in area burnt, a statistic related to weather, but also to decisions made regarding fire fighting. All provinces incur costs related to fire management, which are shown in Figure 4.13. From the period 1985-1995, Ontario spent over $800 million, more than any other province. Annual fire management costs are shown in Figure 4.14. Costs peak in 1995 at over $450 million.

*Hydro Companies*
The provincial hydro companies were contacted in order to find impacts due to hazards. Ontario Hydro provided the best documentation, but only of the larger events, the cost of which are shown in Figure 4.15. Annual costs range from zero to $3 million, and average $1.4 million/year. Figure 4.16 shows a partial inventory of costs by hazard from several of the companies. This data set is very incomplete, and this figure is only provided for illustration purposes. The most costly hazard was 'wet snow+high wind', the total cost of which occurred due to one event at Vegreville and Lloydminster, Alberta. This two-day storm destroyed 108 steel transmission towers, 300 wood transmission structures, and more than 3000 wood distribution poles. In addition more than 250 miles of conductor had to be replaced. From the data provide, tornadoes (numbering 8) come second in terms of cost, though they were all from the Ontario Hydro list. Undoubtedly the prairies have experienced damaged towers from tornadoes, even though the information was not available.

### *4.5.4 Federal Payments by Emergency Preparedness Canada to the Provinces*

Figure 4.17 shows payments made by EPC to the provinces over the period 1970-1996. Audited totals are $425 million ($16 million/year) while the EPC payouts come to $263 million ($10 million/year), in 1995 dollars. These numbers do not include 19 events not yet settled and costs after March 31, 1996, and therefore the prairie hail disasters and Quebec floods of July 1996 are not included. A rough estimate of federal costs due to the Quebec flood is $280 million (Chris Tucker, personal communication).

Figure 4.18 shows how these costs are distributed by province. Quebec has received the most support (around $134 million in 1995 dollars- which amounts to 32% of all payouts - and which may increase to $414 million if the Saguenay floods are included), Manitoba the next with $83

Table 4.4 Weather related natural disasters in the U.S. where the cost exceeded $1 Billion US (1980-1995) – ordered by economic cost. (Source: NCDC)

| Event | Date | Economic cost ($ billions u.s.) | Lives lost |
|---|---|---|---|
| Drought/Heat Wave | Summer 1988 | 40 | 5,000 to 10,000 |
| Hurricane Andrew | August 1992 | 25 | 58 |
| Drought/Heat Wave | June-Sept. 1980 | 20 | 1,300 |
| Midwest Flooding | Summer 1993 | 15 to 20 | 48 |
| Hurricane Hugo | Sept. 1989 | 7.1 | 57 |
| Texas, Louisiana, Mississippi Flooding | May 1995 | >3 | 27 |
| California Flooding | Jan-March 1995 | >3 | 27 |
| Southeast Ice Storm | Feb. 1994 | >3 | 9 |
| Storm/Blizzard | March 1993 | >3 | 270 |
| Hurricane Opal | October 1995 | 2-3 | 21 |
| Florida Freeze | Dec. 1983 | 2 | 0 |
| Hurricane Allicia | Aug. 1983 | 2 | 21 |
| Hurricane Iniki | September 1992 | 1.8 | 6 |
| Hurricane Bob | August 1991 | 1.5 | 18 |
| Hurricane Juan | Oct.-Nov. 1985 | 1.5 | 63 |
| Nor'easter 1992 | December 1992 | 1 to 2 | 19 |
| Hurricane Elena | Aug.-Sept. 1985 | 1.3 | 4 |
| California Wildfires | Fall 1993 | >1 | 4 |
| Texas Flooding | October 1994 | 1 | 19 |
| Tropical Storm Alberta | July 1994 | 1 | 32 |
| Drought/Heat Wave | Summer 1993 | 1 | unknown |
| TOTAL | | approx. 115 | 7,000 to 12,000 ? |

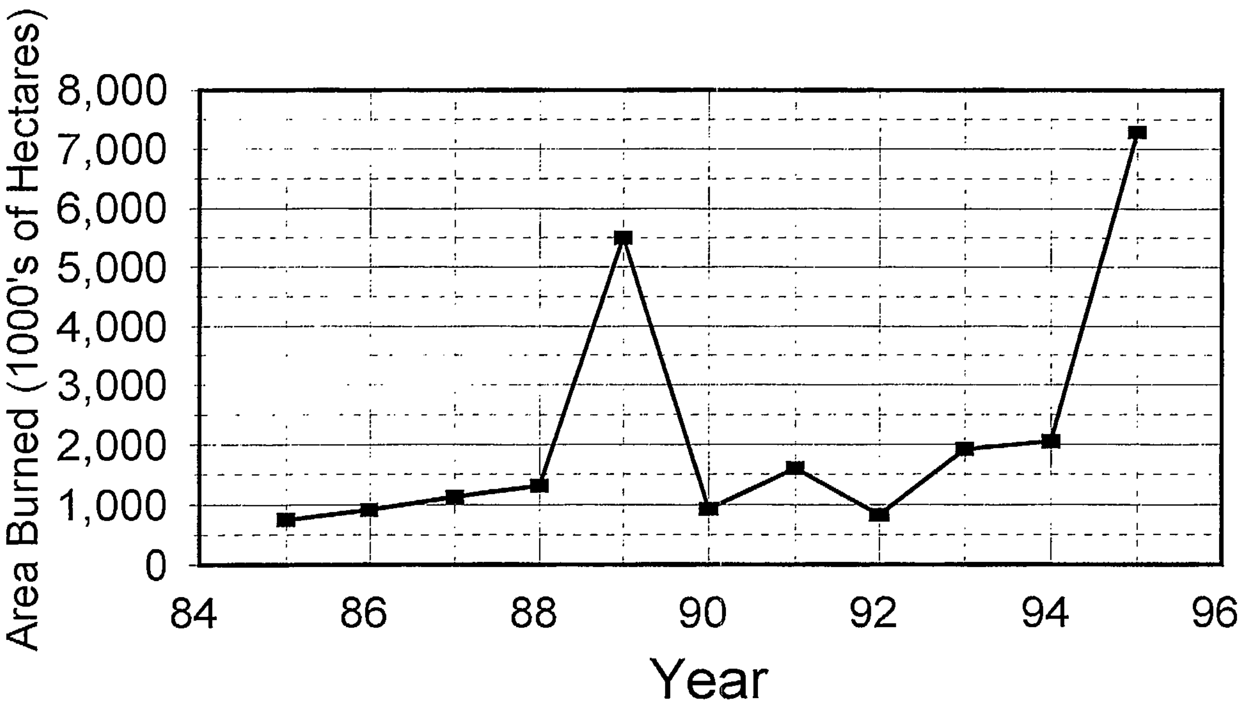


Figure 4.12 Forest Fires in Canada,
Area Burned

Source: Canadian Interagency Forest Fire Centre

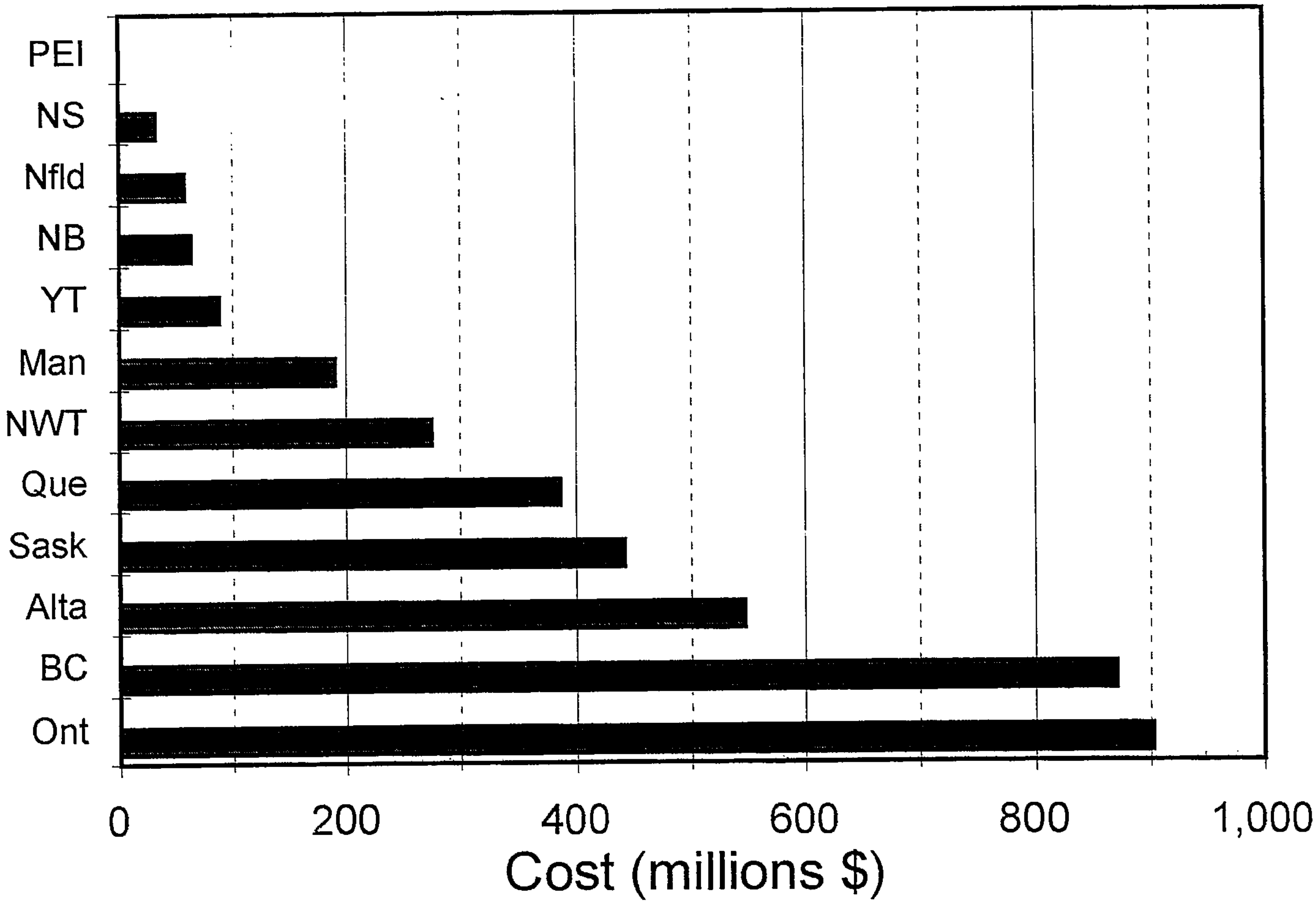


Figure 4.13 Fire Management Costs, 1985-1995, Adjusted to 1995 $
Source: Canadian Interagency Forest Fire Centre

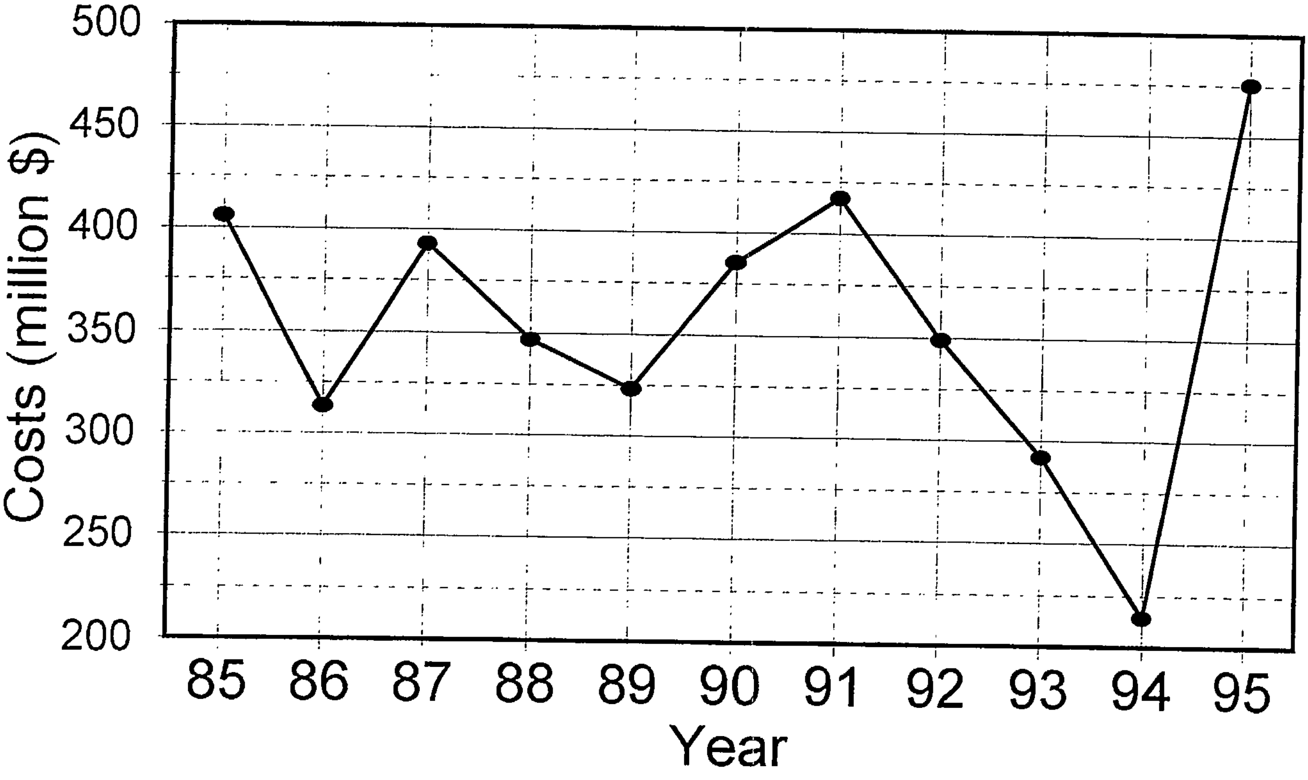


Figure 4.14 Fire Management Costs
Adjusted to 1995 $

Source: Canadian Interagency Forest Fire Centre

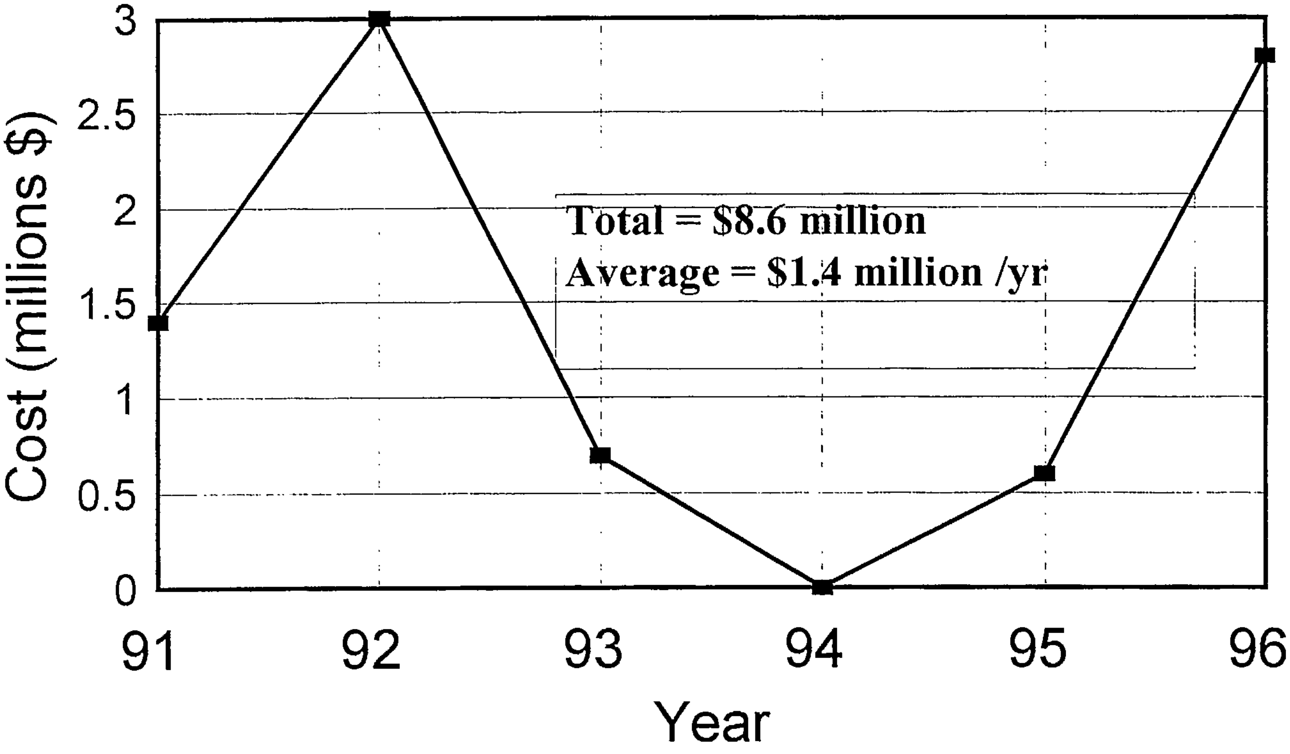


Figure 4.15 Weather Related Ontario Hydro Costs, Adjusted to 1995$
Source: Ontario Hydro

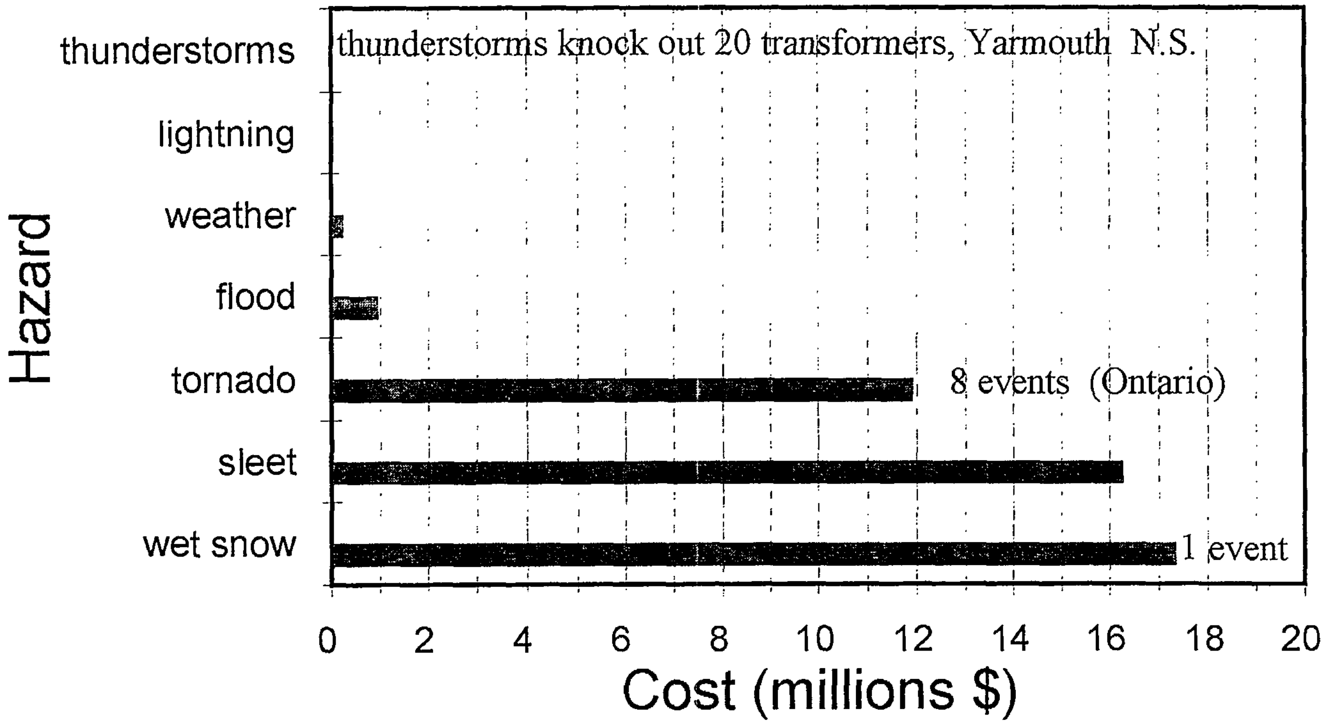
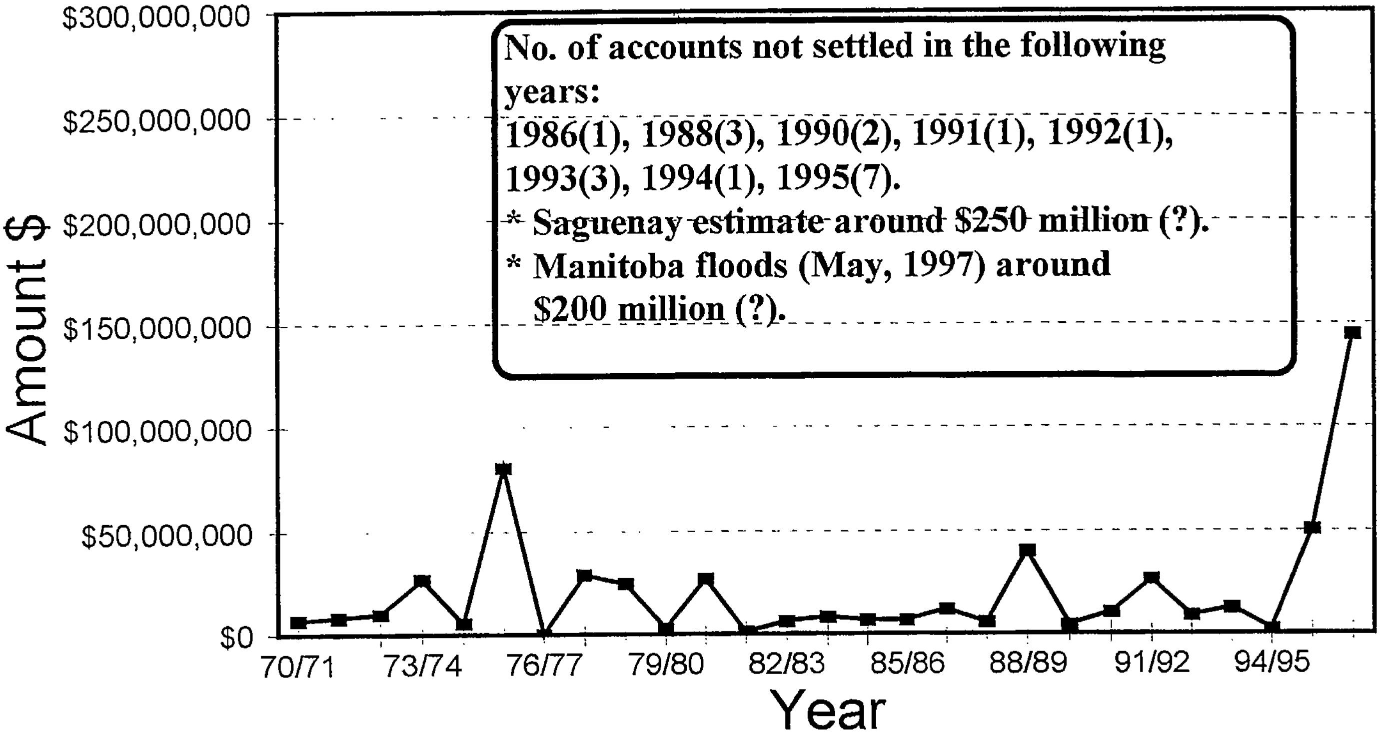


Figure 4.16 A List of Weather Related Costs to Hydro Companies, Adjusted to 1995$. Sources: Ontario Hydro, B.C. Hydro and Power Authority, Nfld. Light and Power Co, Climatic Perspectives. Important Note - this is a very incomplete list.



**No. of accounts not settled in the following years:**
**1986(1), 1988(3), 1990(2), 1991(1), 1992(1), 1993(3), 1994(1), 1995(7).**
*** Saguenay estimate around $250 million (?).**
*** Manitoba floods (May, 1997) around $200 million (?).**

Figure 4.17 EPC Payouts from 1975 to 1995, adjusted to 1995/96 $
Source: Emergency Preparedness Canada (EPC)

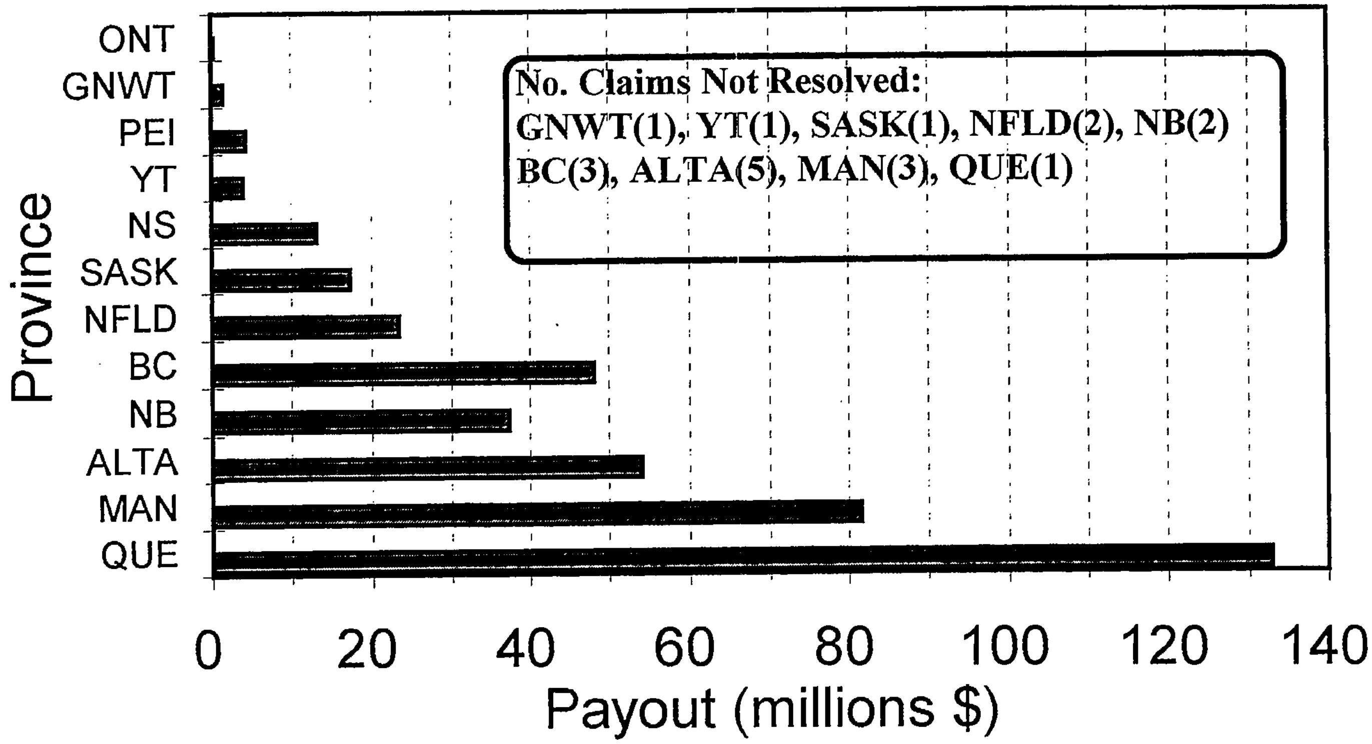


Figure 4.18 EPC Payouts by Province from 1975 to 1995, adjusted to Fiscal Year 1995/96 $

Source: Emergency Preparedness Canada (EPC)

million (20%) while Ontario has received the least ($75,000). Clearly, natural hazards point to the importance of federalism for some provinces.

Figure 4.19 shows payouts by hazard type. Floods have cost the most, by far, with audited totals over $300 million and federal payouts of $150 million (73% of the total payout for disasters in unadjusted dollars) while storm and fire rank second and third with about 11% each. The Saguenay disaster makes floods even more prominent in comparison.

### 4.5.5 Provincial Costs

*Crop Insurance*

Provinces incur costs due to crop damage from hail, flood, drought and a variety of other hazards. Figure 4.20 shows the average annual provincial costs. Saskatchewan has incurred the greatest costs, over $130 million per year (1995 dollars). Crop losses for Manitoba run around $30 million per year, and are detailed in Figure 4.21, which shows the costs by hazard. Drought has had the most impact in Manitoba, almost $400 million 1995 dollars from 1966-1994, followed by excess moisture, hail, heat, and frost. Other hazards are much smaller. Costs vary greatly from year to year, as shown in Figure 4.22a-d. The largest annual expenditure occurred in Saskatchewan, over $550 million 1995 dollars.

*Disaster Financial Assistance*

All provinces also have disaster financial assistance programs. Data on these costs is very incomplete and requires more research. Of the $93 million 1995 dollars paid by the Manitoba Disaster Assistance Board from 1974-95, 73% was for flood, 18% for fires, 7% for tornadoes and the remainder for miscellaneous causes. All of the $74 million B.C. costs from 1990-95 were for flood claims. In Alberta, of the $260 million (1995 dollar) cost from 1986-95, 89% was for flood and 9% for drought.

*Insured Costs*

Summaries of costs to the Insurance industry are provided by the Insurance Bureau of Canada. Figure 4.23 shows the cost of multiple major payouts, from 1983-1994 (Source: Insurance Bureau of Canada). This data does not include the cost of events less than about $4 million, and therefore the true costs are much greater than those shown in this figure. Hail has resulted in the most payouts (over $450 million), followed by tornadoes, flood, storm and wind (Figure 4.24). There appear to have been 9 events in 1995 (Alan Pang, personal communication) which include significant damage from flood, hail, thunderstorms, wind and Hurricane Hortense. Two hailstorms in Alberta and a thunderstorm in Ontario each estimated to cost over $25 million in insurance payouts. Hortense is expected to cost about $3 million. In July, 1996 hailstorms in Calgary and Winnipeg are estimated to cost around $295 million in total (Alan Pang, personal communication). The largest single insured disaster in Canada was the Calgary hailstorm of 1991, which cost around $380 million. The insured costs of the Saguenay floods are currently estimated at $350-400 million.

### 4.5.6 Municipalities

Very little information is readily available on costs to municipalities. A few statistics follow, using unadjusted dollars:

*Regional Municipality of Ottawa-Carleton*

Winter 1993-94: $2.5 million due to a record number of water services freezing.
Winter 1995-96: Unknown cost due to freeze/thaw cycles causing potholes.

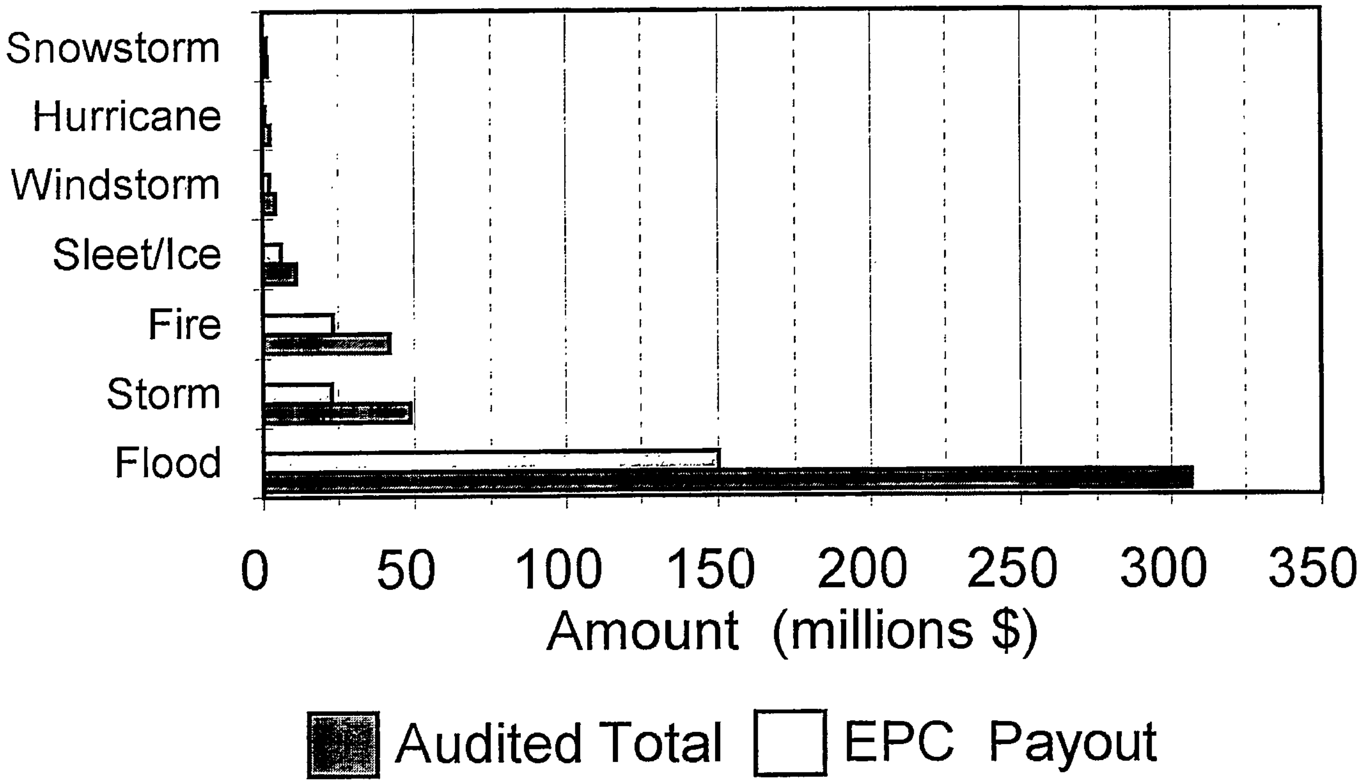


Figure 4.19 EPC Payouts by Disaster Type from 1975 to 1995 (Unadjusted $)
Source: Emergency Preparedness Canada (EPC)

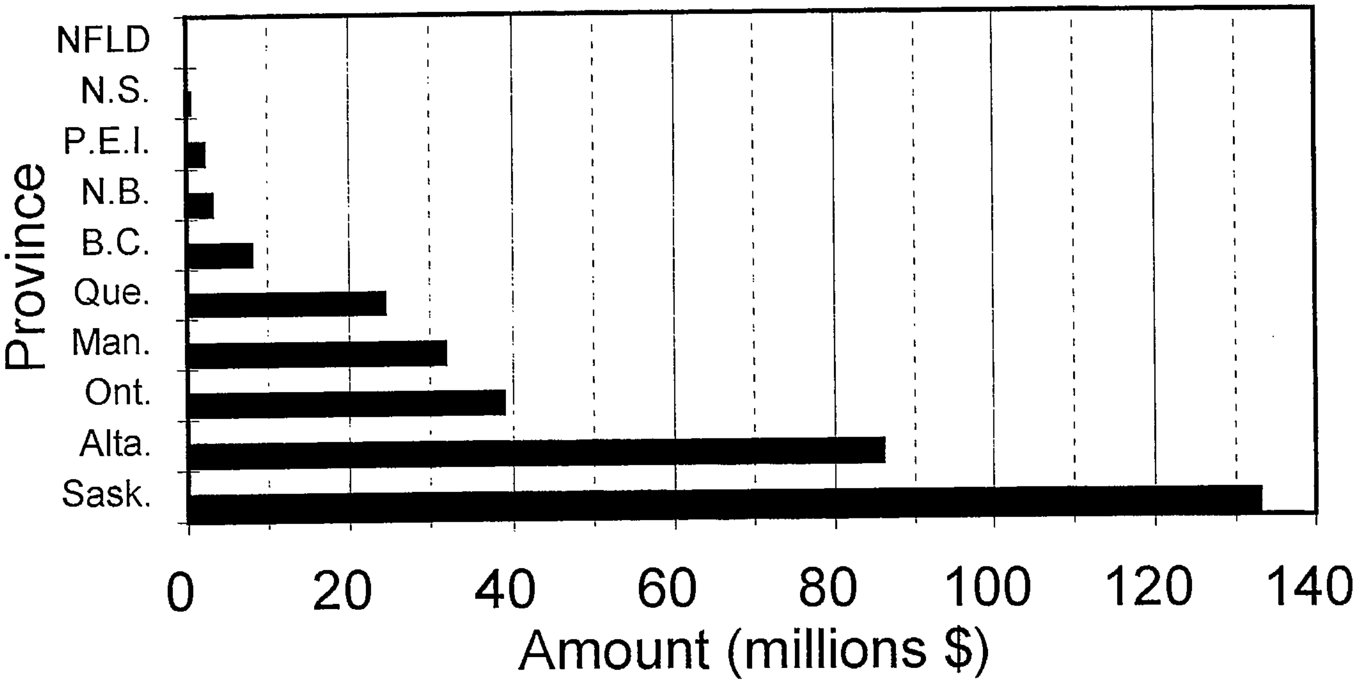


Figure 4.20 Provincial Crop Insurance Payments. Average Paid per Year (1995 $). Programs began as early as 1959 in Manitoba and as late as 1974 in NB. The average annual payment is $328 million.
Sources: British Columbia Ministry of Agriculture, Fisheries and Food, Alberta Hail and Crop Insurance Corporation, Ontario Ministry of Agri-food and Rural Affairs, Manitoba Crop Insurance Corporation, New Brunswick Crop Insurance

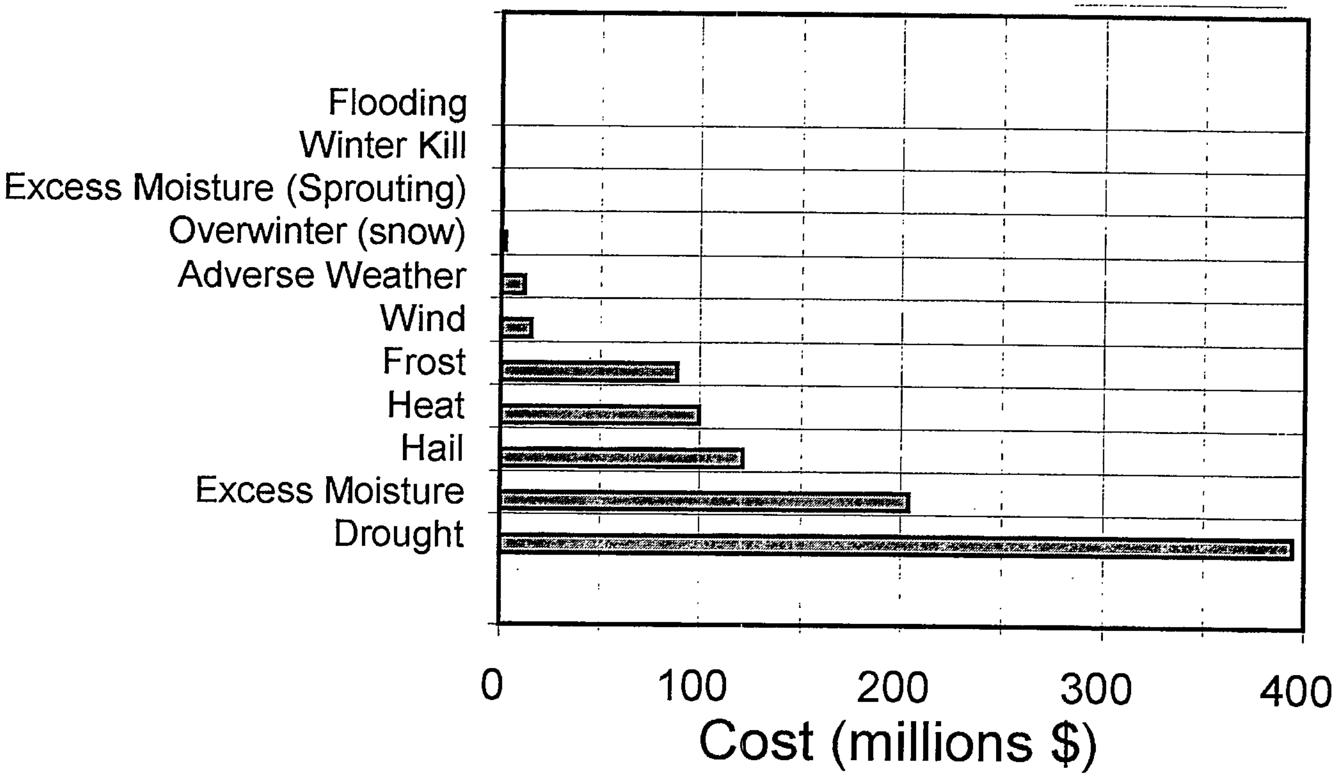


Figure 4.21 Manitoba - Crop Loss by Cause, 1966 to 1994 (1995 $).
Total loss = $865 million; Average loss = $30 million / year

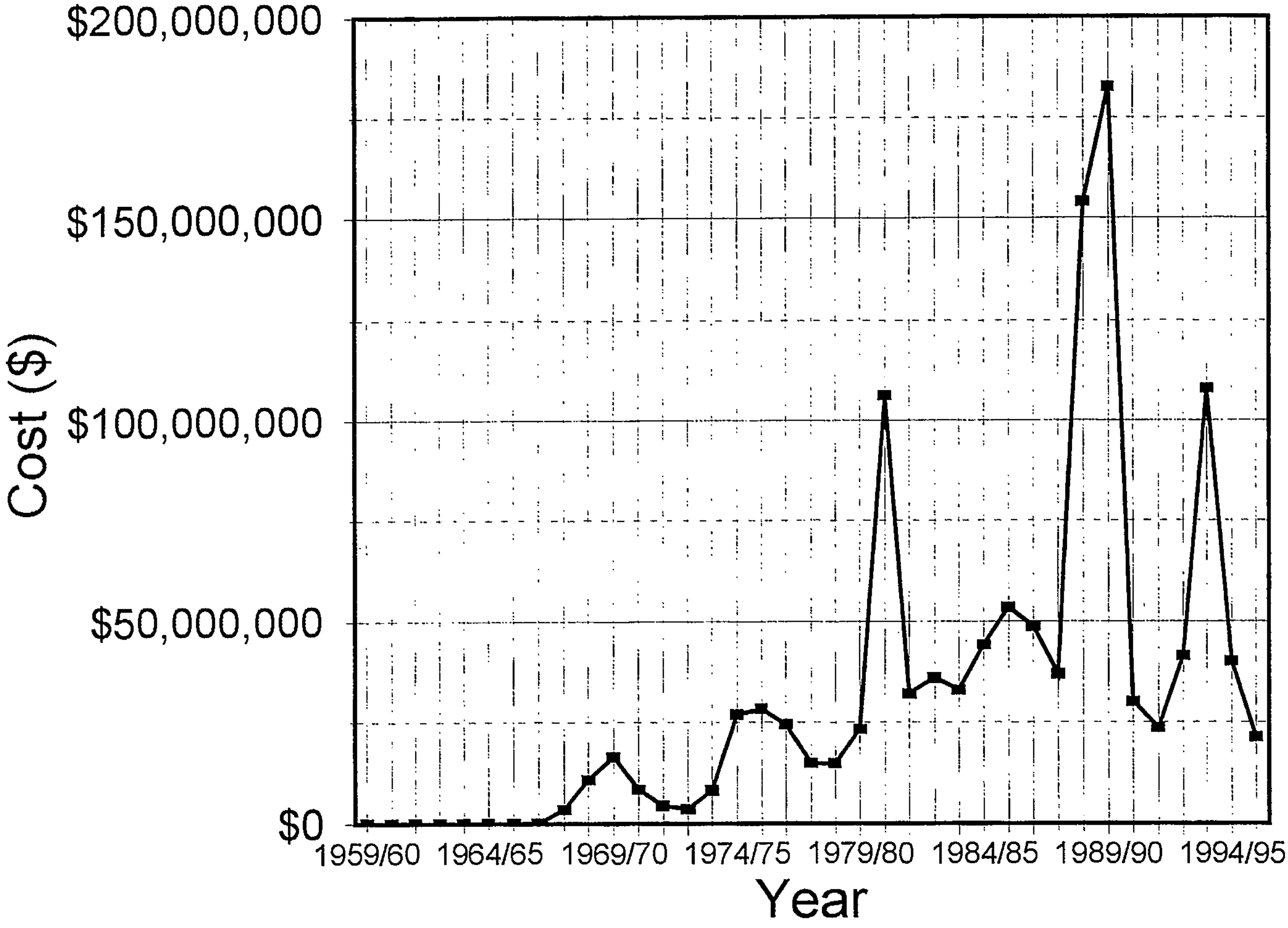


Figure 4.22a Manitoba Crop Insurance Payments (1995$)

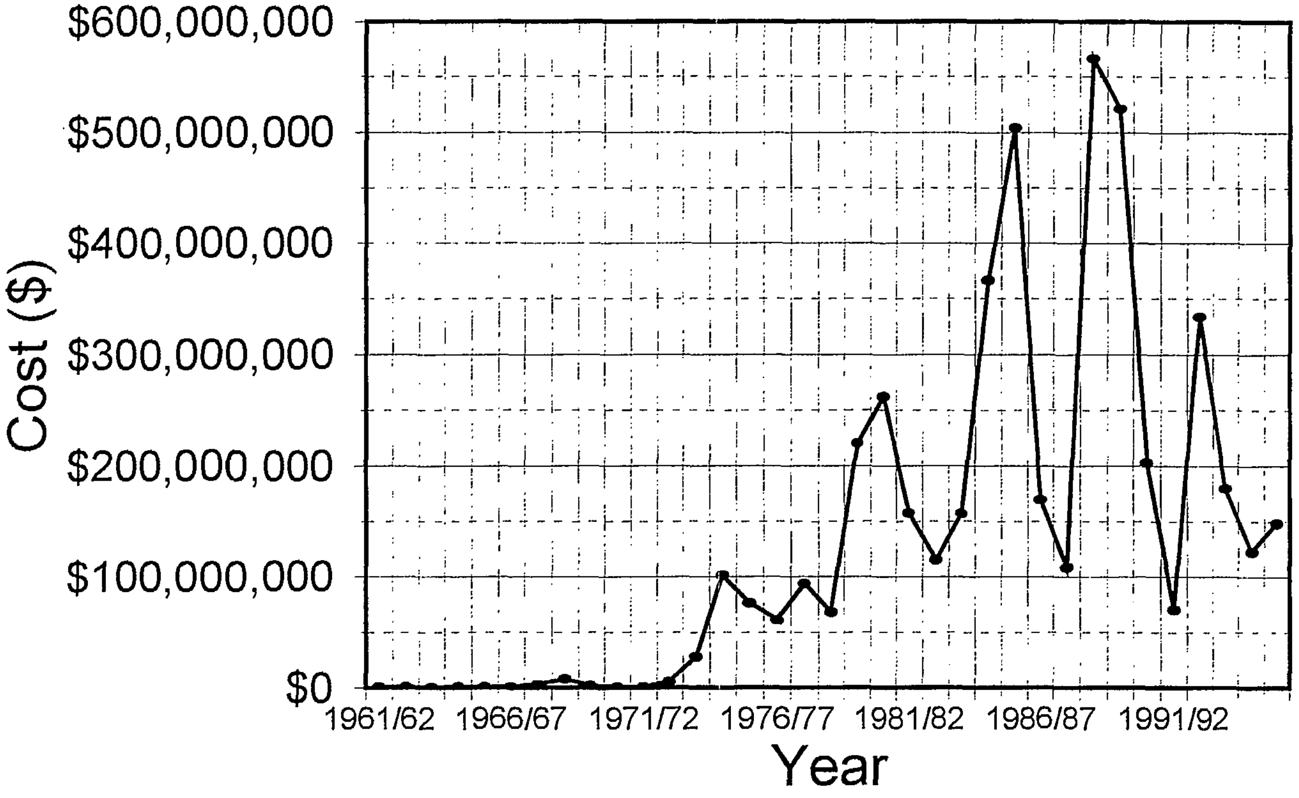


Figure 4.22b Saskatchewan Crop Insurance Payments (1995$)

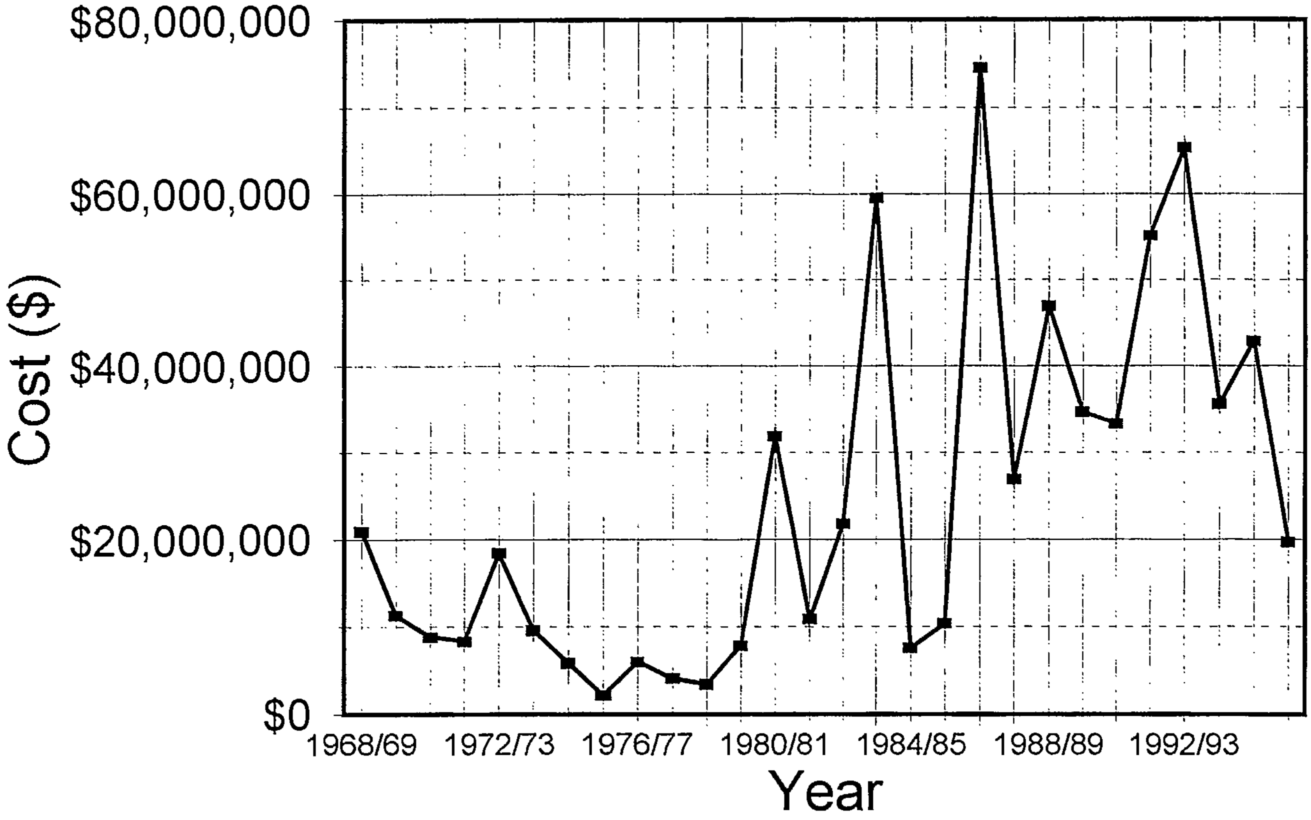


Figure 4.22c Quebec Crop Insurance Payments (1995$)

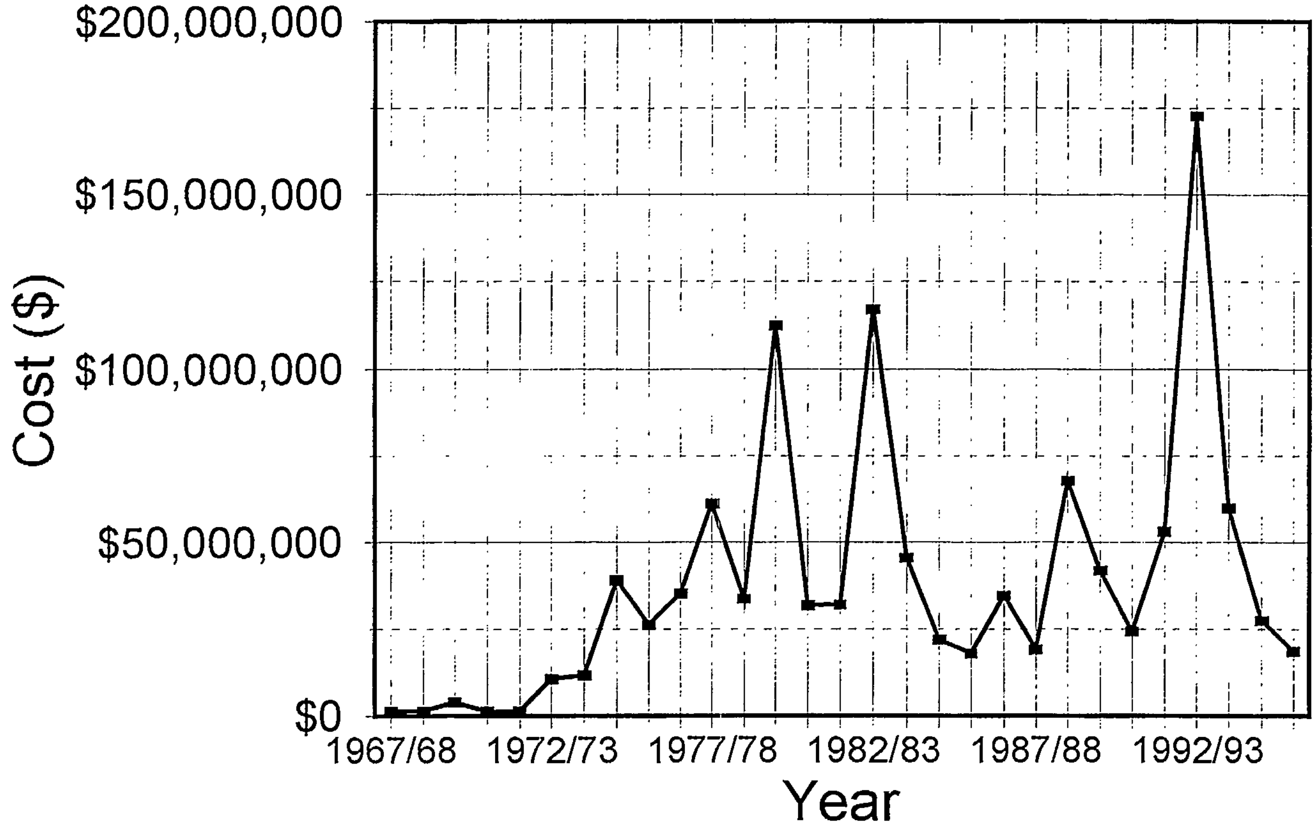


Figure 4.22d Ontario Crop Insurance Payments (1995$)

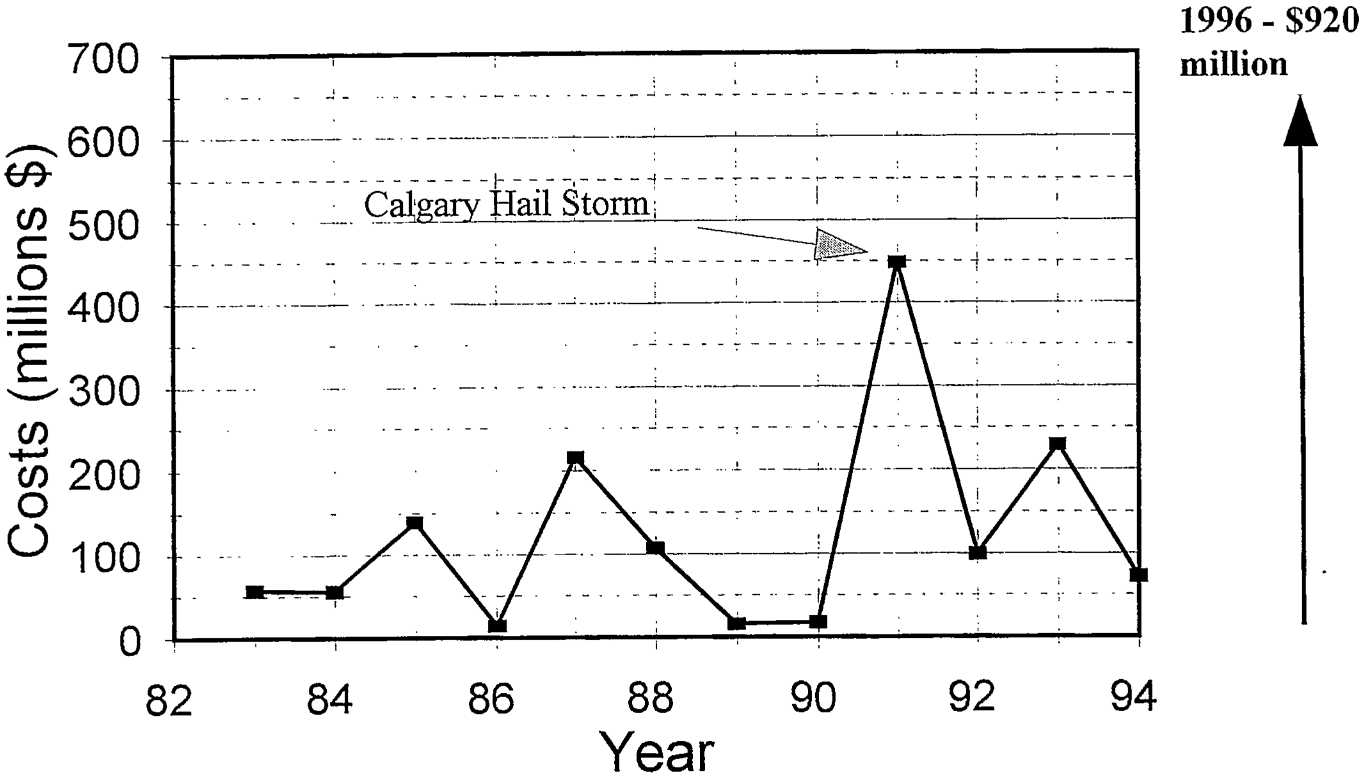


Figure 4.23 Weather Related Insurance Costs from Major Multiple Payouts (1995$).
Source: Insurance Bureau of Canada

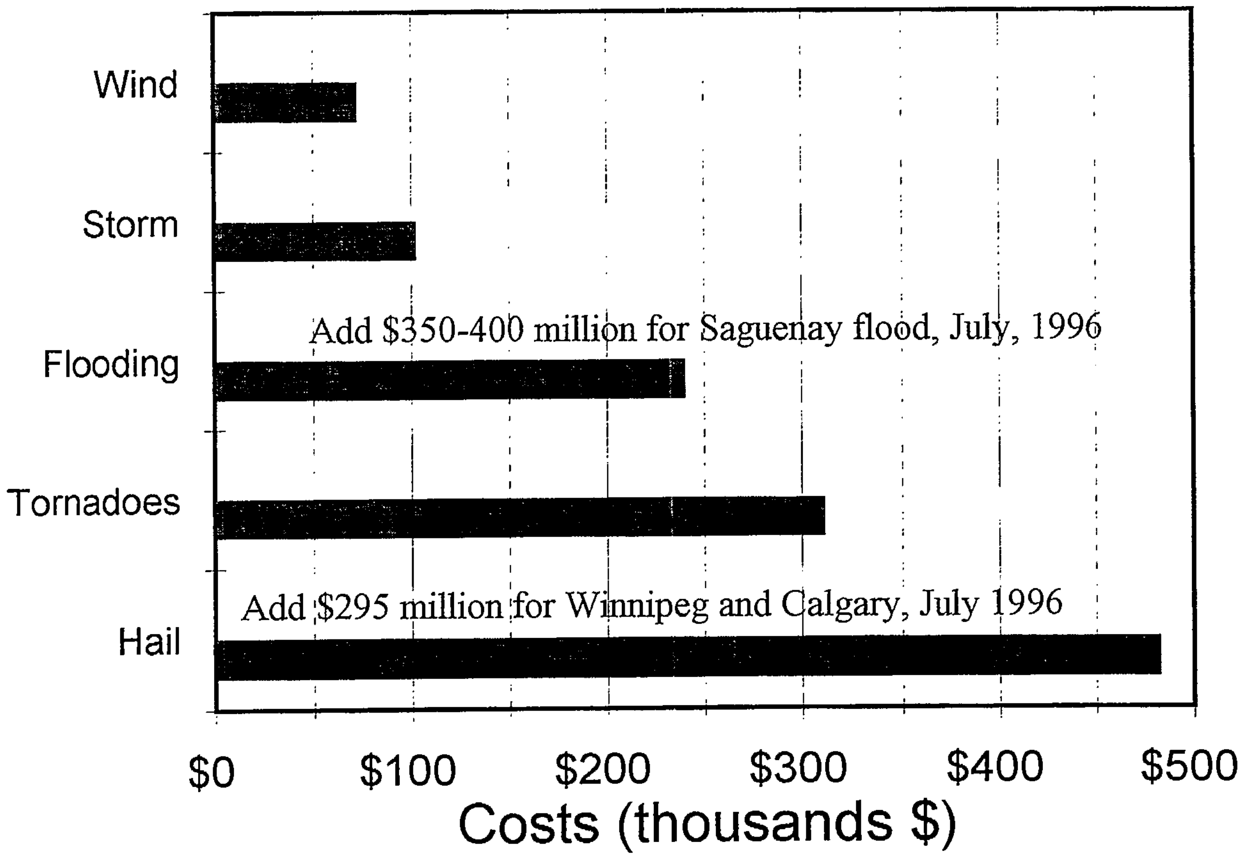


Figure 4.24 Weather Related Insurance Costs from Major Multiple Payouts (1995$).
Source: Insurance Bureau of Canada

Spring 1993: Deep frost from the winter caused a soil slip at a cost of $400,000. A preventative maintenance program was established at a cost of $40,000 per year.

*City of St. Catherines*
They have recently experienced a increased number of intense, high volume thunderstorms (since 1994), resulting in flooding problems. One event that flooded hundreds of basements occurred during the night of June 10/11, 1996.

*City of Calgary*
1991 hail/rainstorm: City damage of $1.5 million of which $1.2 million was insured.
Spring 1995: Severe river flooding with damages of $350,000 to city property such as parks, pathways and bridges.
A city report identified the expected damages from flooding in Calgary due to a riverine flood (Table 4.5).

## 4.6 Summary

Understanding the cumulative costs of various hazards would be an important synthesis. However, there have been almost no studies that provide such a summary, and this analysis is not at a stage where it can be attempted. Clearly, the importance of floods has been shown and highlighted by the recent Saguenay disaster. The costs of droughts can also be very large, if not so dramatic (drought is a slow onset disaster, as compared to flood which is a rapid onset disaster). For example, Wheaton and Arthur (1989) estimated the cost of the 1988 drought at $1.8 billion (unadjusted), or 0.4% of real GDP. Other droughts of significance are: 1978/79 ($2.5 billion), 1980 ($2.5 billion), 1984 ($1 billion), 1985 ($50 million) and 1990 ($96 million) - *[Note... these cost estimates need further tracking in order to confirm their reliability.*]

It is likely that costs associated with hazards will increase in the future, as a result of climate change. Natural hazards and disasters are expensive, but not inevitable. With appropriate planning to reduce vulnerability, their social and economic impact on Canadians can be reduced.

## 4.7 Caveats – Please Read

This paper is incomplete for a number of reasons:

1. Data on the social and economic impacts from natural hazards are frequently not available.
2. Often the data are archived or stored in such a way that it was not practically or economically feasible to obtain them, given the resources currently available for this work.

Table 4.5 Expected flood damage in millions $ (1993) due to a riverine flood

| Return Period (yrs) | 25 | 50 | 100 |
|---|---|---|---|
| Elbow River | $46.3 | $73.9 | $93.3 |
| Bow River | $5.6 | $20.8 | $38.5 |

There are holes in the data resulting from the facts that (a) not all relevant organisations (there are many of them) have yet been contacted, and (b) not all contacted organisations have responded.

## References

Blaike, P., Cannon, T., Davis, I. and Wisner, B. (1994). *At Risk, Natural Hazards, People's Vulnerability and Disasters.* Routledge Publishers, London, 284 p.

Burton, I. (1994). Costs of Atmospheric Hazards. In: *Proceedings of a Workshop on Improving Responses to Atmospheric Extremes: The Role of Insurance and Compensation.* McCulloch, J. and Etkin, D. (eds.). pp. 2-1 to 2-11.

Changnon, S.A., Changnon, D. C., Fosse, R., Hoganson, D.C., Roth Sr., R.J. and Totsch, J. (1996). Impacts and responses of the weather insurance industry to recent weather extremes. Final report to the University Corporation for Atmospheric Research. *CRR-41, Changnon Climatologist,* Mahomet, Illinois, May.

Emergency Preparedness Canada (EPC) (1996). *Natural Hazards.* National Atlas of Canada.

Etkin, D. and Maarouf. A. (1995). An Overview of Natural Hazards in Canada. In, Proceedings of a Tri-Lateral Workshop on Natural Hazards, Merrickville, Feb. 11-14, 1995, Environment Canada, pp. 1-63 to 1-92.

Hooke, B. (personal communication). NOAA, 1995.

Insurance Bureau of Canada (1996). *Environmental Scan: Analysis of IBC's External Environment* (January, 1996). Toronto.

Jones, R. L. (1991). Canadian disasters: An historical survey. *Natural Hazards* 5: 43-51.

Jones, R. L. (personal communication). Environment Canada, 1995.

Kalkstein, L.S. and Somyer, K.E. (1993). The impact of climate change on human health: some international implications. Eperientia, 49(11), pp. 969-979.

Munich Re. (1995). *Annual review of natural catastrophes, 1995.* Munich Re Insurance Company document, 15 p.

Phillips, D. (1990). The climates of Canada. Supply and Services Canada, No. En56-1/1990E, 176 pp.

Phillips, D. (1993). The day Niagara Falls ran dry! Canadian weather facts and trivia. Key Porter Books, Ltd., Toronto, Canada, 226 pp.

Wheaton, E. E. and Arthur, L. M., 1989. *Environmental and Economic Impacts of the 1988 Drought, Vol. 1.* SRC Publication No. E-2330-4-E-89.

# PART 3: AN APPROACH TO THE PROBLEM OF OCCURRENCE DEFINITION

## 5.0 Occurrence Definition

*by Søren E. Brun and David Etkin*

# 5.0 Occurrence Definition

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## 5.1 Introduction

*Incorporating concepts from meteorology has the potential to make occurrence definition more consistent, and therefore less subject to dispute. This would provide benefits to both the insurance and reinsurance communities both in terms of dispute resolution and having a clearer concept of what is covered by reinsurance treaties.*

Within the insurance/reinsurance industry, the criteria for the definition of occurrences are of considerable importance. Occurrence definition, here, does not imply determining the physical characteristics which define a particular incident, as it would in the classical sense (e.g. a tornado can be defined as a rapidly spinning column of air extending down from the base of a thunderhead). Rather, the term is used by the insurance industry to determine whether a catastrophe is composed of single or multiple loss occurrences. Such decisions, and the methods of making them, are crucial, for different interpretations can have substantially different financial ramifications for the insurance and reinsurance industries.

This section examines how scientists, and specifically meteorologists, view occurrences. First, the implications of the present system of occurrence definition from the reinsurers and insurers' point of view will be stated using simple examples. Second, we will point out some of the reasons why differences of opinion arise under the current contractual agreements. Third, an expanded method for occurrence definition will be explored. Since it is relatively straightforward to define occurrences in cases of hydrological and geophysical hazards, this section considers only atmospheric occurrences.

## 5.2 Ramifications of the Present Approach to Occurrence Definition

Most current treaties between reinsurers and insurers define occurrences using a temporal scale (e.g. the 72 hour clause). This defines occurrences by precise periods of time. A catastrophe treaty typically states that the reinsurance company will provide cover in excess of the retention limit for each and every loss occurrence. "Loss occurrence" is then defined within the contract. An example from the London Insurance and Reinsurance Market Association (LIRMA) defines "loss occurrence" as all individual losses arising directly and indirectly out of one catastrophe. The clause limits the duration and extent of each individual loss occurrence to the number of hours stipulated in the clause (e.g. 72). These clauses usually apply only to hurricanes, typhoons, windstorms, rainstorms, hailstorms and/or tornadoes.

Insurance companies (insurer) transfer some of their risk to reinsurance companies (reinsurer) by buying a policy ("reinsurance treaty") from them. One such type of reinsurance treaty is a catastrophe treaty, which limits the insurance companies loss in the event of a natural catastrophe such as windstorm or earthquake. The insurer will aggregate all of the individual losses from that catastrophic event or "occurrence" that they have paid under the policies that they have issued, and the insurer retains a predetermined amount (a deductible commonly called their "net retention"), with the reinsurer paying the amount of loss which exceeds this deductible.

Depending on the type and magnitude of the catastrophe and the way in which the contract is drawn, each party is responsible for a certain share of the insured loss. A catastrophe reinsurance program defines how much of the insured loss the insurer will retain (the "net retention" or deductible amount), and how much the reisurer will pay ("treaty limit") after the amount of the net retention has been exceeded.

However, **depending on how the catastrophe is defined (i.e. as single or multiple loss occurrence), the parties' shares of the insured loss can change significantly**. It may be more advantageous (i.e. paying a smaller amount of the insured loss) for the insurer if a catastrophe is labelled as a single loss occurrence. In other cases, it may be more advantageous for the reinsurer if the catastrophe was deemed to be a single loss occurrence.

An example of how these issues can arise is as follows. Assume that an insurer has purchased a catastrophic reinsurance program of $185 million (*treaty limit*) in excess of $15 million (*insurers net retention*), with the standard hours clause. In the event of a catastrophe, the reinsurer will cover all loss occurrences in excess of $15 million (i.e. net retention) up to a maximum of $185 million (i.e. the treaty limit). To illustrate how the insured loss is shared between insurer and reinsurer under different occurrence definitions, two scenarios will be presented (see Table 5.1).

With scenario A, assume that a $25 million incident occurred on July 31 and a $10 million incident occurred on August 2 – within 72 hours of each other. If these were deemed one loss occurrence, gross loss would total $35 million. Therefore, the insurer's liability, or share, would be $15 million (i.e. the net retention), and the reinsurer is responsible for the remainder up to $185 million – in this case, $20 million.

If, in contrast, scenario A was deemed as two loss occurrences, then there would be two gross losses (i.e. $25 and $10 million) and two net retentions would apply. Therefore, the insurer is responsible for the first $15 million for both occurrences. For the July 31 occurrence, the insurer would cover $15 million, and the reinsurer, $10 million. For the August 2 occurrence, the insurer would incur the full insured loss (i.e. $10 million) as they did not exceed the net retention. Hence, in total, the insurer would cover $25 million of the insured loss, and the reinsurer, $10 million.

With scenario B, assume again that catastrophe happened on two separate days. However, insured losses of the July 31 occurrence totalled $150 million, while on August 2, the insured losses were $125 million. Again, if this was deemed as one loss occurrence, gross losses would total $275 million. Because there was only one loss occurrence, then only one net retention is applicable. The insurer would cover the loss for the first $15 million (i.e. the net retention). However, since the reinsurer is only responsible for the losses in excess of the net retention (i.e. $15 million) up to the limit of the program coverage (i.e. $185 million), their share of the losses would be

Table 5.1 Example payouts for single and multiple occurrences.

| **Scenario A (Low Magnitude)** | | | **Scenario B (High Magnitude)** | | |
|---|---|---|---|---|---|
| Occurrence | Damage | | Occurrence | Damage | |
| July 31 | $25M | | July 31 | $150M | |
| Aug 2 | $10M | | Aug 2 | $125M | |
| 1 Occurrence: Total Insured Loss $35M | | | 1 Occurrence: Total Insured Loss $275M. | | |
| Party: | Payment: | Total: | Party: | Payment: | Total: |
| Insurer | Up to Net Retention | **$15,000,000** | Insurer | Up to Net Retention and Remaining Beyond Program Coverage | $15M +$75M<br>=<br>**$90,000,000** |
| Reinsurer | Excess of Net Retention Up to Program Coverage | $35M - $15M<br>=<br>**$20,000,000** | Reinsurer | Excess of Net Retention Up to Program Coverage | $185M<br>=<br>**$185,000,000** |
| 2 Occurrences: Two Losses, $25 and $10M | | | 2 Occurrences: Two Losses, $30 and $245M | | |
| Party: | Payment: | Total: | Party: | Payment: | Total: |
| Insurer | Up to Net Retention for **Both Policies** | First occurrence: $15M<br>Second occurrence: $10M<br>**$25,000,000** | Insurer | Up to Net Retention for **Both Policies** | First occurrence: $15M<br>Second occurrence: $15M<br>**$30,000,000** |
| Reinsurer | Excess of Net Retention Up to Program Coverage for **Both Policies** | First occurrence: $10M<br>Second occurrence: $0M<br>**$10,000,000** | Reinsurer | Excess of Net Retention Up to Program Coverage for **Both Policies** | First occurrence: $135M<br>Second occurrence: $110M<br>**$245,000,000** |

the full limit of the program coverage (i.e. $185 million) as the losses totalled $275 million. The insurer is responsible for all remaining insured losses above the program coverage (i.e. an additional $75 million). This excess loss is due to insufficient coverage. Therefore, in total, the insurer would cover $90 million and the reinsurer would cover $185 million.

Conversely, if scenario B had been deemed two loss occurrences, then each would be treated separately – one of $150 million and another of $125 million. Again, two net retentions are applicable and the insurer would cover the insured losses below the net retention for each occurrence. In this double-occurrence scenario, neither occurrence exceeded the amount of program coverage. Therefore, the insurance company would cover combined losses below the net retentions (i.e. $30 million). The reinsurer, on the other hand, would cover all remaining losses (i.e. $245 million).

Therefore, with these two scenarios, whether the catastrophe is defined as one or two occurrences dramatically alters the shares of losses for the insurer and reinsurer. In scenario A (a low magnitude catastrophe), it is more advantageous for the insurer if the catastrophe is defined as one occurrence, and better for the reinsurer if it is deemed two. In scenario B (a high magnitude catastrophe), the reinsurer benefits if the catastrophe is defined as only one loss occurrence. It is more advantageous for the insurer only if the catastrophe is deemed as two occurrences.

Though treaty wording can lead to differences of opinion regarding occurrence definition, the hours clause was originally designed for flexibility – to aid the insurer or reinsurer in cases where insufficient coverage existed, and to provide limits to the time span of occurrences.

## 5.3 Concerns About Current Occurrence Definition

Quandaries with occurrence definition stems from both the contract wording and how catastrophes are viewed by the insurance industry. The dilemmas with contract wording are three-fold.

1. Wordings such as "catastrophe" do not provide a physically based definition of an occurrence – in fact, the word itself can imply both single and multiple occurrences.
2. The time delineation in the hours clause is arbitrary and has no physical connection with the actual duration of catastrophic occurrences. This may, for instance, lead to the splitting of a single occurrence into multiple occurrences if it lasted longer than the prescribed time period (e.g. 72 hours).
3. As discussed below, the reference frame in which the insurance/reinsurance industry views catastrophes may lead to complications when determining the number of occurrences.

As a result, there have been instances where disagreement has arisen regarding the number of loss occurrences.

### *5.3.1 "Catastrophe"*

The word catastrophe can imply both single and multiple occurrences. It neither defines the physical, spatial dimensions of actual perils nor implies (or denies) possible causal links between individual perils. For example, if insured losses were the product of a series of occurrences on the same day (i.e. tornado families or multiple hailstorms), these perils could be viewed as one or more occurrences. The catastrophe could be considered as:

1. the total area damaged by the occurrences (i.e. a single occurrence); or
2. each of the damage swaths produced by the individual storms (i.e. multiple occurrences).

**If contracts included both a physically based, spatial description of the hazards covered and some stipulation regarding linkages between perils, it could make the definition of a loss occurrence more robust.**

### *5.3.2 Time Delineation*

Contracts do not usually deal with time in a way that unambiguously define cause and effect. Cause and effect require relating physical processes that exist in space as well as time, to specific occurrences. Therefore the absence of spatial criteria in the contracts compounds ambiguity. A result of this is that multiple occurrences may arbitrarily be assigned to a single cause. For example, two storms occurring within 72 hours of each other may be lumped together and deemed one occurrence, even if spatial analysis suggests that their link is tenuous. On the other hand, one storm lasting more than 72 hours could be deemed as multiple occurrences. Therefore, a time-delineating clause can deem two occurrences as a single one if they occur within the stipulated time period; while single occurrences can be deemed as separate if they lasted longer than that stipulated.

Therefore, a time-delineating clause can deem two occurrences as a single one if they occur within the stipulated time period; while linked occurrences can be deemed as separate (in this case they could be one) if they were differentiated by a time period greater than that stipulated.

### *5.3.3 Reference Frame*

The reference frame in which catastrophes are viewed can lead to differences of opinion. In general, there are two frames of reference in which to view catastrophes. In a fixed frame (or point-scale) of reference, a stationary observer views an object moving past it – for instance, a hitchhiker, standing on the side of the road, watches cars pass him. In a moving frame of reference, the observer is moving and watches stationary objects move past – that is, the driver of a moving car appears to be "stationary", while the hitchhiker, standing on the side of the road, appears to be in motion.

The 72-hours clause can link together all occurrences which pass through a city during that period. For example, over any given three-day period, a city may experience two or more distinct cold fronts that produce damaging conditions. A fixed-frame of reference would treat all losses stemming from these cold fronts as one occurrence, even if they were not produced by the same weather systems. A moving frame of reference would treat them as separate occurrences. **Depending on the frame of reference in which a catastrophe is viewed, the definition of an occurrence can have radically different conclusions.**

## 5.4 Defining Atmospheric Occurrences: A Proposal

Treaties between reinsurers and insurers could be made more physically based. Such treaties could include appropriate space-time scales, links between occurrences, and defined reference frames. They could also provide a standardised procedure for defining occurrences. However, although a physically based wording would be more quantitative and deal specifically with the perils themselves, there will always be a certain amount of qualitative judgement. Therefore, the new method proposed here does not provide a cure-all solution.

The proposed method defines atmospheric occurrences through the use of temporal and spatial scales. It can simultaneously address space-time scales, linkages between occurrences, and references frames. The atmospheric sciences commonly define the temporal and spatial scales of atmospheric occurrences as shown in Figure 5.1. The x-axis – a logarithmic time scale – represents the duration of the atmospheric occurrence, not the amount of time it takes to pass through a location. The y-axis – a logarithmic space scale – describes the length/diameter of a feature, not the amount of areal damage.

From this figure, atmospheric phenomena can be grouped according to the following scales of motion: microscale, mesoscale, synoptic scale, and planetary scale. Each scale is associated with well-established time and space dimensions. For instance, synoptic scale occurrences last for a period between hours to days and encompass regions ranging in size from 50 km in diameter to 1000 km. However, some ambiguity and overlap (i.e. fuzzy boundaries) add uncertainty to scale delineations.

Also included on this figure are a number of atmospheric occurrences. Each falls roughly into the four scale categories. On this plot space and time, in relation to atmospheric occurrences, are directly related. That is, occurrences associated with large spatial dimensions also have the longest durations, and *vice versa.*

This figure serves as the basis for allowing treaties to deal more quantitatively with atmospheric phenomena by considering their temporal and spatial dimensions, the appropriate frame of reference and the physical link between occurrences. For instance, a cold front, or synoptic scale occurrence, can produce tornado families. A synoptic scale specification in a contract would provide the temporal and spatial dimensions of the catastrophe and implicitly attribute the tornadoes to a common cause.

### *5.4.1 The Space-Time Proposal*

From the plot, it can be seen that there are four general categories of atmospheric motion. Most treaties could ignore the planetary scale and microscale. Planetary scales indirectly encompasses all atmospheric motion, since large-scale circulation patterns eventually determine local weather conditions and serve to link all atmospheric occurrences. An example would be to define all damage caused by blizzards in Canada during one winter as a single occurrence. Microscale occurrences (e.g. microbursts, downbursts, dustdevils,...,etc.) are extremely localised and are usually linked to other mesoscale or synoptic scale occurrences. Because these are localised, insuring for the microscale would consider, for example, each gust of wind in a windstorm as a separate occurrence. Therefore, given that the two extreme scales are not useful, one need only consider mesoscale and synoptic scales of motion.

Treaties and contracts could deal with mesoscale and synoptic-scale occurrences. For instance, instead of insuring a catastrophe for a period of 72 hours, the contract could insure synoptic scale or mesoscale occurrences.

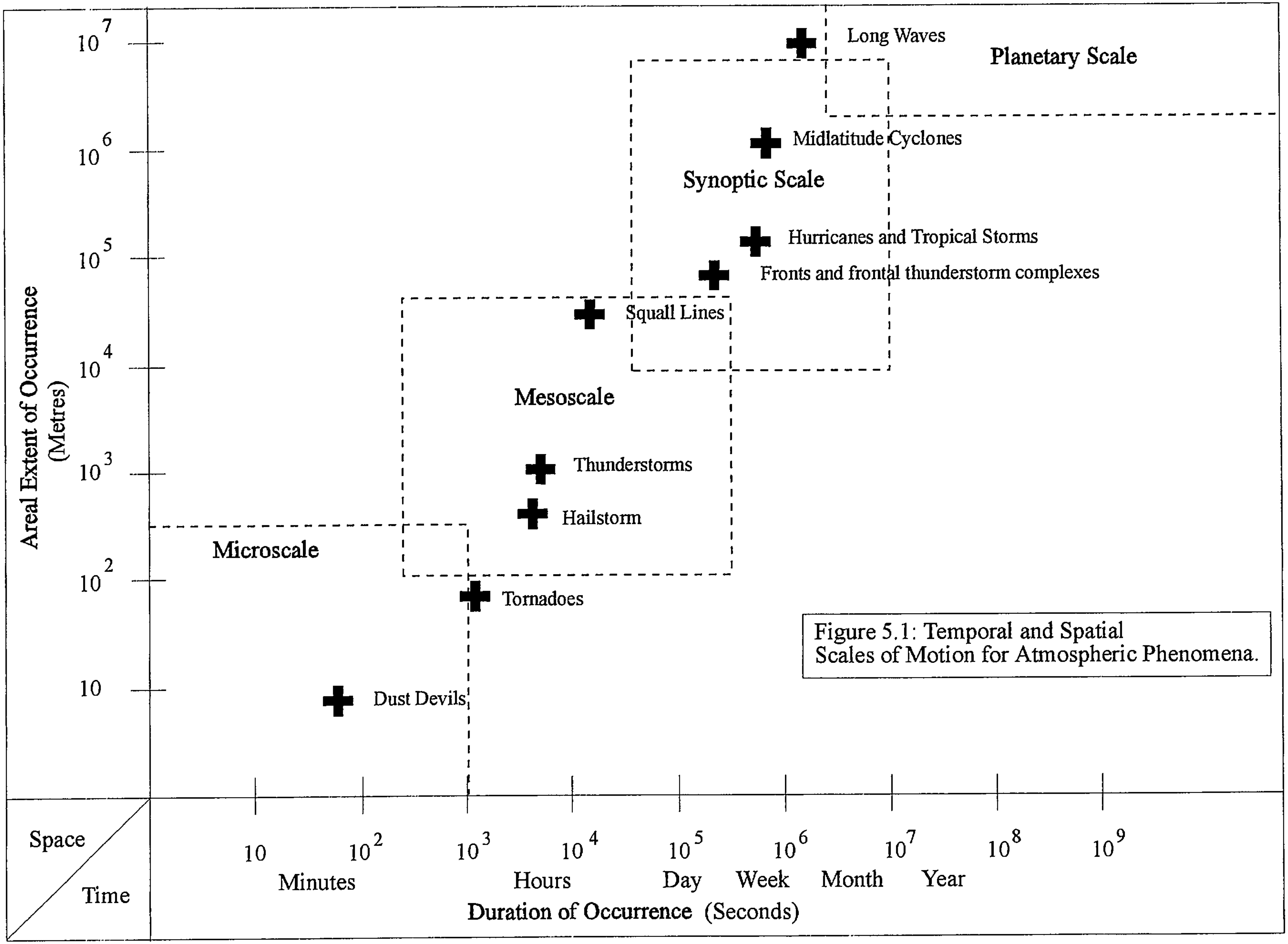

Figure 5.1: Temporal and Spatial Scales of Motion for Atmospheric Phenomena.

- *Mesoscale* - if only a mesoscale were included, insurance would cover only losses stemming from mesoscale occurrences. If a single, isolated thunderstorm produced both damaging hail and a tornado, then the damage would be deemed as one occurrence, as they are linked by a single mesoscale occurrence. If two isolated thunderstorms occurred – one produced hail and the other a tornado, then there would be two occurrences.
- *Synoptic scale* - synoptic-scale wording would, for example, cover all damage stemming from thunderheads associated with a single cold front extending from a synoptic scale storm. If two or more damaging cold fronts passed through a region, they would be deemed as individual occurrences.

There are some potential pit-falls with this methodology. Unlike mesoscale phenomena which are isolated and of short durations, synoptic occurrences, such as the mid-latitude cyclone, can travel the entire east-west distance of Canada. In a case like this all damage nation-wide stemming from one mid-latitude cyclone could be deemed as one occurrence.

### *5.4.2 The Barrie-Leamington Case Study*

Taking the Barrie-Leamington occurrences as an example, one can see the benefits of this time-space method. On May 30, 1985, an F0 tornado and a heavy hail storm struck the town of Leamington, Ontario. The following day (May 31), at approximately 4 p.m., an F4 tornado caused extreme amounts of damage to the town of Barrie, Ontario resulting in eight fatalities. The insured losses from these occurrences totalled $84 million. These occurrences stemmed from multiple severe thunderstorms (mesoscale occurrences) linked by a single synoptic-scale occurrence – a mid-latitude cyclone – which passed through this region. On May 30, the warm front east of the mid-latitude cyclone swept through south-western Ontario producing severe thunderstorms and the Leamington hailstorm and tornado. On May 31, the cold front extending south-west from the same mid-latitude cyclone swept through the same region producing the Barrie, Orangeville and Grand Valley tornadoes.

In the treaties enforced at the time, as these occurrences occurred within 72 hours of one another, reinsurers and insurers differed on whether these constituted one or two occurrences. Furthermore the wording in the clauses was not 100% consistent which lead to these different interpretations (Reiner, personal communication) Arbitration resulted in contradictory conclusions – these incidences had been defined as both one occurrence and two occurrences.

If the proposed method had been used, few disputes would have arisen. For instance, on the synoptic scale, these would have been deemed one occurrence, the tornadoes and hail were all produced by a single synoptic scale system. They were linked by a common cause – the mid-latitude cyclone. A mesoscale contract would have determined two occurrences since they were produced by distinct thunderstorms not linked by a mesoscale phenomenon such as a squall line. Even though a common synoptic link existed (i.e. the mid-latitude cyclone), the mesoscale wording would treat the Barrie tornado and Leamington hailstorm and tornado as separate mesoscale occurrences. Unlike the current method, the space-time method would have treated these as either one or two occurrences, but never as both one and two occurrences.

## 5.5 Summary and Recommendations

The space-time proposal classifies occurrences by scale (synoptic or mesoscale) and physical links, and allows for fairly straightforward determination of the number of occurrences. By making the definition of an occurrence more robust, less confusion would arise in classifying losses. Further research is recommended to:

1. apply the space-time method to a series of case studies, covering all types of severe weather events; and
2. develop a set of sample contracts, in order to test the implications of this method on past and future incidences.

## Reference

Reiner, J. (personal communication). Co-operators General Insurance Company, 1997.

# PART 4: COMPUTER MODELS OF PROBABLE MAXIMUM LOSS

## 6.0 Seismic Risk Models

*by Dionne Gesink Law*

# 6.0 Seismic Risk Models

*by Dionne Gesink Law*

## 6.1 Introduction

*The purpose of this chapter is to address the questions: What are the seismic risk models doing and how can they be critically examined? The objective of this section is to explain seismic risk modelling in greater depth, for the purposes of model examination and assessment of model output. The steps outlined in a generic seismic risk model will be discussed in further detail by reviewing the components of the model. This includes the insurance inputs, the seismic hazard module, the vulnerability module, and the financial outputs.*

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As the awareness of the threat of a catastrophic earthquake along the south-west coast of British Columbia motivates the individual to purchase more earthquake insurance, the threat of insolvency within the insurance and reinsurance industry also grows. This concern has created an effort by both government and the industry to determine a company's exposure to seismic risk, and methods of managing that risk.

In attempts to prevent insolvency in the event of a catastrophic earthquake, the federal Office of the Superintendent of Financial Institutions (OSFI) has distributed a questionnaire to insurers and reinsurers regarding earthquake risk assessment. From this survey, OSFI hopes to ascertain the severity of the loss exposure of the industry as a whole, and amend the best practices recommendations to include a strategy for effective risk management (Stratton, personal communication). For example, several larger insurance and reinsurance companies use seismic risk models to:

- determine their exposure to insured earthquake losses,
- develop a risk management strategy,
- aid in underwriting.

As the potential costs of a catastrophic earthquake near an urban centre become fully realised, strategies to manage seismic risk will be crucial in preventing insolvency. It is in the best interest of all insurance and reinsurance companies to use AT LEAST TWO methods of risk analysis, whether they be mathematical equations or sophisticated computer models. However, model users should be aware that different methods can produce different results. These discrepancies can either confuse the user, or draw attention to the uncertainty involved in seismic risk modelling. As risk analyses are performed, it will become increasingly imperative that those individuals responsible for risk management of the exposures understand the methods and models used, and the meaning of the results produced.

There are several natural hazard risk models that can be used to assess both the Canadian exposure to a hazard, and the potential insured losses in the event of a catastrophe. Some of the natural hazards which pose the greatest threat to Canadians are floods, droughts, earthquakes, hail storms, tornadoes and severe winter storms (reviewed in section 2.0, above). Due to the important economic and industry implications of an earthquake near an urban centre, this review of risk models will be restricted to those that analyse insured losses resulting from earthquakes in Canada.

## *Chapter 6: Seismic Risk Models*

The purpose of this chapter is to:

1. Provide an overview of seismic hazard;
2. Explain seismic risk modelling; and
3. Provide an approach to evaluate the various seismic risk models available to the insurance industry.

Many of the available seismic risk models estimate damage and losses due to seismic shaking, fire following, landslide, liquefaction, and tidal wave inundation. **Seismic shaking**, however, will be the only portion of the model reviewed and evaluated in depth since it is responsible for most of the damage associated with an earthquake. Future studies should review the other modules in the seismic risk model, especially since landslides in Western Canada are not yet thoroughly understood.

Historically, the Montreal-Quebec City region has been susceptible to earthquakes. More recently, geologists and seismologists have begun to acknowledge a seismic threat from two types of activity in southern British Columbia. The first is a major subduction earthquake (Guttenberg-Richter magnitude M=8+) originating along the Cascadia subduction zone, 150 km off the coast of south-western British Columbia and Washington State. The other, more significant concern, is a moderate North American continental plate earthquake closer to Vancouver, or any urban area, which would result in far more damage (Atwater et al., 1995; Rogers, 1994). These regions are of such concern because of the high population density and extensive urbanization. In the event of a major earthquake the economic losses are expected to be catastrophic, and the loss of life potentially devastating. Accordingly, government and industry have attempted to quantify the level of risk and possible losses that could be incurred using seismic risk models. Several risk models have been developed in Canada and the United States to be used as tools for planning, emergency information systems, lifeline analyses, and estimations of loss.

*Emergency Planning Model*

Emergency Preparedness Canada is currently developing the Natural Hazards Electronic Map and Assessment Tools Information System (NHEMATIS). The primary purpose of NHEMATIS is to "provide emergency planners with a tool that supports the definition and execution of elaborate models which will assist in predicting/estimating the potential impact of a natural hazard/disaster in a defined area of interest." (EPC, unpublished). NHEMATIS is intended to aid in natural hazard disaster management. It can help planners identify vulnerable areas, improve emergency preparedness, and assist with pre-disaster mitigation (EPC, unpublished). For example, if a potential risk exists in an area, amendments to city plans, zoning laws, and building codes can help to minimise exposure.

*Emergency Information Systems*

In the event of a major earthquake, monitoring the disaster in real-time will require an emergency information systems (EIS) such as the Early Post-Earthquake Damage Assessment Tool (EPEDAT), which was developed by EQECAT for the California Earthquake Authority. EPEDAT has a lag time of 15 to 30 minutes and can optimise the discharge of emergency response and repair units, enable hospitals in high damage areas to prepare for incoming casualties, and begin initial estimates of total dollar loss which can be updated regularly. In effect, EPEDAT performs a lifeline analysis during a catastrophe. In Canada, SoftRisk is used for floods.

*Lifeline Analysis Models*
Lifeline analysis involves assessing the impact of an earthquake on emergency response, communication lines, transportation routes, and power lines. Since this task has a high priority in California, EQECAT has developed the LLEQE model to perform such analyses. In Canada, Munich Re and Rescan performed an extensive study on the economic and insured impact of a severe earthquake in the British Columbia lower mainland (Munich Re, 1990). The Munich Re economic model addressed the effect of an earthquake with respect to structural and content damage, infrastructure damage, onsite injury and loss of life, and offsite damage for seismic shock, ensuing fire, landslide, and inundation. The insured losses model focused on damages due to seismic shaking and fire following. Assuming an earthquake of M=6.5, total economic losses were estimated to range from $14.3 to 32.1 billion, while the total insured loss estimation ranged from $6.67 to 12.72 billion.

*Insured Loss Estimation Models*
Several seismic risk models have been developed for use by the insurance industry. These models include: Munich Re, Risk Management Solution's IRAS, EQECAT's EQEHAZARD or EQECanada, and Risk Engineering's EQCanada. Though developed for slightly different purposes, all attempt to provide additional information for risk management strategies.

To evaluate the different seismic risk models available for insured loss estimation, it is imperative that the modelling process be understood. The process of seismic risk modelling will be explained in four stages:

1. A generic seismic risk model will be presented.
2. Components of the generic model will be explained in more depth with reference to the Vancouver and surrounding area.
3. A framework to examine seismic risk models will be provided.
4. The Munich Re, IRAS, and EQECanada models will be presented using the suggested framework.

At the end of the chapter, recommendations will highlight further work in this area.

## 6.2 Generic Seismic Risk Model

The purpose of this section is to provide an overview of the process of seismic risk modelling. The modeller inputs insurance information into the model, and specifies an earthquake magnitude and location. This information is used by the seismic hazard module to estimate shaking intensity at a sight. Shaking intensity is used in the vulnerability module to estimate damage. Damage is used in the financial module to estimate insured losses.

Some seismic risk models have been developed to aid the insurance industry with risk management via the estimation of the probable maximum loss. Probable maximum loss (PML) is an insurance term for the estimated likely maximum cost that could be incurred in the event of an earthquake of a given magnitude.

Most seismic risk models are comprised of three modules (Figure 6.1). The seismic hazard module simulates actual earthquake shaking. The vulnerability module relates seismic shaking to structural and property damage. The financial module

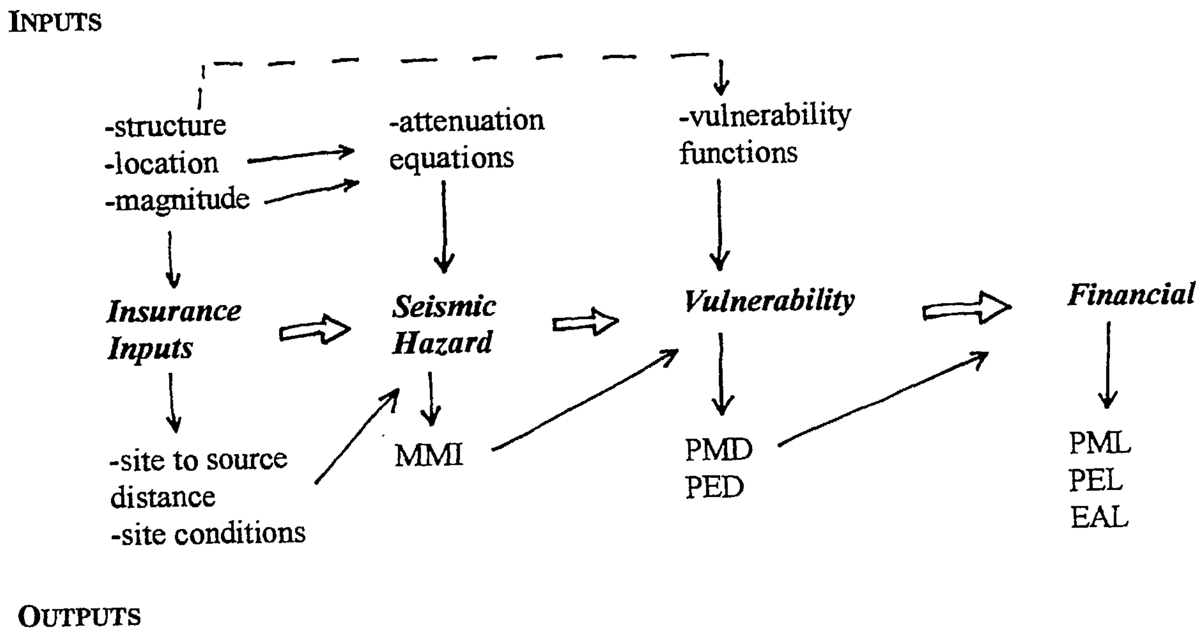


Figure 6.1 Flowchart of seismic risk modelling

assigns a cost to those damages and calculates the maximum potential and/or expected losses. This process of seismic risk modelling is outlined in the following steps.

*Step 1: Insurance Inputs*
The information contained in an insurance company's portfolio is used as input for the seismic risk model. It is vital that this information be as complete as possible; otherwise uncertainty in the results is inflated. This includes data on:

- building location - by cresta zone or postal code (3-6 digit);
- building construction - building type, building age, building height;
- building use;
- building contents; and
- policy information - building value, deductibles, reinsurance, co-insurance.

The location and magnitude of the earthquake are also specified at this stage. The location of the earthquake, usually identified by its epicenter, is specified by a source zone (see Section 6.4). A continental plate earthquake near an urban centre poses the greatest threat to both Canadians and the insurance/reinsurance industry. Thus, when analysing a worst-case scenario, most users will place the epicentre, or centre of the earthquake, in the source zone closest to Vancouver. The magnitude of an event, is usually specified using either:

- a return period,
- the Guttenberg-Richter scale (M), or
- peak ground acceleration (PGA),

and these measures can be either:

- user defined,
- based on a specific historical event,
- an average of several historical events, or
- a proposed maximum magnitude event.

*Step 2: Seismic Hazard Module*
The seismic hazard module uses the location and magnitude of an earthquake, specified in step 1, to estimate the probability of seismic hazard for either individual sites, or the insurance portfolio as a whole. Here, seismic hazard refers to any physical phenomenon associated with an earthquake including ground motion, fire-following, landslide, liquefaction, tsunami, and inundation. Most of the damage incurred by a structure during an earthquake is the result of seismic ground motion. The longer the shaking, the greater the damage. The objective of the seismic hazard module is to estimate the intensity of shaking at sites within the insurance company's portfolio (EERI, 1989).

The module uses the earthquake source zone to identify the earthquake epicenter, where ground motion originates as seismic shock waves. The movement of the seismic waves through the soil is modelled by **attenuation equations**. Ground motion attenuation at a site is a function of:

- earthquake magnitude,
- distance from the source, and
- site effects such as regional geology and soil conditions.

Ground motion itself is not sufficient to describe the degree of damage at a site. Rather it is the duration of strong ground shaking that causes the most damage. Therefore, the ground motion at a site, usually expressed as peak ground acceleration, is converted to a Modified Mercalli Index (MMI). The advantage of MMI is that it is a measure of shaking intensity which incorporates shaking duration and frequency. MMI can also be used to quantify earthquakes that occurred before seismic instrumentation was available (EERI, 1989).

*Step 3: Vulnerability Module*
The purpose of the vulnerability module is to determine the extent of damage to buildings and contents at a site, or for a portfolio, in the event of an earthquake. This is done using MMI estimates from the seismic hazard module which are input into **vulnerability functions**. Vulnerability functions are based on the structural damage, as observed by structural engineers caused by historic earthquakes of given shaking intensities (MMI). Most models use the 1985 Applied Technology Council Report (ATC-13) vulnerability functions which have been modified to include damage information from earthquakes since 1985 and from around the world. Some models also use the Stanford damage tables from California. In Canada, building inventory information is entered into the risk model according to IBC classes which are based on the National Building Code of Canada (NBCC) standards. Thus, the NBCC structural information is converted to ATC-13 equivalents to be used in the vulnerability functions. This conversion is a potential source of error in the calculation of PML. The size of this error is unknown, and worthy of further investigation.

Damage estimates to structures are presented as probable maximum damage (PMD) and/or probable expected damage (PED). Often PMD is calculated at the 90th or 95th percentile. PED is usually calculated around the 50th percentile (see Section 6.5).

*Step 4: Financial Module and Insurance Outputs*
Damage estimates from the vulnerability module are used in the financial module to calculate the probable maximum loss (PML) and probable expected loss (PEL) of an earthquake, based on the company's portfolio. PML is a function of PMD and the insured value of the building. Most risk models calculate losses due to structural damage, damage to property and contents, and business interruption. These estimates are presented either as a percent of the total value of the structure, or as a dollar value. The net PML is calculated by including deductibles, and the appropriate layers of reinsurance and co-insurance. Some models will also provide a measure of uncertainty with the net PML estimate.

Seismic risk modelling is to be used as a diagnostic tool to aid in decision making and management of risk. Alone, it does not provide solutions.

## 6.3 Insurance Inputs

The first step is seismic risk modelling involves insurance information. In addition to specifying the magnitude, duration, and location of an earthquake during analysis, the modeller must provide information on building location, building inventory and insurance structure.

It is the responsibility of the insurance company to provide portfolio information as input to the risk models. This includes data on building location, building inventory, and insurance structure. The records within the portfolio can be complete or incomplete, site specific or aggregated. For site specific analysis, incomplete data are usually handled by the model by assigning weighted averages. This introduces uncertainty into the analysis and elevates the potential for errors. The accuracy and reliability of the earthquake loss estimates calculated by the model can only be improved by increasing the rigor of the insurance and database inputs.

The distance of a structure from the centre of an earthquake will influence the degree of shaking, and hence damage, incurred by the structure. Thus, the **location** of a structure is an extremely important piece of information. Data on structure location can range from site specific, such as street address or postal code, to regionally aggregated, such as earthquake accumulation assessment zones - otherwise known as cresta zones (Figure 6.2). This information is used in the seismic hazard module attenuation equations to determine:

- the distance from building site to earthquake source, and
- site conditions which can strongly influence ground motion attenuation.

It is also important that information on building class, height, and year of construction be as complete as possible because **building inventory** information is used in the vulnerability module to estimate the damage resulting from an earthquake. It is assumed that the quality of materials and workmanship used during construction are to National Building Code of Canada standards. Unfortunately, evidence following the 1985 Barrie tornado (Allen, 1986), Hurricane Hugo in Florida, and other like events, suggest that this assumption should be revisited, and that stronger code enforcement is required.

**Insurance structure** is used in the financial module to assign a cost to earthquake generated losses for property damages, contents damage, and business interruption. Determining gross losses requires information on the value of the structure, as well as its contents, and use. Calculation of net losses requires information regarding deductibles and the insurance structure. The insurance structure includes reinsurance, coinsurance, and retrocession.

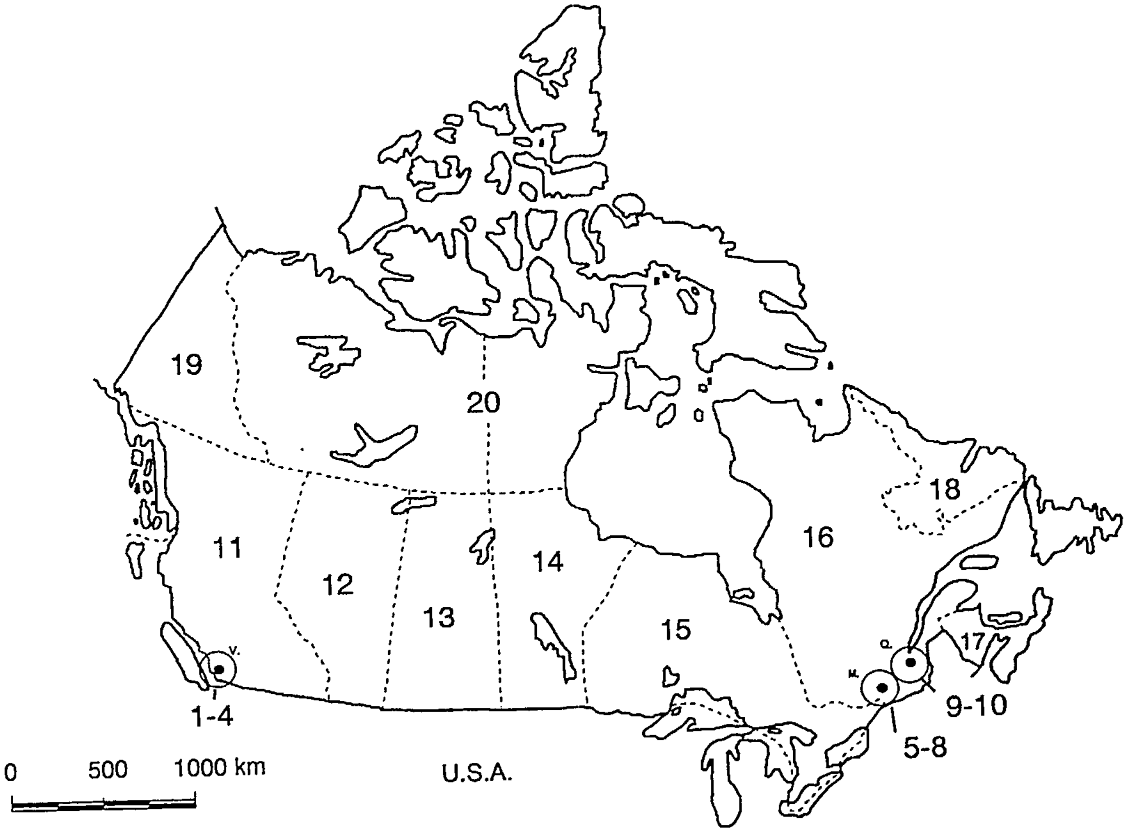
## 6.4 Seismic Hazard Module

The second step in seismic modelling involves seismic hazard modelling. The purpose of the seismic hazard module is to predict shaking intensity at a site some distance from the earthquake source. This is done using the insurance and earthquake information input in step one.

The effectiveness of the seismic hazard model rests on how well it can represent reality. If seismicity is not well understood, or if the model or data used is incomplete, the uncertainty associated with the seismic hazard model outputs is exacerbated, and decisions made using the results are compromised. To evaluate the seismic hazard module several issues need to be addressed. This includes:

- the scientific understanding of the physical nature of seismic hazards. For example, **seismicity** concerns the physical mechanics and processes of earthquakes, as well as its measurement. This includes how well seismic activity is understood in Canada, especially since seismicity in Western Canada and Toronto are areas of debate.

- the sufficiency of the seismic hazard module. **Module sufficiency** issues address three areas of concern:
    1. model representation of seismicity such as inputs, process and outputs;
    2. ground motion attenuation relationships; and limitations due to the assumptions, sensitivities and uncertainties made by the module.



| | | | |
|---|---|---|---|
| Zone 1 | Richmond, Fraser Delta | Zone 11 | British Columbia |
| Zone 2 | Rest of Greater Vancouver | Zone 12 | Alberta |
| Zone 3 | Victoria | Zone13 | Saskatchewan |
| Zone 4 | Rest of Vancouver Earthquake Zone | Zone14 | Manitoba |
| Zone 5 | Montreal | Zone 15 | Ontario |
| Zone 6 | Greater Montreal | Zone 16 | Quebec |
| Zone 7 | Surroundings of Montreal | Zone 17 | Maritime Provinces |
| Zone 8 | Rest of Montreal Earthquake Zone | Zone 18 | Newfoundland |
| Zone 9 | Quebec City and Epicentral Region | Zone 19 | Yukon Territory |
| Zone 10 | Rest of Quebec Earthquake Zone | Zone 20 | North West Territories |

Figure 6.2 Cresta zonation for Canada

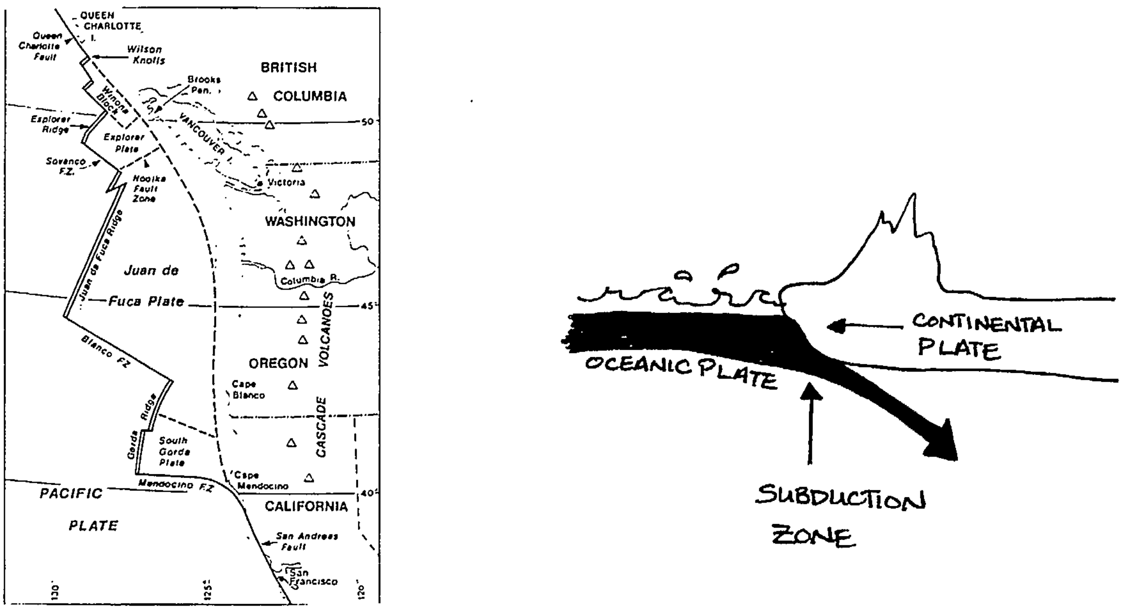
- If the seismic parameter inputs, ground motion attenuation equations, or assumptions are weak, the results of the seismic hazard module will be compromised. **Model sensitivities and uncertainties** can also reduce the integrity of the model, and hence, the confidence associated with the model outputs.

- the sufficiency of the data and databases used in the seismic hazard module. **Data sufficiency** issues of data quality, quantity, availability, objectivity, resolution and completeness apply to both data input into the program, and data stored in databases within the program. If seismic data are deficient, again, the reliability of the results will be compromised. This elevates the uncertainty associated with the outputs. Issues of data sufficiency need to be discussed along with the previous two issues. Thus, this chapter will address data sufficiency inherently within the seismicity and model sufficiency sections. **The impact of data sufficiency in model development is not well understood and requires further investigation.**

### *6.4.1 Seismicity*

The fundamental properties of seismicity are generally well understood by the scientific community (see Section 2.4.1). However, conflicting assessments in a given geographical area can still arise. For example, the seismic activity of the Cascadia subduction zone, 150 km off the coast of Vancouver and Washington, is currently under debate. Here, the Juan de Fuca, Gorda, and Explorer plates are being subducted, or over-ridden, by the North American continental plate (Figure 6.3). Because of the absence of major historical seismic activity in this area (Guttenberg-Richter magnitude, M > 7), subduction has been considered relatively aseismic by some researchers (Campbell, unpublished). Campbell (unpublished) argues that since the Juan de Fuca plate is young, thin and smooth, subduction is occurring aseismically, and may cease altogether within 100 years. He suggests that, at worst, the West coast will experience a few moderate earthquakes (M = 5 to 7.5) over the next few centuries. Rogers (1994) and Atwater et al. (1995) have an opposing interpretation based on evidence from both the Cascadia subduction zone and similar subduction zones around the world. They note that the largest recorded earthquake (M = 9.5) occurred in Chile in 1960 along a young, thin, smooth subducting plate, much like the Cascadia subduction zone (Smith, 1996; Atwater et al., 1995; Rogers, 1994). They have also found evidence suggesting that a major earthquake (M = 8+) occurred along the Cascadia subduction zone approximately 300 years ago (Atwater et al., 1995; Rogers, 1988; 1994) . Current compression and bulging of the coastline suggests that the subducting Juan de Fuca oceanic plate is currently locked with the North American continental plate, building energy for another catastrophic earthquake (Rogers, unpublished). Table 6.1 summarises the West coast debate. Though Campbell (unpublished.) presents interesting arguments which diminish the seismic threat on the West Coast, the findings of Rogers (1988; 1994), and Atwater et al. (1995) are generally more widely accepted.

A moderate earthquake within the continental plate close to Vancouver, or any urban area, would result in far more damage than a movement along the Cascadia subduction zone. Probabilistic modelling



a) Plate boundaries in the Cascadia subduction zone.
*(From: Rogers, 1994)*

b) Movement of the plates at the subduction boundary.

Figure 6.3 Subduction along the west coast of Canada

Table 6.1 Evidence refuting and supporting the possibility of historic and future great earthquakes on the west coast of Canada and the northwestern United States.

| Evidence | Explanation by Campbell | Explanation by Atwater/ Rogers |
|---|---|---|
| Drowned trees, marshes and diatoms along the BC coastline | • world-wide sea level rise due to deglaciation after isostatic rebound<br>• drowned trees common north of Cascadia subduction coastal section | • abrupt subsidence of shoreline (up to 2m) as consequence of great earthquake<br>• identical to those produced on adjacent coasts during Alaska (M=9.2) and world's largest recorded earthquake in Chile (M=9.5) |
| Tsunamis | • evidence tenuous since Alaskan great earthquake hardly visible 30 years later. | • buried marshes often have tsunami sand deposit immediately on top<br>• deposits from off-shore sand sources<br>• similar to those preserved in area of Chile and Alaska quakes<br>• Japanese historical records for 6 different coastline locations of tsunami impacts on Jan. 27, 1700 without local earthquake and absence of large quake in S. America, C. America, Alaska or Kamchatka leaving Canadian-northwestern American coast as source. Estimated magnitude M=9 |
| Underwater Landslides and Liquefaction | • landslides not addressed<br>• glacial loading and unloading | • massive deposits averaging 500 year intervals sampled from deep sea floor; huge slides of unstable deposits expected during great earthquake<br>• liquefaction features present in stratigraphy |
| Subduction Plate Locking | • Cascadia plate very young, thin, and smooth (no seamounts), therefore can NOT lock, hence absolutely NO potential for great earthquake (>7.5M)<br>• only plates older than 25-30M yrs produce great earthquakes<br>• Plate moving at 45mm/yr thus cannot be locked, nor be storing energy to produce a subduction fault or great earthquake<br>• Juan de Fuca plate is excellent example of aseismic subduction (no quakes) | • horizontal geodetic measurements show coastal region being shortened perpendicular to the coast in direction of seafloor convergence and underthrusting. Such elastic deformation only occurs if upper portion of subducting underthrusting oceanic plate locked to underside of overlying continental plate. At time of earthquake, elastic deformation will reverse and outer coast will spring back several meters as has been observed in other regions of great underthrusting earthquakes<br>• vertical geodetic measurements show coastal region bulging upward in characteristic pattern of locked subduction thrust fault. Collapse of coastal bulge during earthquake produces coastal subsidence recorded in buried marshes, and results in large tsunamis that inundate coastal regions.<br>• great earthquakes in Japan, Chile (M=9.5), Mexico City (M=8) have involved plates less than 20M years old, and less than 30km thick. Earthquake in Chile (M=9.5), oceanic crust also devoid of seamounts. |

Table 6.1 (continued) Evidence refuting and supporting the possibility of historic and future great earthquakes on the west coast of Canada and the northwestern United States.

| Evidence | Explanation by Campbell | Explanation by Atwater/ Rogers |
|---|---|---|
| Local Plate Tectonics | • all major earthquakes occur east of hanging wall of Juan de Fuca and are generally at least 50km deep to the hypocenter<br>• mainland BC is essentially aseismic, except for Nootka Fault at depth<br>• Vancouver Island is crossed by subsurface Nootka Fault, and encompasses extreme north end of Juan de Fuca seismic subduction zone | • Vancouver and Victoria have ongoing small earthquake activity beneath them and in the crust nearby.<br>• three source areas: continental crust earthquake, deep earthquakes in subducted Juan de Fuca plate, and very large earthquakes on subduction boundary ~150km offshore |
| Earthquake Hazard | • Slight to non-existent<br>• there will NOT be an extremely large subduction earthquake (M=8+)on the Juan de Fuca subduction plate.<br>• relatively modest earthquakes (M=7.5) at depths below 20km will continue for hundreds of years at worst, or may expire as the Juan de Fuca subduction ceases<br>• no indication of any seismic occurrences on the Mainland north of the 49th parallel, those that might occur will be deep and distant from Vancouver | • High - in addition to subduction earthquake, hazard comes from earthquakes within crust of North American plate and suduction or underthrusting Juan de Fuca plate |
| Modeling Strategy | • Deterministic - all faults known | • Probabilistic - exact location of faults unknown; many faults unknown |

suggests that the building code design levels for ground motion are more than sufficient to endure shaking from all seismic wave *frequencies* produced by a large earthquake, however, **it is the *duration* of shaking that makes many structures vulnerable to extensive damage** (Rogers, personal communication). A moderate earthquake close to Vancouver, beneath the Strait of Georgia for instance, would result in disastrously large insured losses, forcing many companies into insolvencies. In order to improve risk management strategies and prevent insolvencies, the insurance industry should use seismic risk models to assess their exposure. Especially since the absence of evidence is not evidence of absence.

### *6.4.2 Module Sufficiency*

The purpose of the seismic hazard module is to use ground motion attenuation equations to estimate ground motion, or shaking, at a site some distance from the centre of an earthquake. Ground motion moves in six directions: north, south, east, west, up and down (Figure 6.4). Thus there are two horizontal axes (north/south, east/west), and one vertical (up/down). In Canada, there are very few recordings of strong ground motion, particularly horizontal, and so accurate simulation is compromised. Since ground motion attenuation equations are the foundation of every seismic hazard module, this will affect the model results. Just how much the results are affected requires further exploration. Accordingly, the data input, databases, and equations used within the model need to be as rigorous as possible for the model to be considered sufficient. Here sufficient refers to the model adequately or satisfactorily representing the Canadian West Coast seismic situation.

Ground motion attenuation describes how ground shaking subsides with distance. This relationship is dependent on earthquake source conditions, event magnitude and ground shaking, and site conditions. Ground motion attenuation equations are based on seismic data from pre- and post-instrumentation events around the world. The validity of the attenuation results are dependent on the reliability of historical accounts, and the rigor of measures for currently active seismic areas. Thus, it is important that the analysis of historic events be as accurate as possible.

Globally, large magnitude earthquakes occur rarely (on the order of hundreds of years) and without warning, so that traditionally it has been difficult to measure and study them. Canada has not yet had a catastrophic earthquake, and so the severity of its exposure is unclear. However, in efforts to minimise exposure, Canada has built over 100 seismic monitoring stations for research purposes. These stations record seismic parameters including the location of each epicenter, duration, and magnitude for all earthquakes. The *epicentre* is the surficial location of the source of an earthquake, and is found directly above the hypocentre. In areas with enough seismograph stations, such as southwestern British Columbia, the depth of the hypocentre is also measured. The *hypocentre* is the actual location of the source of an earthquake. This is usually at some depth beneath the earth's surface along a rupturing fault. Larger earthquakes are examined more thoroughly and include measures of earthquake intensity, fault dimensions and orientation, causal stress fields and so on (Rogers, personal communication). While this level of detail will be of use in the future, current researchers and models must rely on historic seismic events for risk analysis. A major

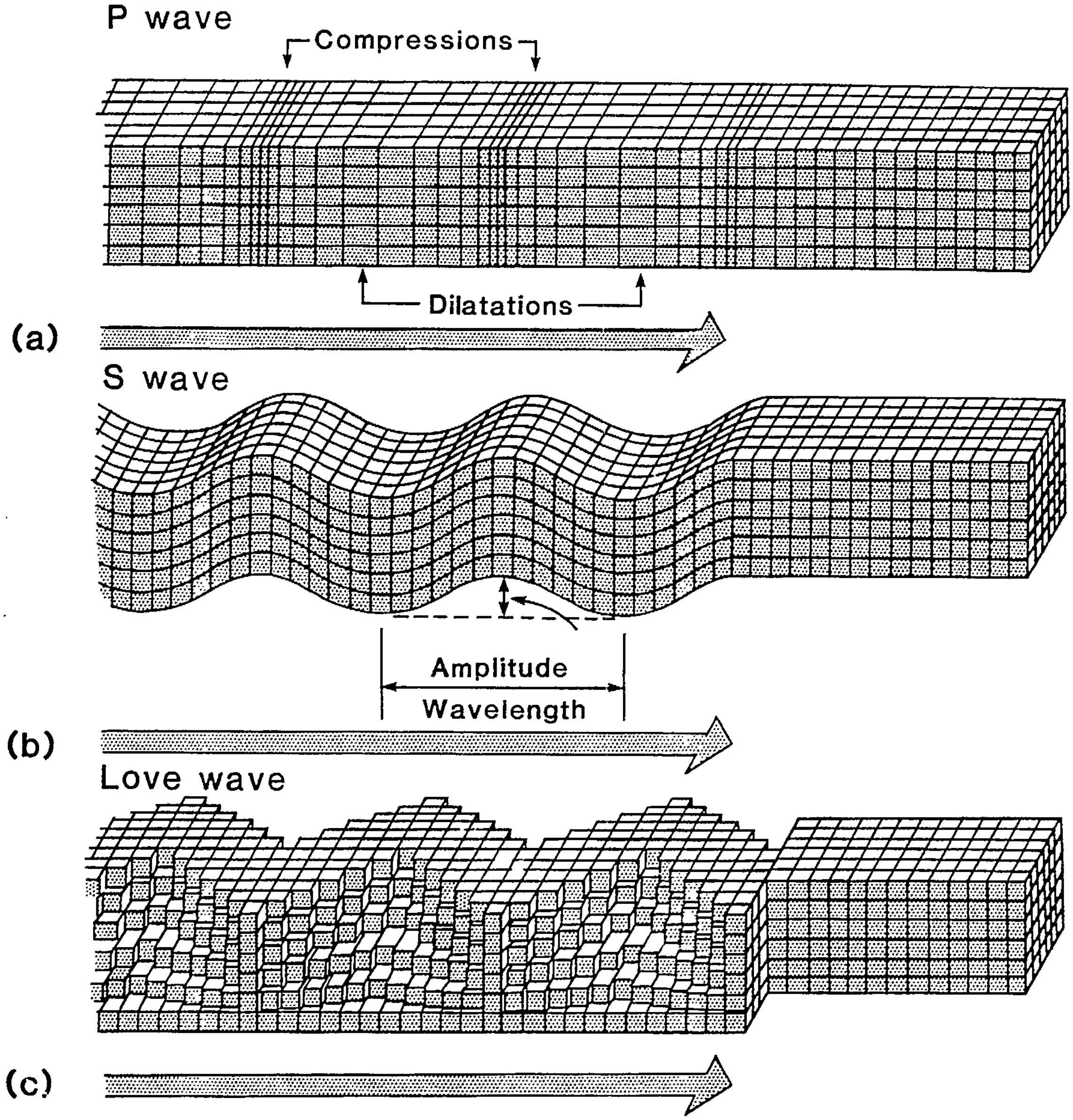


Figure 6.4 Direction of seismic wave motion where (a) is east-west direction; (b) is up-down direction; and (c) is north-south direction. Source: Richards, 1996.

proportion of these events occurred before sophisticated instrumentation became available for measuring seismicity. It is extremely difficult to translate historical data into current settings with any kind of accuracy (Rogers, personal communication). Therefore there is a high degree of uncertainty inherently associated with any earthquake risk analysis.

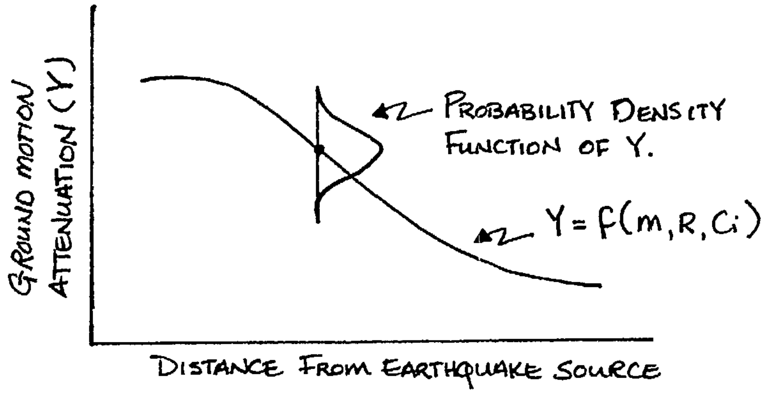
Generally, ground motion attenuation at a site is a function of distance from the source (d), depth to hypocentre (R), earthquake magnitude (M), and site parameters describing regional geology and site soil conditions ($G_i$). As seismic waves pass through the ground, they encounter different mediums which either amplify or dampen their movement. From Figure 6.5 it can be seen that ground motion attenuates exponentially with increasing distance from the epicentre.

The Canadian West Coast is susceptible to two types of earthquakes: shallow continental, and deep subduction. Shallow earthquakes close to Vancouver, such as in the Strait of Georgia, are analysed using attenuation curves from California (Rogers, personal communication). California attenuation equations are based on peak ground acceleration (PGA), local magnitude, depth to hypocentre, and distance to epicentre (Campbell, 1989). PGA is commonly used as the ground motion parameter because data are available and easily measured for all regions in California. Measures of depth to hypocentre for California tend to be overestimated because of the inaccuracy of the velocity models employed routinely to locate earthquakes in one part of the state. As a consequence, they are usually presumed unreliable (Campbell, 1989). Similar problems plague observations elsewhere. For example, measures of depth to hypocentre are not always accurate, or available, for Canadian earthquakes (Rogers, personal communication). Accordingly, distance to epicentre is used as the distance measure. Since the behaviour of a seismic wave is better understood as the depth of the hypocentre increases, eliminating this parameter increases uncertainty about the attenuation of a seismic wave.

California data are not applicable to the Cascadia subduction zone because the two tectonic environments are very different (Crouse, 1991). Therefore, accelerogram data from other subduction zones similar to the Cascadia, such as central Chile, Peru, Mexico, Alaska, and southwest Japan, have been included in the development of ground motion attenuation functions (Heaton and Hartzell, 1987; Crouse, 1991). For example, Crouse (1991) used peak ground acceleration, depth of hypocentre, and distance to epicentre. Distance to epicentre was converted to centre of energy release distances, which is the "distance from the recording station to a point on the fault rupture where the energy was considered concentrated. For all earthquakes less than M = 7.5, this point was assumed to be the hypocentre. For most of the larger events, this point was the centroid of the fault plane." It should be noted that most of the global data were taken at stiff soil sites, and that bedrock sites were under-represented in the global dataset. Ultimately, attenuation for stiff soils became a function of magnitude and distance (equation 1):

$$\ln \mathrm{PGA} = p_1 + p_2 \ln (R + C(M)) \qquad (1)$$

where R is the distance to the centre of energy release (hypocentre), and the rest are constants (Crouse, 1991). For these types of attenuation equations, site PGA is converted



where:
M = magnitude
R = shortest distance from earthquake source to site.
$C_i$ = parameters describing geology and soil conditions at a site.

Figure 6.5 Ground motion attenuation with distance

Table 6.2

| Site PGA (g) | Site bedrock MMI |
|---|---|
| < 0.1 | 5 - 6 |
| 0.1 - 0.2 | 6 - 7 |
| 0.2 - 0.3 | 7 - 8 |
| 0.4 - 0.8 | 8 - 9 |

*Source: Tung et al., 1994.*

Table 6.3

| If medium is ... | Increase MMI by... |
|---|---|
| Rock | 0 |
| Stiff Soil | 0.5 |
| Soft Soil | 1 |
| Bay Mud | 2 |

to site MMI using a conversion table (Table 6.2), and soil effects are accounted for by modifying the site MMI using a set of rules (Table 6.3; Tung et al., 1994). Thus, site conditions are only assessed after the seismic wave has been attenuated. This may be sufficient for sites near the earthquake epicentre, however, for sites further away, interim site conditions amplify and dampen shaking. **Failure to account for site conditions between the seismic source and structural location can misrepresent shaking intensity at the site.**

It is the objective of the attenuation function to determine shaking intensity at a site given the original ground motion magnitude, and distance from the source. To better understand ground motion attenuation, each component of the attenuation equation can be addressed separately. This includes: the source parameters, ground motion parameters and site parameters.

*Source Parameters*
An earthquake is the result of elastic strain released via rupturing along a fault line – the earthquake source. The larger the rupture, the larger the earthquake and surrounding area affected. Seismic waves originate at the source and decay as they move radially outwards from it. In order to determine the level of ground motion at a site, it is important to have some measure of where the source is in relation to the site-to-source parameter. The seismic source can be described by several parameters including the fault location, down-dip extent of the of the plate boundaries, depth of the hypocentre, and location of epicentre.

**Unless seismic activity has been observed along a fault, its location or existence, remains unknown.** For instance, the 1995 Kobe earthquake in Japan (M=6.9) occurred along a previously unknown fault. If an area is thought to have seismic potential and yet little to no physical evidence exists to support the hypothesis, source zones are often used to identify the location of a fault. From 1568 to 1988, 24 000 earthquakes were recorded within Canada and those surrounding areas which could affect Canadian territory (Anglin et al., 1990). Most models have defined source zones by drawing boxes around clusters of epicentres along the west coast (Figure 6.6). If the user defines an epicentre as a point within the source zone, the zone can be divided into segments of equal probability occurrence (Rauch, personal communication). If a fault is known to exist at a certain location, a fault zone can sometimes be specified as the source.

According to Rogers (1994), the most important parameter for seismic hazard zonation in a subduction zone is **down-dip extent**. The down-dip extent is defined as the length of the contact between the brittle, lower portion of the continental crust and the upper oceanic crust. It is along this zone that most earthquakes occur. Since the Juan de Fuca plate is young, this zone is thin such that the uncertainty of the depth of the hypocentre is restricted to 2-3 km. Thus, the depth of the hypocentre can be used to define the down-dip extent (Hyndman et al., 1990; Rogers, 1994).

Depth to hypocentre helps define the down-dip extent of the subduction zone, and helps explain seismic wave motion. As the depth to the hypocentre increases, behaviour of seismic waves becomes more predictable. That is, it becomes increasingly difficult to assess the distribution, maximum magnitude, and acceleration of earthquakes with shallow hypocentres (depth < 70 km). **This presents**

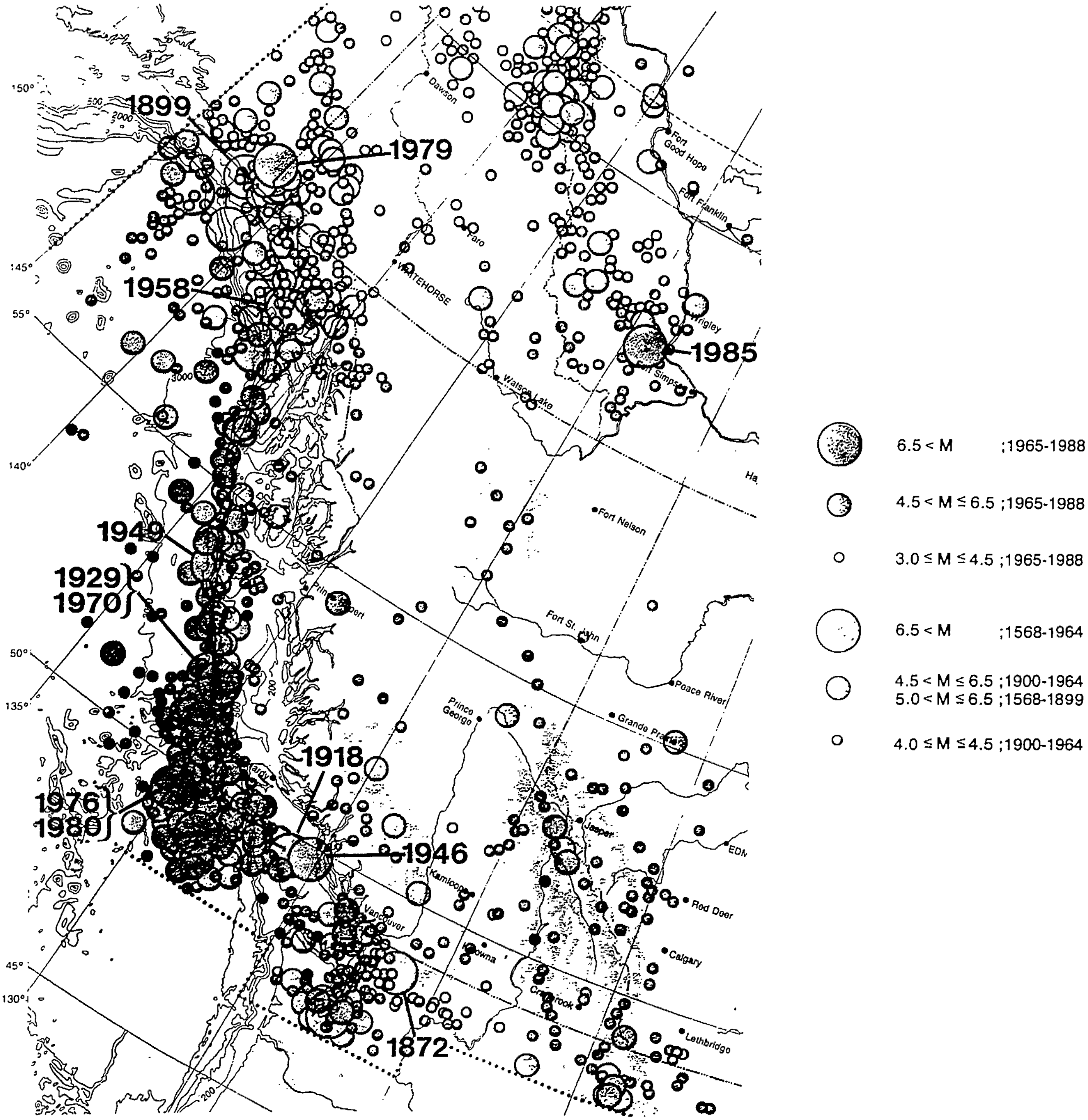


Figure 6.6 Epicentres along the Canadian west coast. Source: Anglin et al. 1990.

**one of the greatest sources of uncertainty in seismic risk analysis** (Rogers, 1994).

Since the movement of a seismic wave attenuates with distance, most attenuation equations have a site-to-source parameter. This suggests a measure from the structure location to the hypocentre. As mentioned earlier, hypocentre measurements are not always available or reliable. However, unlike depth to hypocentre, the epicentre, located directly above the hypocentre at the surface, is a straight forward and reliable seismic measurement. Therefore, it is usually used to measure site-to-source distance. Seismic hazard modules account for depth of hypocentre by adjusting the source-to-site distance.

*Ground Motion*

Ground motion is induced by seismic energy release at the source. It is usually measured by magnitude, seismic shaking intensity, and peak ground acceleration, which can be quantified using seismographs or accelerograms. The 100 seismograph stations in Canada continuously record all seismic activity in Canada with magnitude $M > 3.5$, including $M = 3.5$ for populated areas (Rogers, personal communication). Ground motion shaking intensity is responsible for much of the damage to structures. Thus, as shaking duration increases, so does the amount of damage.

Holding all other factors constant, a subduction earthquake will often produce more damage than a continental earthquake because its larger rupture surface increases the duration of strong shaking (Rogers, 1994). In the various seismic risk models, the user specifies a seismic event magnitude using either a Guttenberg-Richter scale magnitude, M, or a recurrence probability. As the magnitude of an event increases, its return period tends to decrease. The recurrence period is used in a recurrence model to assign the magnitude of an event based on the probability of exceeding the event in a given number of years (Lamarre et al., 1992).

The **Guttenberg-Richter scale** is the scale most commonly used to measure a seismic event. It describes the '*total energy of the seismic waves radiating outwards from an earthquake as recorded by the amplitude of ground motion traces on seismographs at a normalised distance of 100km from the source*' (Smith, 1996). Since it was first developed, the Guttenberg-Richter scale has been modified to include data from modern seismic measurement devices, and local and regional conditions. While the local magnitude scale is acceptable for measuring smaller earthquakes ($M \leq 6.5$), the moment magnitude scale is more appropriate for larger events ($M > 6.5$). The *local magnitude ($M_L$)* is the logarithm of the corrected ground motion in micrometers ($1\mu m = 10^{-3}$ mm). For example, an seismic wave amplitude of 0.5 mm (500 μm) will have an $M_L$ of 2.7 (log (500) = 2.7), while to achieve $M_L = 8$, the seismic wave amplitude must be 100 000 mm or 100 m. Each incremental increase in $M_L$ represents a 10 fold increase in potential ground shaking and 31.6 times increase in energy release (Munich Re, 1990; Smith, 1996).

Earthquakes larger than $M_L = 6.5$ are poorly represented by $M_L$ because the seismic waves from only a small portion of the rupture zone along a fault are measured by the scale. Thus it does not capture the total energy released during an event. Consequently, the magnitude of larger earthquakes are measured by the Guttenberg-Richter *moment magnitude (M)* which uses displaced surface area of the fault, average length of movement, and the rigidity of ground material. Though M > 5.5 accounts for approximately 1% of all earthquakes in the world, they are responsible for 90% of all seismic energy released (Smith, 1996).

The Guttenberg-Richter scale does not include ground shaking intensity, duration, or frequency, which are necessary to infer potential damages. Accordingly, the M is usually converted in the seismic module to a **Modified Mercalli Index (MMI)**. MMI provides a measure of seismic ground shaking intensity by assigning a numerical value to the human observations of felt ground motion and the extent of physical damage to buildings and undeveloped land. An experienced individual will rate the intensity of an earthquake from MMI = 1, not felt except by a very few under exceptionally favourable circumstances, to MMI = XII, total destruction (wave seen on ground surface, lines of sight and level distorted, objects thrown into the air; see Table 6.4).

Though MMI is extremely subjective, it can be argued that it is no less scientific than Guttenberg-Richter Scale measurements since seismologists can disagree on the exact rating of the magnitude of an event. In addition to providing information on the spatial damage pattern after an earthquake, MMI is applicable to pre-instrumentation earthquakes.

MMI has since been modified to be more objective by relating each index increment to a measure of **peak ground acceleration** (see Table 6.2). PGA is the peak value of horizontal ground acceleration at a site. The advantage of PGA is that it is objective and directly measurable. However, PGA does not provide a measure of duration or frequency of ground motion which are important factors for determining damage to structures (Ansary et al., 1995).

Some researchers believe that **Arias Intensity** is a more objective measure of shaking intensity and ground motion characterisation (Arias, 1970; Kayen et al., 1994; Kayan and Mitchell, 1996). Arias intensity is calculated by integrating the entire seismogram wave form, including amplitude and duration of ground motion. The objective is to find the total seismic energy absorbed by the ground either at the surface, or at some depth below. Unlike PGA, which uses a single, high frequency, point in the seismogram, Arias intensity considers the full range of frequencies recorded for all points in the seismogram. Arias Intensity is also directly quantifiable and verifiable, as opposed to MMI (Kayen et al., 1994; Kayen and Mitchell, 1996). However, Arias intensity is still relatively young, and an extensive database is still being developed. There is also the question of how, or even if, Arias intensity can deal with historic earthquakes. As well, Arias Intensity is dependent on the seismic record, and seismograms may not always be available, or triggered, to measure seismic activity. Though this measure does show promise for the future, MMI will likely continue to be used for seismic hazard modelling for some time.

### *Site Parameters*

Ground motion is strongly affected by site conditions. As such, it is important to consider site effects in any ground motion attenuation function. For instance, seismic motion in shallow soils ( ≤ 10 m) is amplified, while in deep soils ( > 10 m) it is attenuated (Campbell, 1989). Most models obtain data on the local subsoil conditions

Table 6.4 Modified Mercalli Intensity Scale

| **Average Peak Velocity (cm/s)** | **Intensity Value and Description** | | **Average Peak Acceleration (g is gravity = 9.8 m/s$^2$)** |
|---|---|---|---|
| | I | Not felt except by a very few under exceptionally favourable circumstances. | |
| | II | Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. | |
| | III | Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing truck. Duration estimated. | |
| 1-2 | IV | During day felt indoors by many, outdoors by few. At night some awaken. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably. | 0.015g-0.02g |
| 2-5 | V | Felt by nearly everyone, many awakened. Some dishes, windows and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop. | 0.03g-0.04g |
| 5-8 | VI | Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight. | 0.06g-0.07g |
| 8-12 | VII | Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. | 0.10g-0.15g |
| 20-30 | VIII | Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, walls, monuments. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed. | 0.25g-0.30g |
| 45-55 | IX | Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. | 0.50g-0.55g |
| >60 | X | Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. | >0.60g |
| | XI | Few, if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and landslips in soft ground. Rails bend greatly. | |
| | XII | Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air. | |

from the Geological Survey of Canada soil maps. Though soil type is well documented for western Canada, soil depth and shear velocity are not (Rogers, personal communication). This introduces a high degree of uncertainty in the prediction of ground motion attenuation, and accounts for a large proportion of the error (Campbell, 1989).

Due to data limitations on soil characteristics, many models assume a simplified soil depth (Figure 6.7a). However, field observations suggest that the soil-bedrock interface undulates irregularly causing soil depth to fluctuate dramatically at the local scale (Figure 6.7b). Generally, the real spatial distribution of soil depth is not well known. Depending on the sub-surface site conditions, an irregular bedrock surface could ricochet seismic waves through the soil beneath the surface so that some locations behave as focal points, while others experience amplified or dampened velocities (Brooks and Vincent, personal communication). This results in highly variable damage patterns that are very difficult to predict.

The overall structure and shear velocity of soil conditions for the Fraser River delta are generally well understood. Thus, ground motion attenuation can be modelled with some confidence. It can be assumed that soils on the Delta are deep enough to dampen most ground motions until the soils start to taper or pinch out. However, in these areas, seismic wave amplification gains importance as it becomes synchronised with the motion of the surrounding buildings (Rogers, personal communication). To explain, every structure has a natural frequency of vibration. As seismic wave frequency coincides with structural frequency, the result is constructive interference. This usually causes the collapse of the structure, such as the Tacoma bridge collapse in Washington State on Puget Sound.

### *6.4.3 Module Limitations*

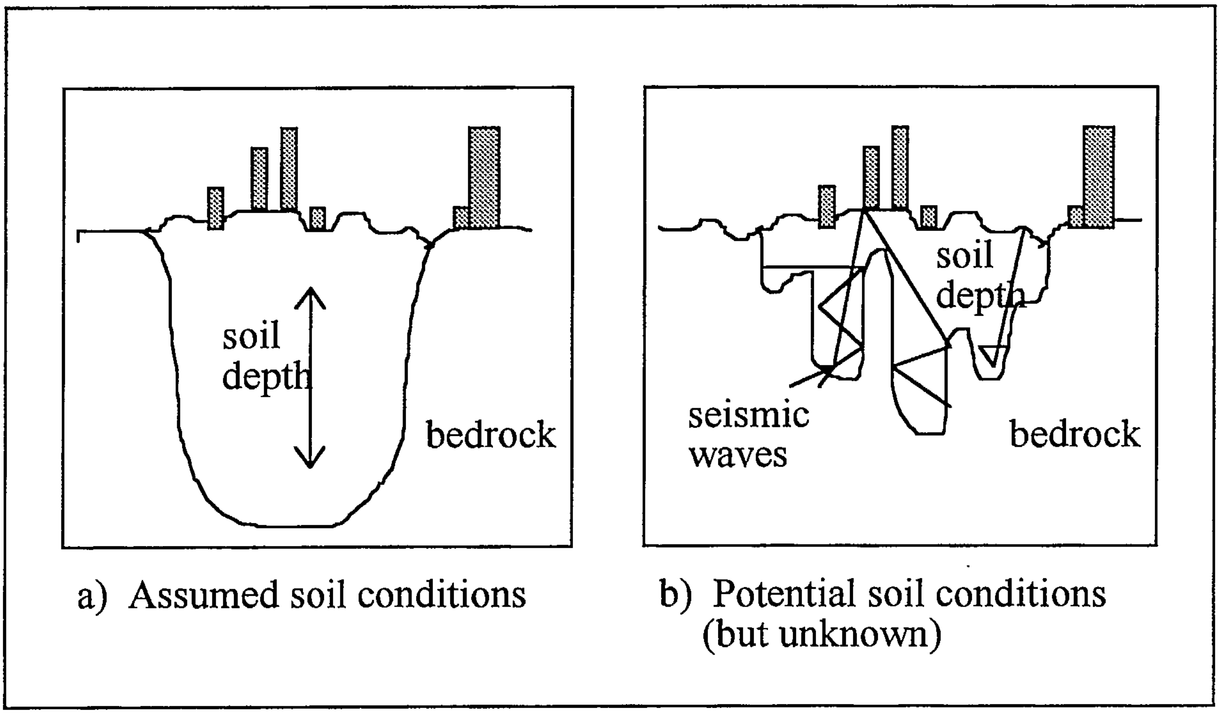
The most significant constraint on a seismic hazard module is related to data limitations. Canadian seismic data is limited due to both the rarity of larger seismic occurrences, and the analysis of pre-instrumentation seismic events. To assess the sufficiency of a seismic hazard module as a whole, the general assumptions, sensitivities and sources of uncertainty must be reviewed.

*Assumptions*

Since Canada has yet to experience a catastrophic earthquake, **one of the most important assumptions is that the data from California and other subduction zones are representative of, and applicable to, the situation of western Canada.**

> Since an earthquake represents the release of elastic strain, seismic risk is highest immediately before and immediately after a major earthquake. Seismic risk is lowest shortly after a major earthquake, and increases with time as elastic strain builds.

Seismic hazard modelling is highly dependent on the occurrence of seismic events in the past. Since the ability to directly measure seismic activity is relatively recent, it is assumed that qualitative descriptions of historic events are sufficiently accurate to enable the event to be consistently converted to a value of MMI. As a corollary, it is assumed that MMI can adequately quantify historic ground shaking intensity. Assuming that the quality of building construction and materials is



a) Assumed soil conditions

b) Potential soil conditions (but unknown)

Figure 6.7 Example of soil conditions in Vancouver Area uniform around the world, this could be feasible. However, the world is composed of a mosaic of building practices that have been developing through time at different rates. An earthquake resistant building design for the Ukraine may not be sufficient by Californian standards. Accordingly, an earthquake of equal magnitude in either area may produce completely different damage results, and hence different measures of MMI. For international comparison of seismic shaking intensity, MMI is highly uncertain. However, within a given jurisdiction, MMI provides a common forum. Seismic measurement is still limited. That is:

- not all seismic parameters are confidently measurable yet, such as depth to hypocentre,
- not all seismically active areas are equipped with instrumentation, and
- often, in areas that are equipped, the instruments are either not triggered, or not immediately triggered, during an event.

Since no alternative measure for historic events is currently available, there is no reason to discontinue using MMI and the MMI-damage relationship in seismic risk modelling (Tung et al., 1994).

*Sensitivities*

For many models, the most sensitive parameter is also the most subjective - MMI. Due to the subjective nature of many of the seismic hazard inputs, some form of sensitivity analysis should be performed to determine how alternative inputs for important parameters will affect model results and, ultimately, decisions made based on these outputs (EERI, 1989; Lamarre et al., 1992).

*Uncertainty*

**Uncertainty is associated with every facet of seismic hazard modelling.** Some attempt to address or quantify uncertainty should be associated with seismic hazard estimates, since this uncertainty may influence decisions regarding seismic risk management. This includes uncertainty due to (Lamarre et al., 1992):

- seismic source delineation,
- maximum magnitude estimation,
- recurrence periods,
- attenuation equations, and
- parameter measurement and estimation.

For example, Lamarre et al. (1992) have attempted to quantify uncertainty by applying the bootstrap method. The bootstrap method is a statistical approach which deals with incomplete datasets. Their objective was to evaluate uncertainty due to:

- incompleteness of the earthquake catalogue;
- errors in magnitude measurement and conversion (M to MMI);
- mismatching of the recurrence and attenuation models with reality; and
- the final seismic hazard estimates.

There is also the potential for uncertainty to be associated with the seismic parameters themselves. This pertains to data sufficiency issues. For instance, depth to hypocentre, used in many attenuation equations, is difficult to measure because of limitations in instrumentation and modelling.

Most models obtain Canadian seismic source and site condition information from the Geological Survey of Canada. Since all models use the same soil data for Canada, all are subject to the same uncertainties associated with the collection, completeness, accuracy and resolution of the data. Thus, there is again an underlying commonality between the models. With so many commonalties between the seismic hazard models, aside from the data limitations, discrepancies in the results are not well understood.

## 6.5 Vulnerability Module

The third step in seismic risk modelling involves modelling structural vulnerability to damage. The purpose of the vulnerability module is to estimate the degree of damage to structures and contents, as well as the potential cost of business interruption for a given earthquake. To do this, the shaking intensity estimated in step two is used in vulnerability functions.

In the vulnerability module, **damage is estimated using vulnerability functions which relate ground motion to damage for various structures.** Since Canada has not had a serious earthquake, damage information is limited, and so, the vulnerability functions are based on observations of historic and recent earthquake damage from around the world. As with the attenuation laws, it is therefore necessary to have a complete understanding of how historical shaking intensities are converted to estimates of damage (see Section 6.4).

Building inventory information, including Insurance Bureau of Canada class and age of structure, are converted to Applied Technology Council Report (ATC-13) equivalents to infer the relative vulnerability of a structure to failure. Using modified ATC-13 vulnerability functions, the percent of structural damage is estimated based on relative vulnerability of the building and MMI shaking intensity at the site.

The ATC-13 vulnerability functions, developed in 1985 by a group of Structural Engineers from the Applied Technology Council, describe the modes of failure for different types of structures given earthquake shaking intensity. They also provide a measure of the likely cost of repair for a structure given its construction type, defined by the ATC-13 classification system (Table 6.5). MMI was used as the measure of shaking intensity because it was available for historic and more recent earthquakes. Additional measures of structural damage were obtained from field and shake table investigations. Damage and shaking intensity were then used to estimate structural vulnerability to failure in the event of an earthquake, with functions developed for each construction type (Figure 6.8). The vulnerability curves are then used by the vulnerability models to estimate damage to a structure. That is, the ATC-13 construction class is used to determine structural vulnerability, which along with MMI, is used to estimate structural damage. Most vulnerability modules have since modified and updated the ATC-13 vulnerability functions to include information from global field observations and shake table experiments.

Probable Maximum Damage (PMD) is the upper bound for estimating total portfolio damage. Total portfolio damage is the sum of all individual cases. The PMD for a structure is usually calculated at the 90th, or 95th, percentile on the vulnerability curve (Figure 6.8). This means that

1. for an event with a 300 year return period or an event that has a 1 in 300 chance of occurring, and
2. given that the event has happened such that the probability of exceeding damage at the 90th percentile is 1/10 (10%),

Table 6.5. ATC-13 Construction Classes (Sample)

| Class Code | Construction Type |
|---|---|
| 0 | Unknown |
| 1 | Wood Frame |
| 2 | Light Metal |
| 3 | Unreinforced Masonry Wall |
| 4 | URM Wall with Frame |
| 5 | RC Shear Wall with Frame |
| ⋮ | ⋮ |

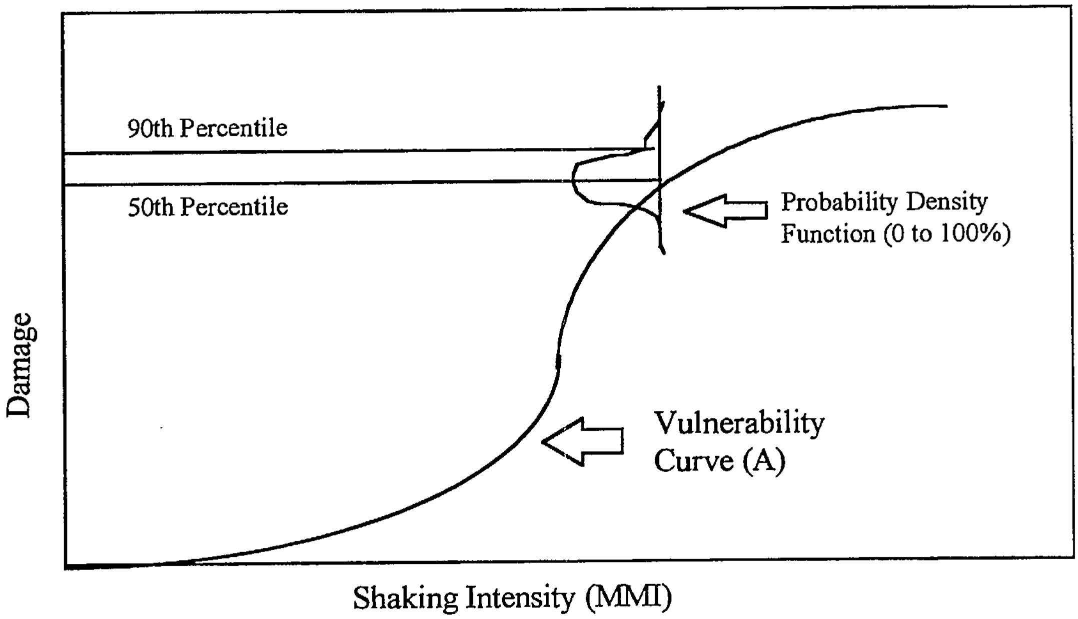


Figure 6.8. Example Vulnerability Function

there is a 1 in 3000 chance of the event happening and the damage estimate being exceeded at the 90th percentile on the vulnerability curve. Many modellers will select a return period coincident with that specified for building code standards.

Calculating PMD at the 90th or 95th percentile can provide the modeller with an unwarranted sense of confidence in the damage estimates. However, events with a higher return period can have more detrimental effects if the confidence level is decreased. For example, Probable Expected Damage (PED) is calculated at the 50th percentile on the vulnerability curve (Figure 6.8). Given an event return period of 500 years, or an event that has a 1 in 500 chance of occurring in a year, there is a 50% probability, or 1 in 1000 chance, of the damage estimate being exceeded. If the PED estimate for a 500 year return period is greater than the PMD estimate for a 300 year return period, the real risk could be under-estimated (Walker, unpublished).

Three assumptions should be made when the ATC-13 vulnerability functions are applied to estimate damage in western Canada:

1. lag period between NBCC changes and implementation;
2. level of NBCC enforcement; and
3. given equal magnitude earthquakes, damage will be worse in Vancouver and the surrounding area, than in California. This is because Vancouver's NBCC standards for earthquakes are not as rigid as those for California. (However, this could be updated soon.) As well, much of Vancouver is powered by natural gas which could have serious repercussions in the event of fire-following.

How do these assumptions change the results produced by the vulnerability functions? Failure to account for these assumptions could lead to severe under-estimation of potential damages.

MMI is a subjective and sensitive parameter. Since there is a non-linear relationship between shaking intensity and level of structural damage, small changes in MMI will result in large differences in structural damage. Level of damage also depends strongly on structural vulnerability. Incomplete building inventory information is usually compensated for either by calculating a weighted average for the construction types in that area, or by querying the database for an appropriate inventory distribution. However, this can result using the wrong construction type to determine the vulnerability function; therefore, structural information must be as precise and complete as possible.

As with the seismic hazard module, there is uncertainty associated with each step in the vulnerability module. As the complexity of a structure increases (e.g. multiplex buildings), the uncertainty also increases since collapse of these structures

> Not all insurance, seismic, or vulnerability data can actually be measured or collected. That which can be measured may not be to the accuracy or quantity desired. Thus, there are tradeoffs associated with seismic modelling and data analysis. With increased data accuracy and completeness, increased costs are incurred, potentially to the point where costs outweigh gains. As data is aggregated to reduce costs and compensate for incomplete data, uncertainty in model results is increased, potentially to unacceptable levels. Accordingly, compromises must be made to enable seismic risk modelling.

are not well understood (EQECAT, unpublished). This can result in over-estimation of damage. As well, it is assumed that structures are built to code, and maintained over time, which is not always the case. Failure to account for the condition of a structure could result in an under-estimation of potential damage. Finally, the conversions from IBC class to ATC-13 class may further introduce uncertainty into the vulnerability module. There are several other sources of uncertainty in the vulnerability module which require further investigation.

## 6.6 Financial Module

The final step in seismic risk modelling involves the estimation of losses in the financial module. The purpose of the financial module is to calculate the insured losses of an earthquake based on three factors: insurance structure, structural damages estimated by the vulnerability module and cost to repair the damages incurred.

A majority of seismic risk models have financial modules which estimate probable maximum loss (PML) for property, contents and business interruption. To estimate gross loss, the cost of repair is calculated for each insured structure using the percent damage incurred by the structure. Next, the insured value of the structure and policy limits are considered. The same is done for contents and business interruption.

Net PML is calculated by considering the insurance structure. That is, the layers of reinsurance, coinsurance, and retrocession are subtracted from the gross PML. For individual analysis, each site is considered independently. For a portfolio analysis, the losses are statistically aggregated. Some financial modules also estimate probable expected losses (PED), based on a worst-case-scenario, and expected annual losses (EAL), which account for all possible earthquakes that may affect a site over a period of time.

Loss estimations are directly linked to the cost of repairing damage. However, following a catastrophe, the high demand for scarce materials and labour tends to drive up the costs of repair. The cost of inflation can be substantial and therefore should be considered in the calculation of PML. Some models include the cost of inflation by adjusting coinsurance and deductibles, others have built-in inflation factors and some do not acknowledge the issue. As well, the final PML estimate should include the cost of removing debris from the site before repairs can be made.

In addition to calculating loss estimates, another important function of the financial module is to quantify the uncertainty that pervades each component of the seismic risk model. Since the model is a decision making tool, some measure of uncertainty should be associated with the loss estimates. This can be in the form of a level of confidence, standard deviation, confidence interval, or a range of loss estimates.

## 6.7 Review of Seismic Risk Models

This section poses some questions that should be considered before modelling seismic risk. It also examines three seismic risk models currently available to the insurance industry to aid in decision making and seismic risk management. Some attempt to validate the results of the models has already been put forth by some of the modelling companies (see Jones et al., 1995).

There are several decisions that must be made before an appropriate seismic risk model can be selected. First, and foremost, the company must decide what it hopes to achieve by using a seismic risk model. This can be addressed by answering a few questions concerning the modelling effort. That is:

1. How will results from the model be used to assess the risk of a company? That is, will the results be used as the final estimation of probable maximum loss (PML), or will they be used to improve inputs for a more comprehensive and tailored PML estimation method? This will help determine both the necessary resolution of the data for input, and which model to use for the analysis.

2. Which cost calculations should be performed? For example, if only an estimate of PML is required, there is no need to use a model that also calculates probable expected losses (PEL), expected annual losses (EAL), or other loss calculations.

3. What factors should be included in the model calculation of cost? This includes cost of seismic shaking given property damage, content damage, business interruption, and/or secondary costs due to fire-following, landslide, liquefaction, or inundation. Addressing this question can aid in model selection.

Second, assessment of a company's risk can be performed either at the portfolio level, the individual level, or both, depending on the model used. Before beginning an assessment, the insurance company must decide at what level they wish to perform their analysis. This will likely produce different PML estimates. Depending on the resolution of the company's input data, this decision could already be made. That is, if the company's data is aggregated according to cresta zone, it is not possible to perform a site-specific analysis.

Finally, the company must also decide whether to have the analysis performed as a service by the model provider, or to license the model for in-house analysis. There are advantages and disadvantages for both of these options. Using the model as a service ensures that a qualified individual with a thorough understanding of the model performs the analysis. However, the disadvantage is that the service modeller may not have a thorough understanding of the insurance data provided, or of the insurance industry. Licensing a model both

1. enables that an individual with a thorough understanding of the company's data and the insurance industry performs the risk analysis, and
2. enables the company to get a better sense of the limitations, uncertainties and sensitivities of the program, and also enables more experimentation and tailoring of the program to the company's needs.

However, there are many startup costs associated with licensing from hardware to learning the program. As well, it is possible that the uncertainty and error could increase initially depending on the skills, or experience, of the in-house modeller. If the analysis is performed as a service, usually the insurance company must provide detailed information regarding portfolio building inventory, insurance structure, and assumptions.

The information provided during the review of the seismic hazard module (Section 6.4) can be used as a framework for both other modules in the seismic risk model, and for the seismic risk model as a whole. This method of examination has been summarised in Figure 6.9.

First, the **science** behind the what is being modelled should be investigated. For instance, how well is damage to structures understood by engineers, and then modelled by the vulnerability module. If the scientific community does not have a good understanding of the hazard, modelling will be inherently limited.

Second, potential users should review the **purpose, application and approach** of each model. This allows the user to match the needs of the company with the appropriate model.

Third, all models simplify reality. Therefore, it is important to examine the integrity of a model. This includes how well a hazard is modelled, or what the **components of the model** are. This requires looking at the entire modelling process from user inputs, to database inputs, to each module through which the data is manipulated, to outputs. In order to determine how well the seismic risk model simulates the damages attributable to seismic shaking, the model components must be examined. This includes the insurance inputs, and the seismic hazard, vulnerability, and financial analysis modules. Certain assumptions make this simplification possible, and these assumptions must not violate the laws of physics. As well, since the seismic risk models are used as a decision making tool, their sensitivities, uncertainties, and limitations also need to be understood.

Finally, there are issues of **data quality and quantity**. The quality of data affects model results. **Data quality** is affected by the data sources, collection procedure, accuracy, resolution, and completeness. For example, in Ontario, the soil maps produced by the Geological Survey of Canada (GSC) differ from those produced by the Ontario Geological Survey (OGS) because of collection procedure. Given the same soil type - 70% sand and 30% silt - the GSC will describe the soil as a sandy silt, while the OGS will call it a silty sand. If these differences occur in Ontario, it is likely that a similar problem could exist in other provinces and with respect to other measurements. **Data quantity** is affected by the frequency of earthquakes, and the ability to measure them. One of the problems with estimating insured losses due to earthquakes along the West Coast of Canada is the rarity of events. This limits the quantity and availability of attenuation and damage data. In addition, there are issues of subjectivity in the collection procedure, such as the case with Modified Mercalli Intensity measurement (MMI). Finally, issues of data matching and transfer functions need to be investigated since this can decrease the accuracy and increase the uncertainty associated with the data. For instance, converting peak ground accelerations to MMI, or IBC classes to ATC-13 classes. These issues are usually addressed throughout the model review.

The objective now is to review some of the seismic risk models available to the insurance industry using the proposed examination scheme. There are some areas

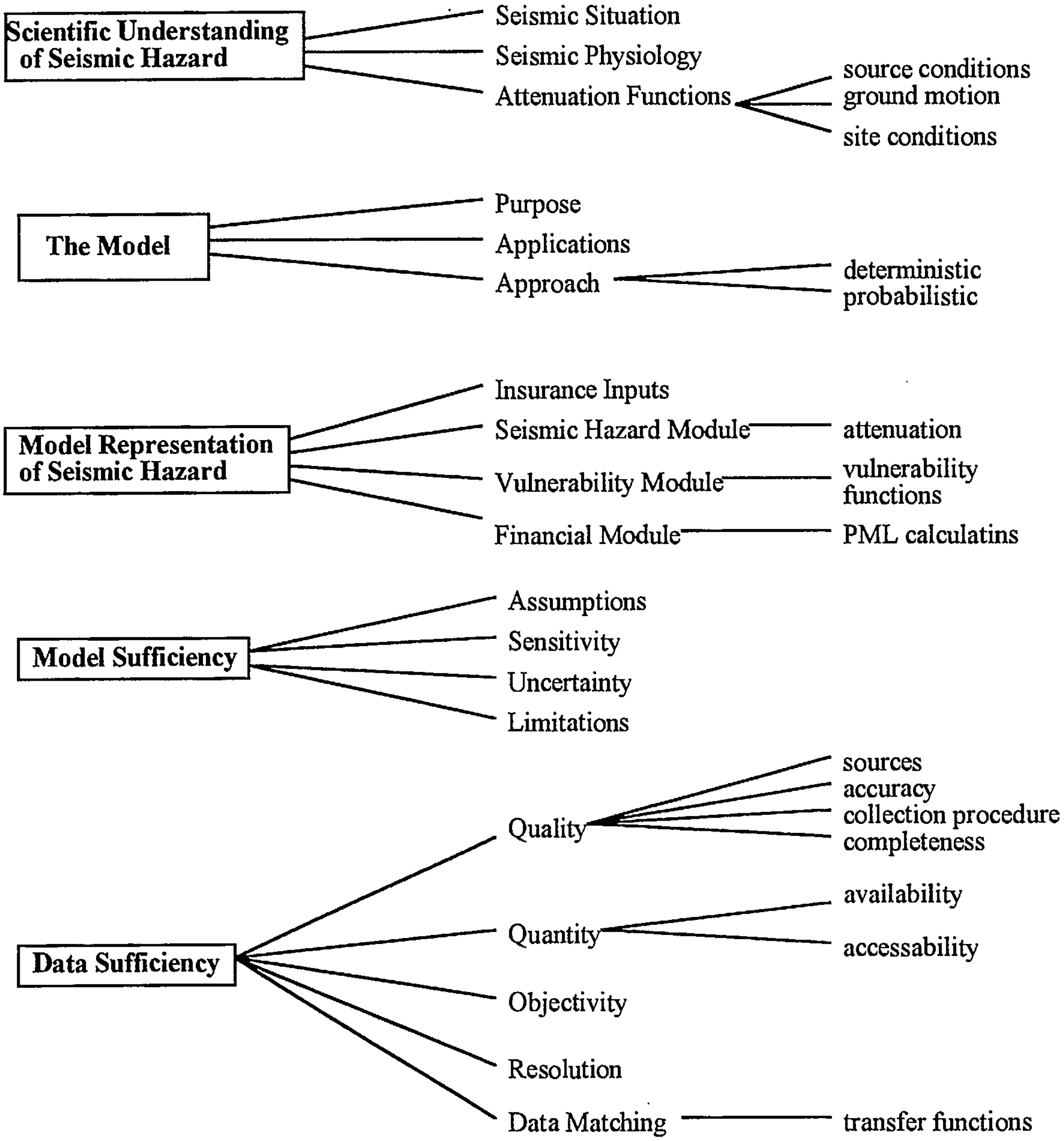


Figure 6.9 Proposed method of seismic module evaluation.

which overlap between the models, such as in the scientific understanding and data sufficiency of seismic hazard. These areas need not be compared, but rather addressed as in the seismic hazard section (6.4).

### *6.7.1 The Models*

A preliminary examination of the Munich Re Probable Maximum Loss Calculation model, the RMS - IRAS model, and the EQECAT - EQEHazard model was performed using the proposed evaluation scheme as a guideline. Before comparing the models, they should be briefly reviewed.

*Munich Re – Probable Maximum Loss Calculation Model*

The purpose of the Munich Re model is to calculate the PML resulting from an earthquake, for a given property portfolio (Figure 6.10). The model uses a probabilistic approach to calculate loss based on damage from 1200 earthquakes. PML is calculated for losses due to property and contents damage, and business interruption given earthquake shaking and fire following. The model can be used to determine the effectiveness of an underwriting strategy, and as a decision making tool regarding reinsurance protection. By using a probabilistic approach, some measure of uncertainty is inherently provided with the results. Though the Munich Re model has been criticised for performing loss estimation by cresta zone, at the time of its development this was the only level of insurance data available. In response to improvements in insurance portfolio information, Munich Re is developing 6-digit postal code site analyses capabilities for its model. The model is currently provided as a free service to its clients.

*Risk Management Solutions – IRAS Model*

The purpose of Risk Management Solutions (RMS) IRAS model is to educate people on risk associated with an earthquake (Figure 6.11). This can be performed using both deterministic and probabilistic methods at the site-specific or portfolio levels. Losses are calculated primarily from damages due to less severe, but more frequent earthquake shaking, with estimates for landslide, liquefaction, and fire following. Results from the analysis are meant to:

- provide information for input into the risk analysis methods of the company;
- aid in underwriting and portfolio management;
- assess the quality of current rates; and
- evaluate incremental load risk placed on a portfolio.

At this time, IRAS is the model most commonly used to assess risk in Canada. The risk model can be provided as a service by RMS, or licensed to the insurance/reinsurance company.

*EQECAT – EQEHazard*

The purpose of EQECAT's EQEHazard model is to evaluate the risk due to an earthquake by estimating catastrophic event losses for an individual risk or portfolio (Figure 6.12). A probabilistic approach is used to estimate probable maximum loss, net expected loss, and annual expected losses. Property, contents and business interruption losses are calculated for earthquake shaking, fault rupture, fire following, liquefaction, landsliding, tsunami, inundation, and hazardous material release. The objectives are to: facilitate policy writing for underwriters; evaluate existing books; develop strategies for managing catastrophes; determine pure premium; and test scenarios. EQECAT has had limited activity in Canada, however, it is gaining

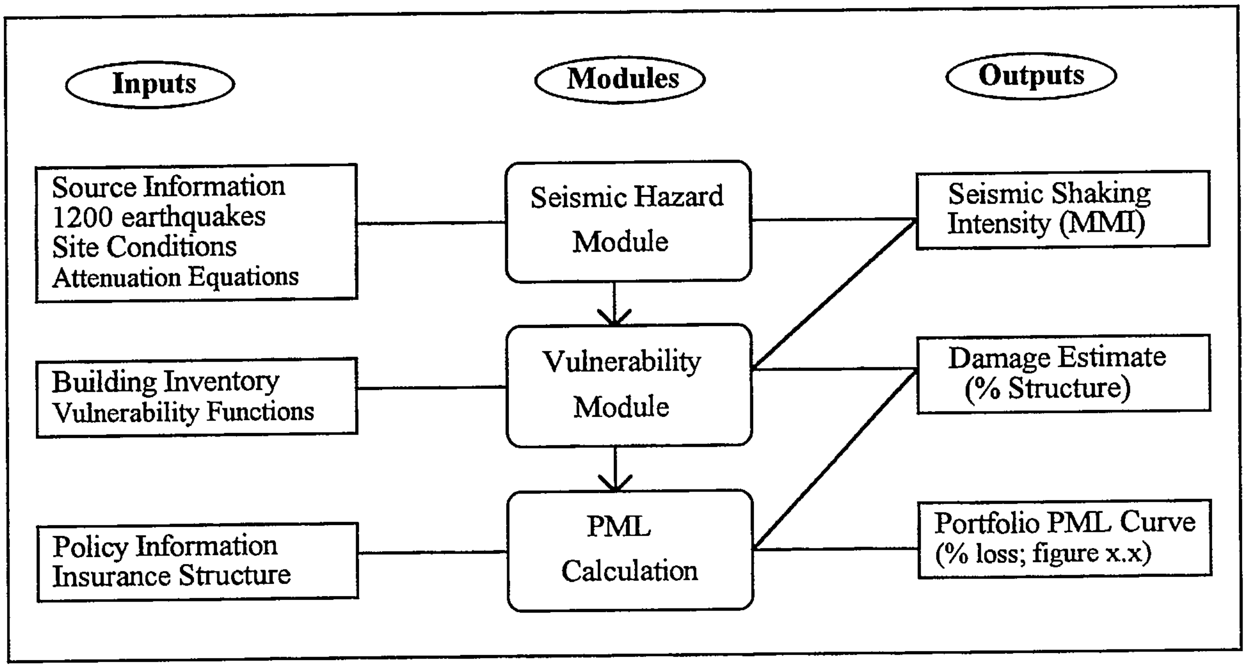


Figure 6.10 The Munich RE PML calculation model.

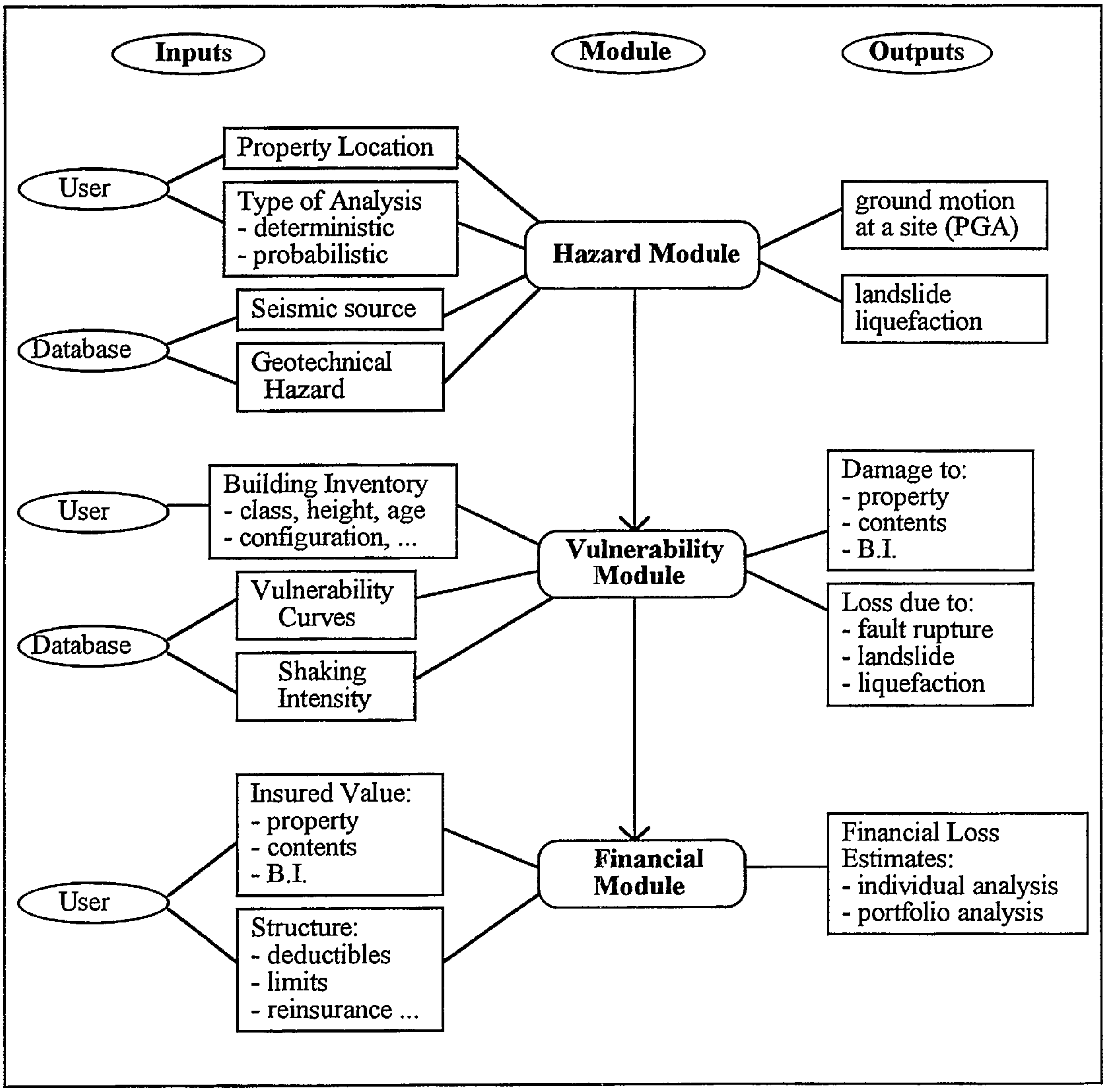


Figure 6.11 IRAS earthquake model flowchart. Source: Risk Management Solutions, unpublished.

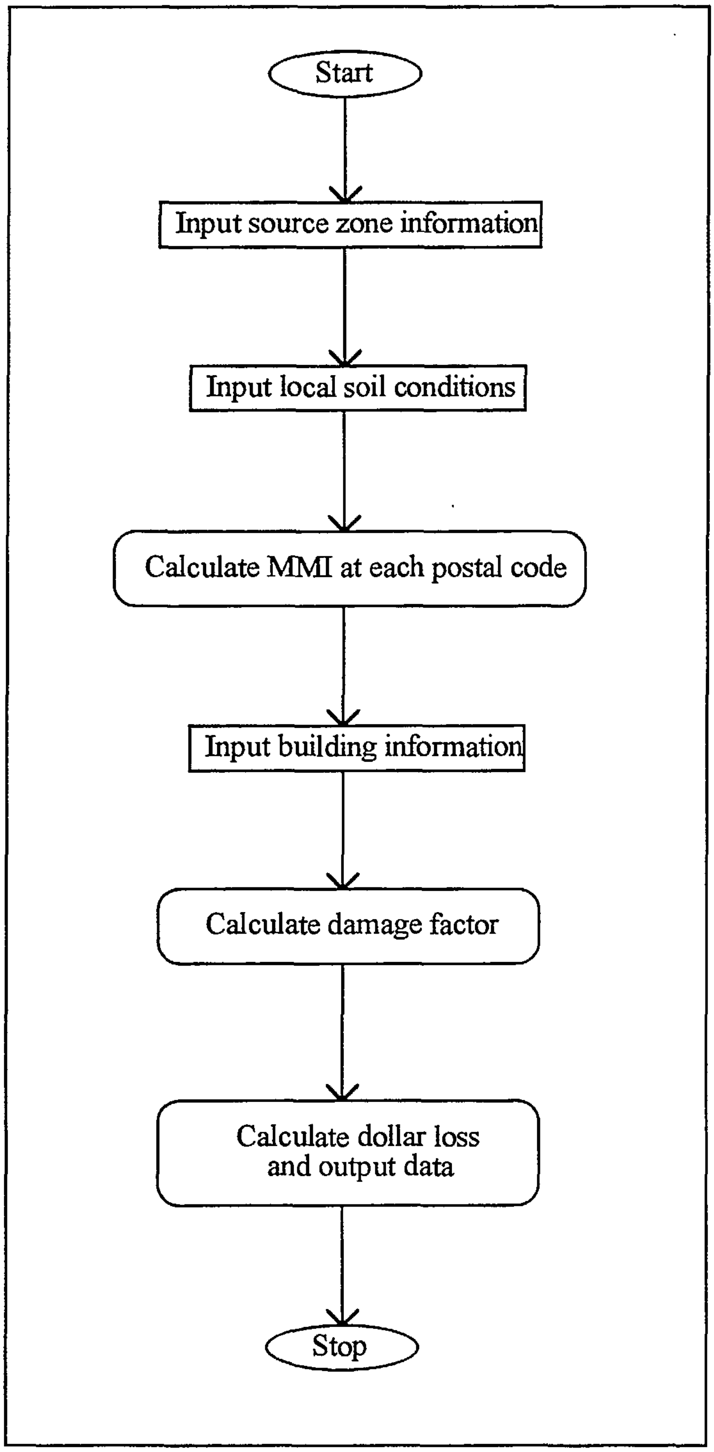


Figure 6.12 EQE Hazard loss estimation method. Source: Jones et al., 1995.

attention. Due to its complex nature, EQEHazard has been offered as a service. However, EQECAT hopes to have the model ready for licensing by 1997.

### *6.7.2 Examination of the Seismic Risk Models*

Table 6.6 reviews the preliminary results of the proposed examination scheme for the Munich Re, RMS, and EQECAT models. The models are compared generally. The purpose and applications of each model is revisited, followed by a brief review of the approaches used to estimate seismic risk and losses, that is, deterministic vs. probabilistic modelling. The primary and secondary consequences of an earthquake accounted for by the models are assessed based on the modules within the seismic risk models. For example, the Munich Re model investigates the cost of earthquake shaking and fire following. The RMS model uses earthquake shaking and fire loss, and also includes landslide and liquefaction losses. In addition to these modules, the EQECAT model includes loss estimates due to inundation, fault rupture, and hazardous materials release.

Representation of seismic hazard is explored by reviewing the components of the model: the insurance inputs, seismic hazard, vulnerability, and loss calculations (Table 6.7). Insurance inputs are nearly identical for all three models, except that the Munich Re model currently uses cresta zone to specify building location. The seismic hazard modules differ in their treatment of ground motion, attenuation, and site conditions. For example, the Munich Re model uses Guttenberg-Richter magnitude, then Modified Mercalli Intensity (MMI) to measure ground motion while the RMS and EQECAT models use peak ground accelerations (PGA) and MMI. As well, the RMS and EQECAT attenuation equations differ. The RMS attenuation equation is a function of site to source distance and peak ground acceleration. Site conditions are accounted for in a separate step. In contrast, EQECAT uses a logic tree approach to weight the average of three attenuation equations which are functions of rupture length, site to source distance, PGA, shaking duration, and site conditions. Each model uses modified vulnerability functions to estimate damages, and each model calculates loss in a different way.

Model integrity is examined by reviewing the major assumptions, sensitivities, uncertainties and limitations of the three models (Table 6.8). Since the models often use the same data and scientific principles, many of the uncertainties and limitations are shared. The differences between the models tend to occur in how unknowns are treated, the assumptions made and the sensitivities of the seismic parameters.

## 6.8 Summary and Recommendations

The different seismic risk models available to the insurance industry all have a **similar** structure. First, each requires insurance input data including building inventory, insurance structure, and seismic event parameters. Next, each has a seismic hazard module which uses the seismic event data and building location in attenuation functions to estimate seismic shaking at a site. Each model then uses a vulnerability module to estimate the extent of damage at the site based on the site seismic shaking. Finally, each model has a financial module that

Table 6.6 Preliminary review of seismic risk models

| **Earthquake Loss Estimation Model** | **Munich RE Earthquake PML Model** | **Risk Management Solutions - IRAS** | **EQECAT - EQEHazard** |
|---|---|---|---|
| **Purpose** | • calculation of the PML resulting from earthquake for a given property portfolio or individual risks | • educate people in the insurance industry of the risk associated with a natural catastrophe<br>• individual risk or portfolio analysis | • catastrophic event loss estimation for an individual risk or portfolio<br>• evaluation of risk due to earthquakes |
| **Applications** | • reinsurance protection decision making tool<br>• determine effectiveness of underwriting strategy | • provide information for input into the risk analysis methods of the company<br>• underwriting aid<br>• portfolio management<br>• assess quality of current rates<br>• evaluate incremental load risk places on portfolio. | • facilitate policy writing for underwriters<br>• evaluate existing books<br>• estimate PML<br>• develop catastrophe management strategy<br>• determine pure premium<br>• scenario testing |
| **Approach** | • probabilistic: probability of loss occurrence (not event reoccurrence) | • probabilistic - loss over time, exceeding probability<br>• deterministic - scenario, maximum credible, bounded max., user defined earthquakes<br>• model less severe but more frequent earthquake | Currently for the US model (not yet implemented for Canada):<br>• probabilistic<br>• logic tree approach to weighted average of three attenuation equations |
| **Modules** | • earthquake shaking:<br>  • seismic hazards (including liquifaction)<br>  • vulnerability<br>  • financial<br>• fire following (model takes on deterministic approach, not probability of occurrence) | • seismic hazard:<br>  • shaking<br>  • landslide<br>  • liquefaction<br>• vulnerability<br>• fire loss<br>• financial | • earthquake shaking:<br>  • hazards model, vulnerability functions, computational models<br>Other hazards in the US model, not currently available for the Canadian model:<br>• fault rupture<br>• fire following<br>• liquefaction<br>• landsliding<br>• tsunami<br>• inundation<br>• hazardous material release |

Table 6.7 Components of the seismic risk models

| **Seismic Risk Model** | **Munich RE Earthquake PML Model** | **Risk Management Solutions - IRAS** | **EQECAT - EQEHazard** |
|---|---|---|---|
| **Insurance Inputs** | *Building Inventory*<br>• longitude/latitude<br>• building location - 3 or 6 digit postal code. Cresta zone capabilities<br>• construction class<br>• year of construction<br>• building exterior, cladding, frame, height, ornamentation, occupancy,...<br>• building contents<br>*Policy Data and Insurance Structure*<br>• deductible, limits, reinsurance treaties | *Building Inventory*<br>• building location - 3 or 6 digit postal code. Cresta zone capabilities<br>• construction class - IBC converted to ATC-13 within model<br>• year of construction<br>• building exterior, cladding, frame, height, ornamentation, occupancy, ...<br>• building contents<br>*Policy Data and Insurance Structure*<br>• deductible, limits | *Building Inventory*<br>• building location - 6 digit postal code (converted to cresta zones or lat/long by program) or GPS for remote sites<br>• building construction - type, age, material of construction, IBC structural codes<br>• year built, building code design effects<br>*Insurance Information*<br>• insured value, deductible, occurrence layers, reinsurance structure, site and policy limits, facultative and treaties |
| **Seismic Hazard Module** | • line and area sources<br>• seismic shaking measure (MMI, PGA)<br>• site conditions: soil type<br>• liquefaction and landslide potential<br>• attenuation = F(distance, soil, source type) | • select line source or area source - 31 possible zones, 24 in area of Vancouver Island<br>• seismic shaking measure (PGA, MMI)<br>• site conditions: soil type<br>• liquefaction and landslide potential<br>• **attenuation = F (distance, soil PGA)** | • updated seismic hazard model from Geological Survey of Canada (GSC)<br>• multiple models - H (historic) and R (regional) models<br>• line faults and area sources<br>• quantify event: location of fault, type of fault, maximum magnitude, rupture length, duration, ground motion (PGA)<br>• site soil conditions from database<br>• **attenuation = F(distance, rupture length, PGA, duration, site conditions)** |

| Seismic Risk Model | Munich RE Earthquake PML Model | Risk Management Solutions - IRAS | EQECAT - EQEHazard |
|---|---|---|---|
| **Earthquakes** | • analysis of specific earthquake scenarios, or probabilistic analyses<br>• maximum magnitudes defined using historical events and geological characteristics of source<br>• source model integrates work of GSC | • analysis of specific earthquake scenarios, or probabilistic analyses using all regional sources.<br>• maximum magnitudes defined using historical events and geological characteristics of source | • comprehensive model with representation of sources in eastern and western Canada<br>• specification of earthquake<br>*Magnitudes*<br>• building code specified return period<br>• user specified<br>• historical<br>• deterministic (scenario) or probabilistic analyses |
| **Vulnerability Module** | • IBC class converted to ATC-13 classification<br>• modified ATC-13 vulnerability functions based on input from Canadian consultants | • IBC class converted to ATC-13 classification<br>• modified ATC-13 vulnerability functions | • IBC codes converted to ATC-13 classification<br>• modified ATC-13 vulnerability functions which include field observation and shake table experiments<br>• world's largest database of earthquake damage effects<br>• damage is calculated for each individual property and summed to calculate the damage factor for a portfolio |

Table 6.7 continued on next page...

Table 6.7 (continued) Components of the seismic risk models

| Seismic Risk Model | Munich RE Earthquake PML Model | Risk Management Solutions - IRAS | EQECAT - EQEHazard |
|---|---|---|---|
| **Financial Outputs** | • Catastrophe PML calculation in % as a function of probability of loss occurrence<br>• Damage amounts for buildings, contents, business interruption and property of every description for given part subdivided into personal commercial business<br>• Post-event inflation may be accounted for by adjusting co-insurance and deductibles | • Average Annual Loss - pure premium, loss cost before expenses and other loads<br>• PML (%) calculation given 250 year event and excedence probability curve. Return period is adjustable.<br>• Post-event inflation can be accounted for using a user-defined scaling factor<br>• Individual loss detail<br>• Insurance layer and reinsurance structure loss | • Calculates loss to buildings, contents, business interruption<br>• Effects of post-event inflation may be included, at user's option<br>• PML and PMD are calculated for worst case scenarios using the damage factor at the 90th percentile of the vulnerability probability distribution, or can be user specified<br>• NEL and NED are calculated at the 50th percentile<br>• Loss and damage both include limits and deductibles<br>• Expected Annual Loss calculated |
| **Measure of Uncertainty** | • disclaimer | • variance, confidence intervals and probability distributions | • confidence interval associated with outputs; calculates means, standard deviations, and/or probability distributions<br>• full loss exceedance curve generated from probabilistic analysis |
| **Validation efforts** | • actual event calibration<br>• review/input from Canadian consultants | • currently underway at UBC | • Northridge Earthquake (Jones et al, 1995)<br>• peer reviewed<br>• hazard verified against Geological Survey of Canada (GSC) model for various locations |

Table 6.8 Integrity of seismic risk models

| **Model Sufficiency** | **Munich RE Earthquake PML Model** | **IRAS** | **EQECAT Canada** |
|---|---|---|---|
| **Unknowns** | • averages used as substitute<br>• some possibility of PML underestimation due to averaging | • weighted average of potential attributes based on regional inventory characteristics<br>• increases uncertainty in loss estimate according to importance of information and level of uncertainty in unknown data<br>• places property at geometric or occupancy weighted centroid of postal code for unknown locations<br>• distributes exposure over likely classes, or distribution of inventory – if building class is unknown | |
| **Assumptions** | • within area source, earthquake has equal probability of occurring along any segment; rate of occurrence of events within source divided equally among segments<br>• vulnerability curves vary based on year of construction to reflect building code changes | • within source area, earthquake has equal probability of occurring along any segment; rate of occurrence of events within source divided equally among segments<br>• structures built to code<br>• lag between building code amendment and implementation<br>Vulnerability functions are presently under review, however currently:<br>• vulnerability of structures in BC higher than that in California, but lower than the east coast<br>• since building code requirements same for eastern and western Canada, same vulnerability functions applied to both areas<br>• see treatment of unknown data table figure 5.6 | • structures built to code<br>• lag between building code<br>• uniform probability of occurrence of earthquakes anywhere along or within faults or area sources |

Table 6.8 continued on next page...

Table 6.8 (continued) Integrity of seismic risk models

| **Model Sufficiency** | **Munich RE Earthquake PML Model** | **IRAS** | **EQECAT Canada** |
|---|---|---|---|
| **Sensitivities** | • MMI | • exposure data have significant impact on loss estimate<br>• MMI in fire loss model | • quality of input data |
| **Common Uncertainties** | • randomness of occurrence and magnitude of events<br>• as resolution of data decreases, uncertainty increases<br>• uncertainty due to unknowns: increases with increasing unknowns<br>• quality of exposure data<br>• analysis of historic or pre-instrumentation events<br>• ground motion attenuation functions<br>• source uncertainty: location of faults, depth to hypocenter, distance from epicenter<br>• ground motion measurement: MMI<br>• site uncertainty: soil information, soil amplification effects<br>• building data: assessments, square footage, material, date of construction<br>• building performance, damage factor, vulnerability functions, damage curves of ATC-13<br>• increasing uncertainty with increasing complexity of structure<br>• landslide, liquefaction (not currently addressed in EQE Canadian model)<br>• ensuing fire components | | |
| **Common Limitations** | • limited by quality of data input, accuracy and completeness of exposure data<br>• resolution of analysis<br>• aggregation and averaging of information<br>general lack of Canadian seismic damage data | | |

calculates the potential insured losses given the extent of property and content damage, business interruption, and insurance structure.

The seismic risk models **differ** in their purposes, applications, secondary effects considered, attenuation and vulnerability functions, assumptions, sensitivities, and other more minor functions. They will also differ in services and support provided, and operation costs.

The purpose of this section has been to explain the process of seismic risk modelling, and to provide a method by which to examine the models currently available for risk management. In addition to this, other questions should be considered, this time regarding the company producing the model. This includes how often databases are updated, what kind of support is offered by the company, how credible the company is, and what time and space costs will be incurred.

*Recommendations*

1. Watch National Geographic's documentary on natural hazards: ***Born of Fire.***
2. This analysis should also be performed for Eastern Canada.
3. A similar examination of the **vulnerability and financial** modules should be undertaken. The **seismic hazard** portion of the risk models should be studied in greater detail.
4. **Landslide, liquefaction, inundation, and fire following modules** were not addressed in this document and need to be evaluated in a similar manner.
5. **Other risk models**, such as Risk Engineers' EQCanada, should also be reviewed.
6. This analysis should be repeated for **Wind Models**.

## References

Allen, D. E. (1986). *Tornado damage in the Barrie/Orangeville Area, Ontario, May, 1985.* National Research Council, Ottawa.

Anglin, F. M., Wetmiller, R. J., Horner, R. B., Rogers, G. C. and Drysdale, J. A. (1990). *Seismicity Map of Canada.* Geological Survey of Canada. Canadian Geophysical Atlas, Map 15. Scale: 1:10 000 000.

Ansary, M. A., Yamazaki, F., Katayama, T. (1995). Statistical analysis of peaks and directivity of earthquake ground motion. *Earthquake Engineering and Structural Dynamics* 24: 1527-1539.

Arias, A. (1970). A measure of earthquake intensity. In: *Seismic Design for Nuclear Power Plants.* Hansen, R. J. (ed.). MIT Press, Cambridge.

Atwater, B. F., Nelson, A. R., Clague, J. L., Carver, G. A., Yamaguchi, D. K., Bobrowsky, P. T., Bourgeois, J., Darienzo, M. E., Grant, W. C., Hemphill-Haley, E., Kelsey, H. M., Jacobi, G. C., Nishenko, S. P., Palmer, S. P., Peterson, C. D. and Reinhart, M. (1995). Summary of coastal geologic evidence for past great earthquakes at the cascadia subduction zone. *Earthquake Spectra* 11: 1-18.

Brooks, G. and Vincent, S. (personal communication). Geological Survey of Canada, 1996.

Campbell, D. D. (unpublished). Seismicity of Cascadia Subducting Plate. *Manuscript.* March 19, 1996.

Campbell, K. W. (1989). The dependence of peak horizontal acceleration on magnitude, distance, and site effects for small magnitude earthquakes in California and eastern North America. *Bulletin of the Seismological Society of America* 79: 1311-1339.

Crouse, C. B. (1991). Ground motion attenuation for earthquakes on the Cascadia subduction zone. *Earthquake Spectra* 7: 201-236.

EERI Committee on Seismic Risk. (1989). The basics of seismic risk analysis. *Earthquake Spectra* 5: 675-702.

Emergency Preparedness Canada (EPC). (unpublished). *NHEMATIS Progress Report.* 1996.

EQECAT, Inc. (unpublished). *CAT Loss Modelling Methodology.* 1995.

Heaton, T.H. and Hartzell, S.H. (1987). EQ hazards on the cascadia subduction zone. *Science* 236: 162-168.

Hyndman, R. D., Yorath, C. J., Clowes, R. M., Davis, E. E. (1990). The northern cascadia subduction zone at Vancouver Island: seismic structure and tectonic history. *Canadian Journal of Earth Science* 27: 313-329.

Jones, N. P., Thorvaldsdottir, S., Liu, A., Narayan, P., and Warthen, T. (1995). Evaluation of a loss estimation procedure based on data from the Loma Prieta earthquake. *Earthquake Spectra* 11: 37-61.

Kayen, R. E. and Mitchell, J. K. (1996). Arias intensity approach for assessing liquefaction potential of the ground during earthquakes. In preparation.

Kayen, R. E., Mitchell, J. K. and Holzer, T. L. (1994). Ground motion characteristics and their relation to soil liquefaction at the Wildlife Liquefaction Array, Imperial Valley, California. In: *Proceedings from the Fifth U.S.-Japan Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures Against Soil Liquefaction,* O'Rourke, T. D. and Hamada, M. (eds.). pp. 267-283.

Lamarre, M., Townshend, B. and Shah, H. C. (1992). Application of the bootstrap method to quantify uncertainty in seismic hazard estimates. *Bulletin of the Seismological Society of America* 82: 104-119.

Munich Reinsurance Company of Canada (Munich Re). (1990). *The calculation of the probable maximum loss (PML) resulting from earthquake.* Munich Re Insurance Company document.

Rauch, E. (personal communication). Munich Re, 1996.

Risk Management Solutions (RMS). (unpublished). IRAS Canada Earthquake Model. 1995.

Rogers, G. C. (1994). Earthquakes in the Vancouver area. In: *Geology and Geological Hazards of the Vancouver Region, Southwestern British Columbia,* Monger, J. W. H. (ed.). *Geological Survey of Canada, Bulletin* 481: 221-229.

Rogers, G. C. (1988). An assessment of the megathrust potential of the Cascadia subduction zone. *Canadian Journal of Earth Science* 25: 844-852.

Rogers, G. C. (personal communication). Geological Survey of Canada, August 19, 1996.

Rogers, G. C. (unpublished). Response to "Seismicity of Cascadia Subducting Plate" by D. D. Campbell. 1996.

Smith, K. (1996). *Environmental Hazards: Assessing Risk and Reducing Disaster.* Routledge Publishers, New York. Chapter 6.

Tung, A. T. Y., Wong, F. S., Dong, W. (1994). Prediction of the spatial distribution of the modified mercalli intensity using neural networks. *Earthquake Engineering and Structural Dynamics* 23: 49-62.

Walker, G. R. (unpublished). *Catastrophe Loss Modelling. Getting the Most out of the Results.* Technical Services Bulletin. Alexander Howden Canada Limited, 1996.

# PART 5: RESPONSIBILITY FOR NATURAL HAZARDS

*by Lindsay Wallace*

## 7.0 Mitigating Natural Hazards and Their Effects

## 8.0 Preparing for an Emergency

# 9.0 Disaster Response and Relief

## 10.0 Recovery

# PART 5: RESPONSIBILITY FOR NATURAL HAZARDS

*by Lindsay Wallace*

## Introduction

***Chapters 7-10** examine how Canadian society manages the total risk for natural hazards. Canada has developed a patchwork of publicly funded programs and private market services, encompassing four main types of response activities: mitigation (Chapter 7), preparation for an emergency (Chapter 8), response to a disaster (Chapter 9), and recovery (Chapter 10).*

These activities are performed in what we term the "human response cycle" (FEMA, 1996). Mitigation and preparation occur prior to a disaster, while response and recovery are initiated by it. Ideally, mitigation and preparation should address flaws in earlier response and recovery endeavours. Assessing previous efforts increases the ability to cope with natural hazards and minimize their effects. Outside this response cycle, a variety of factors determine the socioeconomic impact of natural hazards on Canadian society; these may be geographical, demographic, economic, financial, and even psychological.

Mitigation of natural hazards (Chapter 7) is the means by which people strive in advance to reduce the effects of natural hazards. Most effort focuses on reducing the physical effects of a hazard and include changes in land use and in enforcement of building codes. This chapter also looks at mitigation of hazards and of financial impact. Ideally, the best form of mitigation is the total elimination of the hazard, which is not technically feasible. Recent experiments to seed storm clouds have not always met with success. As for financial impact, an example is the current underfunded liability faced by the property and casualty insurance industry as a result of earthquake exposure. Were a large earthquake to hit the lower B.C. mainland, its financial impact would be quite widespread due to this underfunded liability (IBC, 1994a). Private and public responsibilities for all kinds of mitigation are also outlined in this chapter.

Preparing for an emergency (Chapter 8) is the process of planning for and warning people about natural hazards. While it is a form of mitigation, we are considering it as distinct. Activities include emergency planning, ensuring adequate response, and providing effective warning. As such, emergency planning is inherently linked to emergency response efforts.

After a disaster strikes, emergency response efforts (Chapter 9) are initiated. These activities include government and private responses to emergency medical needs and fires, evacuation, and establishment of shelters and feeding stations – in other words, ensuring the safety of the population. Secondary activities include restoring essential services, such as electricity, telecommunications links, and water services, as well as private efforts such as sending adjusters to deal with insurance claims.

Finally, efforts at disaster recovery (Chapter 10) occur after peoples' immediate needs have been addressed. They include private- and public-sector payouts from insurance schemes and financing arrangements. They also encompass public and private rebuilding. Ideally, rebuilding should occur with mitigation in mind so that over time the impact of disasters will be reduced. These activities are explored in Chapter 10.

These four chapters are intended to provide the reader with an overview of the types of programs and services provided by private and public agencies. It is by no means a complete list. Given that most provinces and municipalities have similar departmental structures, to list all programs and services would make for a monotonous paper. Moreover, time constraints made such a task impossible. We chose examples primarily on the basis of availability of data. Consequently, many examples are from British Columbia, where information on emergency measures is widespread. Furthermore, much of that province's emergency preparedness focuses on earthquake threat, as reflected in the examples drawn from this region. We do not in any way intend, however, to minimize the hazardousness of other communities and provinces in Canada.

# 7.0 Mitigating Natural Hazards and Their Effects

*by Lindsay Wallace*

## 7.1 Introduction

*Individuals and society use a range of techniques to mitigate the effects of hazards and reduce vulnerability to them. While the division between mitigating a hazard and preparing for an emergency is somewhat arbitrary, we consider as mitigation any activity that reduces the effects of the hazard. In this chapter we examine both physical and financial mitigation. First, we consider various bodies' responsibility for mitigating the physical effects of hazards. Second, we explore efforts to mitigate the potential financial effects of the insurance industry's underfunded liability.*

A variety of techniques are available to mitigate the effect of natural hazards on buildings and other structures. One can, for example, reinforce existing buildings, ensure that new construction meets standards, and prevent development in hazard-prone areas such as floodplains. Specific mitigation techniques vary by hazard; most fall within the jurisdiction of local and municipal governments.

A brief note about one natural hazard that humans think they can physically mitigate – hail. The Alberta Severe Weather Management Society, composed of representatives from the insurance industry, government, and academe, has been experimenting with seeding of clouds to try to mitigate the impact of hail storms on the prairies. This program is similar to one operating in North Dakota. As shown above in Chapter 2, injection of silver iodide into storm clouds can render the resulting hail smaller and thus less damaging.

One impediment to increased mitigation of natural hazards in Canada is lack of incentive, particularly in areas where the last major disaster occurred long ago or where the probability of a disaster is low. Given current fiscal constraints, increased spending on mitigation seems unlikely. Public support becomes strong only after a disaster (Petak and Anderson, 1982). Fiscal constraints and lack of public support may well hinder development of new measures. To increase public support and encourage individuals to attempt mitigation requires financial incentives and public education. Both insurance and tax incentives can encourage or compel policy holders and taxpayers to increase their own activities in this direction. Public education can also motivate people to act. Responsibility for mitigation lies with municipal and local governments, with provincial and federal governments providing back-up research.

## 7.2 Physical Mitigation

Responsibility in Canada for mitigating the physical effects of hazards is spread among seven groups – the federal government (research), joint federal-provincial arrangements (on reducing flood damage), the provinces (flood mitigation and setting construction standards), municipal authorities (flood mitigation and enforcing building standards), public institutions (research), the insurance industry (promoting mitigation), and individual homeowners (private mitigation efforts).

### 7.2.1 Federal Government

The federal government conducts research on natural-hazards mitigation through five departments and agencies. A number of departments conduct research and educate citizens about mitigation, and others could potentially play a role. (Emergency Preparedness Canada, the primary federal agency planning for hazards – see Chapters 8 and 9 – does not have an explicit mandate for disaster mitigation. Its U.S. counterpart, the Federal Emergency Management Agency (FEMA), does, however, and views promotion of mitigation as essential. Furthermore, Revenue Canada could potentially make mitigative retrofits to homes tax deductible.)

*Agriculture and Agrifoods Canada (AGAFC)*

AGAFC is responsible for the farm sector in Canada. It conducts research on crop strains that can withstand long periods of drought. It also investigates drought-sensitive farming techniques.

*Canadian Mortgage and Housing Corporation (CMHC)*

The CMHC is a crown corporation that provides mortgage insurance and conducts research on housing matters. Like the NRC, it conducts some limited research into disaster-proof construction.

*Environment Canada*

Environment Canada's goal is to make sustainable development a reality through protection, conservation, and restoration of the natural environment. It is responsible for conducting research into flooding and represents Ottawa on federal-provincial steering committees established under the Flood Damage Reduction Program (see Section 7.2.2). Environment Canada also conducts research on atmospheric hazards.

*National Research Council (NRC)*

The NRC conducts research into seismic evaluation through the Institute for Research in Construction (IRC). IRC research differs from that of the Geological Survey in that it focuses on the impact of seismic events on buildings. This research is used in the setting of construction standards under the National Building Code of Canada (NBCC), which has, since 1941, contained provisions on seismic loading based on national seismic zoning maps. A new building code is being planned for the west coast for the year 2000. Seismic-loading standards are established to prevent structural collapse during a major earthquake and thereby protect human life. The provisions will not, however, prevent serious damage to structures (IBC, 1994a).

*Natural Resources Canada (NRCan)*

Natural Resources Canada is one of several science-based government departments. It ensures sustainable development of natural resources. One of its branches, the Geological Survey of Canada, conducts research into seismicity and earthquake exposure, which is widely used in zoning maps (IBC, 1994a). Another branch, the Canadian Forest Service, conducts research into techniques for wildfire mitigation.

### 7.2.2 Joint Federal-Provincial Program

The joint federal-provincial Flood Damage Reduction Program (FDRP) is a major mitigative tool used by both levels of government. Flooding destroys more property in Canada than any other natural hazard (Newton et al., 1996). Established in 1975, the FDRP promotes use of non-structural means of flood control through mapping and designation of areas as flood-prone. The purpose of the program is threefold. First, it seeks to reduce loss of life and minimise human suffering due to flooding. Second, it attempts to reduce the financial burden of disaster losses. Third, it seeks to reduce the need for expensive, structural flood-control projects (Newton et al., 1996).

The program is administered under terms of a series of federal-provincial agreements. Each province has a steering committee composed of representatives from the provincial ministry of environment or natural resources and from Environment Canada. These committees oversee FDRP mapping. For each area designated as flood-prone, neither level of government will build, approve, or finance development or provide financial disaster assistance for any development built after such designation. Provincial authorities encourage municipalities to zone land on the basis of flood risk. For more than 20 years, the FDRP has worked with 900 communities, at a cost of approximately $40 million (Newton et al., 1996).

### *7.2.3 Provincial Governments*

Provincial governments set standards and advise municipal governments in matters of mitigation and are also active in flood mitigation. Several provide standards for building construction. In Saskatchewan, for instance, the Ministry of Municipal Services sets standards for construction. Saskatchewan, like many other provinces, recommends that municipalities adopt the National Building Code of Canada (Government of Saskatchewan, 1995). The provincial government may also advise municipalities on how best to enforce these standards.

The Ministries of Environment in Ontario and Quebec are active in flood mitigation along the Ottawa River. The Ottawa River Regulation Planning Board is responsible for ensuring integrated management of the principal reservoirs of the river's basin. The board's goal is to reduce flood damage along the river, on its tributaries, and in the Montreal area. It also administers and co-ordinates inflow forecasting, flow routing, and optimisation models to reduce flood damage while affecting users of the basin as little as possible.

In Ontario, the Ministry of Natural Resources also involves itself in flood mitigation. Its Conservation Authorities Section encourages conservation and wise use of water and related resources by providing advice and grants to regional conservation authorities to support such resource-management projects as watershed planning, flood prevention, and flood-control works, including dams. The Aquatic Ecosystems Branch leads in development of policies and programs related to aquatic ecosystems, including flood-risk management, watershed planning, flood-damage reduction, and dam safety (Government of Ontario, 1996).

### *7.2.4 Municipal Governments*

Most mitigative activities are municipal, including land-use planning and management and building-code enforcement. Municipalities must abide by provincial building codes and may create by-laws to extend or enhance their requirements (IBC, 1994a). For example, Calgary's Planning and Building Department is responsible for land use and building permits; it also enforces conditions of approval (City of Calgary, 1996). Most municipalities in Canada have similar departments.

Vancouver, because of its earthquake risk, has undertaken a variety of mitigation efforts. First, it has applied NBCC guidelines to its building stock, identifying 15,000 structures with potential problems and more than 1000 requiring further evaluation (IBC, 1994a). The Insurance Bureau of Canada (IBC) feels that the city has been particularly slow in implementing retrofitting of problematic buildings (IBC, 1994a). The Vancouver School Board assessed its building stock and found that half of its schools required seismic upgrading. In the past three years, the board has spent $11 million to upgrade two of its schools at greatest risk (IBC, 1994a). Second, an $11-million project to upgrade the city's older bridges seismically is nearing completion (City of Vancouver, 1996).

Metropolitan Toronto (Metro) was particularly active in mitigation activities following the devastating Hurricane Hazel in 1954. As a result of the flooding caused by the hurricane, Metro bought all marginal floodplain land and rezoned it as public parkland (Environment Canada, 1996). It has been suggested that newly developed shoreland in Metro's neighbouring municipalities is vulnerable to flooding during a period of high water levels in the Great Lakes (Grima, pers. comm.).

### *7.2.5 Public Institutions*

Other publicly funded institutions such as universities and public utilities conduct research on natural-hazard mitigation. For example, B.C. Hydro is a world leader in landslide mitigation. The Disaster Research Unit at the University of Manitoba, the Disaster Preparedness Resource Centre at the University of British Columbia (UBC), and the Boundary Layer Wind Tunnel Laboratory at the University of Western Ontario conduct research in hazard mitigation. So do Ontario Hydro, an expert in flooding, Carleton University's natural-hazards group, and UBC's seismic researchers.

### *7.2.6 Insurance Industry*

Aside from its activities in the Alberta Severe Weather Management Society, the insurance industry in Canada has not been very active in mitigating physical impact, though it is beginning to strengthen its role. The Insurance Bureau of Canada (IBC) has undertaken a three-year project to study earthquake-mitigation techniques. The insurance industry has not yet offered financial incentives to individuals to implement mitigation techniques in homes and businesses.

In the United States, where the costs of natural hazards have been much greater, insurers have been promoting mitigation through two programs. First, the Insurance Institute for Property Loss Reduction (IIPLR), a non-profit organisation, was established by 300 firms that write more than half of U.S. property insurance premiums. IIPLR's mission is to conduct research and to disseminate pertinent information to the public. It has been working with city and state officials in Los Angeles to set up a program to assist residents in retrofitting homes to make them more resistant to damage from earthquakes (Covaleski, 1995).

Second, the U.S. Insurance Services Office (ISO) rates the effectiveness of local enforcement of building codes. Its Building Code Effectiveness Grading Schedule allows insurers to vary premiums, depending on local enforcement (Covaleski, 1995). In Florida, an estimated 25 to 30 % of losses from Hurricane Andrew could have been avoided, had codes been enforced; the state now forces municipalities to pay a surcharge for not participating in the ISO's building-code-rating program.

### *7.2.7 Individual Homeowners*

Individual homeowners can protect their property through structural and non-structural modifications. Structural measures include anchoring the foundation, strengthening the foundation, bracing walls and posts (for homes built on hillsides), bracing the garage if there are rooms above it, and bracing or replacing the chimney. Non-structural measures include shutting off utilities, bracing the water heater, reviewing safe or dangerous rooms in the house, replacing cupboard latches, and securing heavy furniture, mirrors, and picture frames (Palm, 1990). The insurance industry and/or government could use financial incentives to encourage or compel such measures.

## 7.3 Financial Mitigation

Individuals and businesses can purchase insurance to protect themselves from the financial consequences of natural disasters. Insurance provides protection from low-probability, high-consequence events. However, should an earthquake hit the lower B.C. mainland, several large insurance companies would probably be unable to meet their policy holders' claims and would be forced into bankruptcy.

Lessening the effect of this underfunded liability and its consequences, discussed in Chapter 6, is the responsibility of three groups – federal regulators, provincial regulators, and the insurance industry itself.

### *7.3.1 Federal Regulators*

Federal and provincial governments regulate the property-and-casualty insurance business. The federal Office of the Superintendent of Financial Institutions (OSFI) deals primarily with the solvency and stability of companies registered under federal statute. Its mission is to regulate financial institutions and pension plans under federal jurisdiction in order to contribute to public confidence in the Canadian financial system. The OSFI's Property and Casualty Insurance Division supervises and regulates all federally incorporated and registered property-and-casualty insurance companies. It also conducts examinations of Manitoba- and Newfoundland-based, provincially registered companies.

In 1994-95 there were 231 federally registered and supervised companies in that field, of which 98 were incorporated in Canada. The division reviews companies' operation results, analyses financial ratios derived from information obtained, and discusses its findings with companies' officials. It also carries out on-site examinations and oversees winding-up of companies in liquidation.

Research into the size of the industry's underfunded liability is currently under way. OSFI is conducting a survey of all property-and-casualty reinsurance companies in Canada. It hopes to determine how firms calculate their earthquake exposure, using the risk models described in Chapter 6. Results are expected in late 1996/early 1997. OSFI will release guidelines on the best method for calculating earthquake exposure sometime in 1997.

### *7.3.2 Provincial Regulators*

Provincial superintendents of insurance supervise insurers operating under provincial charters. However, they also help supervise terms and conditions of insurance contracts and licensing of companies, agents, brokers, and adjusters (IBC, 1994a). They also seek to ensure public confidence in the insurance industry by monitoring its activity.

In British Columbia, the Financial Institutions Commission, or FICO, regulates provincially registered insurance companies. The legislation that FICO administers provides rules and guidelines intended to ensure that financial institutions operate prudently and that consumers receive sufficient information for making decisions. FICO has the authority to deal with breaches of standards (Government of British Columbia, 1995).

As of 31 March 1994, there were 190 property-and-casualty or general insurance companies in British Columbia. More than 90 % are federally incorporated or registered. All insurance companies authorized to conduct business in the province must belong to the Property and Casualty Insurance Compensation Corporation (PACICC – see below). FICO reviews annual submissions and conducts on-site examinations of companies incorporated in British Columbia.

### *7.3.3 Insurance Industry*

The Property and Casualty Insurance Compensation Corporation (PACICC) is an industry-operated mechanism for protecting policy holders against isolated insolvencies caused by "normal" insurance risks (IBC, 1994a). PACICC was formed in 1988 as a non-profit organization. The maximum possible recovery from PACICC is 70% of unearned premiums ($1,000 limit) and $250,000 in respect of all claims that arise from each policy issued by the insolvent insurer (IBC, 1994a)[1].

PACICC operates through after-the-fact assessment. It does not collect any premium in advance of any payout and does not have reserves for meeting future liabilities. In the event of a payout, current PACICC by-laws provide for an assessment levied on all licensed insurers in the province of the insolvent insurer, in accordance with their share of total gross premiums written in the province. This levy can be at most 0.75% of the insurer's gross premium (IBC, 1994b).

However, many in the industry feel that if a catastrophe such as an earthquake in British Columbia occurred, PACICC would be unable to meet incurred losses. Consequently, the industry, through the IBC, has proposed changes to the federal *Income Tax Act* and other federal regulations to help reduce potential losses from a devastating earthquake. First, the industry seeks to add earthquake-related risks to the additional policy reserves permitted under Regulation 1400f to the act. The industry would not have to pay taxes on premium income during years when no earthquake occurred. Second, IBC recommends adding a provision to the act that segregates investments relating to earthquake reserves and to allow the income on those investments to accrue untaxed. Third, it seeks to work with the B.C. and Quebec governments to provide an interim credit facility until the industry was able to build up sufficient reserves – approximately 24 years (IBC, 1994a). Were an earthquake to strike and the facility be called on, funds would be repaid from future premiums over a mutually agreeable period. Through these efforts, the industry hopes that it can build reserves adequate to prevent widespread insolvency following an earthquake.

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[1] At the April 3rd 1997 annual meeting, PACICC set up a pre-funded Compensation Fund to accumulate $30 million over a 3-year period beginning in 1998.

The IBC is also recommending that governments dedicate a portion of expenditures to preventing earthquake losses, including setting up tax incentives to encourage individuals to act (IBC, 1994a). Insurance companies are also asking the B.C. government to remove the requirement that fire following earthquakes be covered under normal homeowner's policies (Ross, pers. comm.). Such action would allow insurers to price earthquake risk efficiently. Over time, it could also reduce underfunded liability.

## 7.4 Summary

To summarize, physical mitigation is performed by all levels of government. Involvement of local governments is crucial to reducing the physical impact of natural hazards. Provincial governments can ensure that this occurs. Moral suasion has caused some individuals to take preventive action in their homes and businesses, but financial incentives could increase these efforts. The property-and-casualty insurance industry faces a large, underfunded liability because of its earthquake exposure. Whether or not the federal government will respond positively to its request for reduced taxes while it builds a reserve remains to be seen. The insurance industry also awaits the response of the B.C. government to its request for separate policies for fire following earthquakes.

## References

City of Calgary. (1996). *Internet Home Page*, (http://www.gov.calgary.ab.ca).

City of Vancouver. (1996). *Internet Home Page*, (http://www.city.vancouver.bc.ca).

Covaleski, J. (1995). Mitigation catastrophe losses. *Best's Review* (December): 42-97.

Environment Canada. (1996). *Main Estimates, Part III*. Department of Finance, Ottawa.

Federal Emergency Planning Agency (FEMA). (1996). *Internet Home Page*, (http://www.fema.gov/homepage.html).

Government of British Columbia. (1995). *Canada-British Columbia Agreement Respecting Floodplain Mapping, Annual Report 1993-1994*. Government of British Columbia, Victoria.

Government of Ontario. (1996). *Internet Home Page*, (http://www.gov.on.ca).

Government of Saskatchewan. (1996). *Saskatchewan Emergency Planning*. Government of Saskatchewan, Regina.

Grima, L. (personal communication). University of Toronto, 1996.

Insurance Bureau of Canada. (1994a). *Canadian Earthquake Exposure and the General Insurance Industry: A Proposal for Action*. IBC, Toronto. October.

Insurance Bureau of Canada. (1994b). *Canadian Earthquake Exposure and the General Insurance Industry, Part II: Financial Impact Analysis*. IBC, Toronto. February.

Newton, J., Myers, M. F. and Monday, J. (1996). *A Comparative Assessment of Flood Damage Reduction Initiatives in Canada and the Unites States – Preliminary Research Design*. Prepared for the Environmental Adaptation Research Group, Environment Canada.

Palm, R. (1990). *Natural Hazards: An Integrative Framework for Research and Planning*. John Hopkins University Press, Baltimore.

Petak, W.J. and Atkinson, A.A. (1982). *Natural Hazard Risk Assessment and Public Policy: Anticipating the Unexpected*. Springer-Verlag, New York.

Ross, A. (personal communication). SOREMA, 1996.

# 8.0 Preparing for an Emergency

*by Lindsay Wallace*

## 8.1 Introduction

*After mitigation, the second phase in the human-response cycle is emergency preparedness – development and practice of emergency plans to respond to natural hazards and monitoring of the geophysical and atmospheric environment to allow for timely hazard warnings. Responsibility for these activities rests with various agencies, as laid out in legislation, regulations, and by-laws, as well as by custom and practice. This chapter examines emergency planning in detail and then briefly summarises federal and provincial duties concerning hazard warnings and environmental monitoring.*

## 8.2 Emergency Planning

During a time of crisis, such as a severe natural disaster, having a response plan can increase the effectiveness of response efforts. Testing emergency plans is also an effective way to strengthen emergency preparedness and to uncover weaknesses in current capabilities and plans. This section describes emergency planning by the federal government, joint federal-provincial bodies, provincial governments, municipalities, business and the insurance industry, and individuals.

### *8.2.1 Federal Government*

*Emergency Preparedness Canada (EPC)*

EPC, which is part of the Department of National Defence, coordinates federal emergency planning and preparedness, which involves at least the 14 departments listed below. It has four areas of responsibility:

1. It monitors potential and actual emergencies from the Government Emergency Operations Co-ordination Centre in Ottawa. The centre operates around the clock and monitors national and international media as well as weather services.
2. It trains emergency planners from all levels of government at the Canadian Emergency Preparedness College (CEPC) at Arnprior, Ontario.
3. It promotes the awareness of emergency preparedness through the SAFE GUARD program
4. EPC finances the Joint Emergency Preparedness Program (JEPP), which provides funds for provincial preparation for emergencies (see Section 8.2.2).

The *Emergency Preparedness Act* requires each federal minister to plan and prepare for emergencies related to his or her normal area of responsibility, and helps departments to develop and maintain appropriate arrangements (EPC, 1994). Consequently, every minister must provide services and expertise to other governments and federal departments (EPC, 1995).

*Agriculture and Agri-food Canada (AGAFC)*

AGAFC oversees the agricultural sector of Canada. It develops and maintains civil emergency plans for dealing with the agricultural effects of droughts, floods, and other natural disasters.

*Canada Mortgage and Housing Corporation (CMHC)*
CMHC is responsible for developing plans to provide emergency shelter for refugees, evacuees, or homeless victims of disasters. It does so in collaboration with Health Canada and the relevant provincial authorities. CMHC must also plan for temporary emergency lodging in available vacant housing under its control.

*Canadian Heritage*
Canadian Heritage maintains Canada's national parks, national historic sites, and other areas of historical significance to the country. It is responsible for developing plans for responding to emergencies in or on national parks, historic canals, national historic sites, and other properties and facilities over which it has jurisdiction.

*Environment Canada*
Environment Canada has a mandate to develop and maintain civil emergency plans for:

- conducting observations and forecasts of the weather system;
- recommending alterations to the volume of water in national and international waterways, to accommodate unusual water flows, and to alleviate ice jams;
- ensuring equitable apportionment of available water-supply.

Environment Canada also promotes awareness of tornado threats through Project Tornado – a one-day seminar to aid municipalities in developing emergency plans in response to tornado threats (Cutler, 1994).

*Fisheries and Oceans*
The Department of Fisheries and Oceans (DFO) is responsible for Canada's fisheries and for regulating activities in inland and ocean waters. The Canadian Coast Guard falls under its jurisdiction. DFO is required to develop and maintain civil-emergency plans for:

- ice-breaking in navigable waters in response to emergency situations;
- provision of hydrographic and oceanographic information, including navigational charts, sailing directions; monitoring of currents, tides, and water levels, and related model simulations and predictions.

*Foreign Affairs and International Trade*
The Department of Foreign Affairs and International Trade (DFAIT) deals with political and trade relations with other countries. It is responsible for the Canada–United States Agreement on Emergency Planning, signed in 1986, which outlines 10 principles of cooperation intended to make possible bilateral arrangements in civil emergency planning to deal with emergencies along the border.

*Health Canada*
Health Canada has a mandate to develop and maintain civil emergency plans for:

- establishing, procuring, and maintaining national stockpiles of medical and health supplies, including reception-centre kits, to be used in an emergency;
- allocating these supplies as required for use in emergencies;
- providing advice on emergency health standards for food, water, drugs and pharmaceuticals, and exposure to hazardous environments (radiological, chemical, or biological);
- providing advice and assistance to provincial authorities responsible for delivery of emergency health and social services.

*Indian and Northern Affairs Canada (INAC)*
INAC fulfils Canada's fiduciary responsibilities to First Nations peoples and has jurisdiction over Yukon and Northwest Territories. It is required to develop and maintain plans for lessening the effects of emergencies on Indian and First Nations reserves. These plans must include arrangements for temporary community evacuations and for assistance by provincial and territorial emergency services. The department also coordinates federal assistance and response to emergencies occurring in Yukon and Northwest Territories. It does so in support of First Nations reserves and in response to requests from territorial authorities.

The department has been devolving powers to First Nations communities, including those for emergency preparedness. Through its First Nations Emergency Preparedness Initiative, it helps communities to plan emergency measures and provides expert managers to help deal with emergencies on reserve lands (Government of New Brunswick, 1996).

*Industry Canada*
Industry Canada provides government support to business. In telecommunications, it has a mandate to

- develop telecommunication contingency plans;
- develop an emergency broadcast system (EBS) in collaboration with provincial and territorial governments and the telecommunications industry (currently focused on development of an All Channel Alert system in collaboration with Environment Canada);
- chairs 10 Regional Emergency Telecommunications Committees (RETCs) and a National Emergency Telecommunications Committee (NETC);
- develop at Canadian Emergency Preparedness College courses on managing emergency telecommunications.

*Natural Resources Canada (NRCan)*
Natural Resources Canada oversees development of Canada's geological resources. Through the Geological Survey of Canada, NRCan can offer seismological information and advice to help other agencies understand the occurrence and intensity of earthquakes, eruptions, subsidence, tsunamis, and electromagnetic storms.

*Public Works and Government Services Canada (PWGSC)*
PWGSC maintains infrastructure – for example, buildings owned by the federal government. It has a mandate to plan federal response to emergencies involving or affecting government properties or facilities. It is also responsible for planning for assistance to provinces requesting emergency response support, through such means as acquisition of engineering and construction resources or services, particularly from outside the affected province.

*Solicitor General Canada*
The Solicitor General, in conjunction with the RCMP, CSIS, and the Canadian Correctional Services, must develop and maintain civil emergency plans for use and operation of correctional facilities. It is also responsible for planning for the safety and welfare of prisoners during an emergency. As the department responsible for the RCMP, it also plans for assistance by the RCMP to federal departments, provinces, and municipalities in the maintenance of public order.

*Transport Canada*
Transport Canada's responsibilities include federally regulated ports, harbours, and airports. It is responsible for emergency plans in five areas:

- coordinating civil transportation resources and services;
- responding to emergencies in or on federally regulated ports and harbours;
- air search-and-rescue emergency plans and search-and-rescue volunteer training;
- federal response to emergencies involving civil aircraft and federally regulated civil airports;
- provision or augmentation of essential air and marine transport services and operations in the north under emergency conditions.

*Treasury Board of Canada*
The Treasury Board Secretariat administers and finances government services; it is responsible for expediting allocation of supplementary funds to cover departmental emergency responses. It must also plan for temporarily amending its own procedures, regulations, or authorities to avoid delay in provision of federal resources, services or assistance.

### *8.2.2 Joint Federal-Provincial Initiatives*

*Joint Emergency Preparedness Program (JEPP)*
EPC runs the Joint Emergency Preparedness Program (JEPP), whereby Ottawa funds projects that improve national emergency preparedness. The federal government shares costs of projects with provinces, which in turn provide funds to local governments. Eligible projects include emergency planning, emergency preparedness training, and acquisition of emergency equipment (EPC, 1995). The program is financed at an annual rate of almost $6 million.

JEPP was conceived to encourage federal and provincial/territorial governments to enhance capability to meet emergencies of all types. It also seeks to ensure reasonably uniform emergency services across the country. Projects funded must be receiving resources from federal, provincial, and territorial governments. The federal contribution is negotiated in each case and depends on the nature of the project, the number of other projects under consideration, and the amount of funding available (EPC, 1991).

In Newfoundland, the federal government recently provided $269,320 through JEPP for a variety of projects (Government of Newfoundland, 1996). One included purchase of a mobile training and emergency-response vehicle for the Newfoundland and Labrador Emergency Measures Organization (EMO). The vehicle can also be used as a back-up during emergencies.

In Saskatchewan, the provincial government co-ordinates delivery of the JEPP program with Emergency Preparedness Canada. In 1994, Saskatchewan received federal grants of over $91,700 to assist municipalities acquire emergency preparedness equipment. The federal government also gave $131,800 to provide training and consultative services for municipalities (Government of Saskatchewan, 1995).

*CANATEX 2*
EPC also assists provinces in development of disaster exercises. The CANATEX 2 national exercise was a joint federal-provincial test of the National Earthquake

Support Plan, the British Columbia Earthquake Response Plan, and the Alberta Support Plan (EPC, 1995).

### *8.2.3 Provincial Governments*

All provinces have some form of emergency-preparedness organisation whose size and scope depend on the size and vulnerability of the province. Most natural- hazard emergencies occur at the provincial level (EPC, 1995) and do not require federal involvement. Provincial emergency-measures organisations prepare plans for response activities and encourage and/or mandate local communities to do the same. Each of the provinces and territories has legislation covering emergency management, including local responsibilities as well. Quebec, Alberta, and British Columbia compel all towns and municipalities to write an emergency plan and test it regularly. Ontario encourages municipalities to have an emergency plan (EPC, 1995). This section describes emergency planning in British Columbia, Alberta, Saskatchewan, Ontario, and Newfoundland.

The focus of a province's emergency-measures organizations depends on the most significant threat to the well-being of residents. For example, Emergency Measures Ontario considers a nuclear accident the worst possible hazard. Therefore planning for such an accident is its main concern. Worse case scenario planning induces the development of systems that will allow the province to cope with a less severe disaster. Ontario is currently rewriting its response plan for a nuclear accident (Government of Ontario, 1996).

*British Columbia*

British Columbia is highly vulnerable to an earthquake threat. The Provincial Emergency Program (PEP) plans for earthquakes and other hazards. Operating out of the Ministry of the Attorney General, PEP has developed comprehensive responses, including the Earthquake Response Plan, the Flood Plan, and the Tsunami Warning Plan. It also helps municipalities to develop emergency plans (Government of British Columbia, 1994). PEP is mandated to perform five activities:

- to prepare and maintain a study of hazard, risk, and vulnerability that identifies potential emergencies and disasters that could affect all or any part of British Columbia;
- to assess the potential impact on people or property of these emergencies and disasters;
- to recommend to the Attorney General strategies for emergency prevention, preparedness, response, and recovery;
- to help other ministers develop and implement multi-ministry or multi-agency emergency plans and procedures;
- to help local authorities develop emergency-management organisations and emergency programs (Government of British Columbia, 1996).

PEP also has responsibility for secondary preparedness:

- providing training and training exercise programs for individuals or organisations concerned with emergency planning and operations;
- providing advice and assistance to business and industry in relation to emergency preparedness, response, and recovery;
- assisting in co-ordination of emergency plans between local authorities and provincial crown corporations, and government agencies (Government of British Columbia, 1996).

An Inter-Agency Emergency Preparedness Council chaired by PEP co-ordinates inter-ministerial emergency planning. It recommends measures for emergency preparedness to each minister and helps him or her to co-ordinate emergency plans and procedures with those of all other ministers and with the government's overall strategies for emergency preparedness.

*Alberta*

In Alberta, there is a Disaster and Emergency Programs Division in the Ministry of Transportation and Utilities. It has developed National Emergency Arrangements, the Model School Disaster Plan, the Health Care Facility Evacuation Plan, a Government Emergency Operations Plan, and even a support plan for a Catastrophic British Columbia Earthquake. A number of projects are currently under way, including:

- establishing an emergency public-warning system;
- developing a line-load control program to prevent overloading of the telephone system during an emergency;
- identifying significant resources and facilities in the province;
- developing a planning guide for disaster recovery for government departments (Government of Alberta, 1995).

*Saskatchewan*

Saskatchewan Emergency Planning (SEP) is part of the Ministry of Municipal Government and is mandated to prepare government and private organisations to limit the effects of a disaster (Government of Saskatchewan, 1996). SEP prepares contingency plans for natural disasters. Government departments prepare their own contingency plans and take part in provincial emergency planning. Saskatchewan's system of emergency preparedness includes 12 resource centres that will act as assembly areas for emergency organisations. These facilities also have telecommunication capabilities that can connect resource personnel to municipal centres (Government of Saskatchewan, 1996).

The Community Preparedness Section of SEP seeks to ensure that communities have prepared emergency plans. SEP sees local planning as crucial and offers education, training, and advisory services (Government of Saskatchewan, 1996). It also encourages municipalities to establish emergency-measures organizations.

*Ontario*

Emergency Measures Ontario (EMO) develops emergency plans for the province and encourages municipalities to do the same. It offers emergency-preparedness training, technical advice, and public education. It is located within the Ministry of the Solicitor General and has three branches. Provincial Preparedness manages the Provincial Emergency Plan, co-ordinates inter-ministry/agency preparedness and responses, and operates the Provincial Operations Centre, where ministers would meet during an emergency to co-ordinate responses. Community Preparedness helps municipalities and First Nations to develop community emergency plans and exercises. Training and Administration conducts training courses on emergency preparedness (Government of Ontario, 1996).

Co-ordination among responsible officials in Ontario is constant. Emergency Measures Ontario, for example, sends daily situation reports about current emergencies to 10 other provincial ministries and Emergency Preparedness Canada. Other agencies involved include the Emergency

Health Services Branch of the Ministry of Health. It ensures provision of ambulance services across the province by licensing private, municipal, volunteer, and hospital-based ambulance services (Government of Ontario, 1996).

*Newfoundland*
The Emergency Measures Division of the Ministry of Municipal and Provincial Affairs has four specific responsibilities. First, it must direct emergency planning for the provincial government and its agencies. Second, it must advise and assist municipal governments in emergency planning and third, it does likewise for industry. Fourth,it provides training for provincial government staff, municipal officials, volunteers, and the public.

### 8.2.4 Municipal Responsibilities

Just as all mitigation efforts are local, so emergency planning falls within local jurisdiction. Mayors and other heads of local governments are responsible for emergency plans and their regular testing (EPC, 1995). This section discusses some activities undertaken by Regina and Vancouver.

*Regina*
Regina is an example of a medium-sized Canadian city that is vulnerable to a number of hazards, including hail storms, tornadoes, and flooding. Its emergency preparedness illustrates the types of activities performed at the municipal level. In Saskatchewan, community authorities are legally responsible for emergency preparedness. Consequently, municipal plans are submitted to SEP for review. Sometimes, these plans include protective services for adjacent areas or mutual-aid agreements with neighbouring communities (Government of Saskatchewan, 1996). Regina's emergency planning co-ordinator has plans in place to respond to any disaster or emergency. These plans co-ordinate the efforts of all rescue, emergency-medical, police, environmental-protection, fire-suppression, disaster-relief, and other personnel so as to make the response efficient and appropriate, while minimising loss of life, injury, and family or social disruption (City of Regina, 1996).

*Vancouver*
The type of emergency planning required by a community depends on its most threatening hazard – in Vancouver, earthquake, and the devastating fires that could follow. The Munich Re study of the impact of an earthquake in the lower B.C. mainland suggested that Vancouver upgrade its firefighting capabilities (Munich Re, 1992). In response to this and other assessments, the city has improved its emergency planning and strengthened its ability to respond. The new programs are designed to strengthen the city's infrastructure, inform residents, and train employees to deal with emergencies.

The city is building a new regional emergency-operations and -communications centre (RECC). The facility, designed to withstand an earthquake of magnitude 8.5 on the Richter scale, will support police- and fire-dispatch operations, the regional 9-1-1 system, the city's emergency-response centre, a regional office for the Provincial Emergency Program, and an emergency coordination centre. Housed in the same building will be representatives from B.C. Ambulance Service, B.C. Hydro, B.C. Telephone, B.C. Transit, Canadian National (on behalf of five railways), local port authorities, the provincial government, the RCMP, Vancouver Hospital (on behalf of regional hospitals), and offices of all communities in the Greater Vancouver Regional District: Burnaby, Delta, Langley City and district, New Westminster, Surrey, Vancouver, and White Rock. North Shore municipalities and B.C. Gas may also participate. Though B.C. Ambulance dispatch for the southern part of the city and the Ministry of Transportation and Highways (MOTH) will not be involved, development of the site will provide for their accommodation in the future (City of Vancouver, 1996).

The aim of the facility is four-fold. First, it will provide more rapid implementation of mutual aid when required. Second, it ensures communication capabilities after a major earthquake. Third, it will provide for better coordination of first-response emergency agencies through sharing of information and technologies, including radio systems. Fourth, it will provide large economies of scale by allowing all agencies and jurisdictions to use state-of-the-art technologies at a fraction of the cost (City of Vancouver, 1996).

Vancouver is also launching a "neighbour helping neighbour" program to offer training to communities in skills needed to cope immediately following a disaster. Past events in California, Mexico and recently in Kobe, Japan, have shown that 80 % of all life-saving rescues were accomplished by civilian groups acting without the assistance of trained emergency responders (City of Vancouver, 1996). The Neighbourhood Emergency Response Team (NERT) program will provide limited training in damage assessment, firefighting, first aid, and light urban search and rescue. NERTs are based on the premise that affected areas of the city may have to rely on their own resources for the first seventy-two hours after a disaster. The primary goal of the program will be to encourage citizens towards self-sufficiency, with stored emergency food, water, medicine, and sanitation supplies for these first, critical three days. The program will provide training and information enabling residents to assemble a personal survival kit designed for their family, including information on food, water, and sanitation systems. This program is being run by Vancouver Fire Services (City of Vancouver, 1996).

Additionally, Vancouver has increased its knowledge of emergency preparedness. More than 3,500 civic employees have received basic training in emergency preparedness. Specialized courses for staff in key response roles are available through the Provincial Justice Academy.

Area municipalities and the Provincial Emergency Program have established a joint emergency-liaison committee, made up of senior municipal and provincial representatives, which is developing strategies and protocols to ensure that emergency planning is coordinated between municipalities and provincial ministries (City of Vancouver, 1996).

City departments, in conjunction with local hospitals, are undertaking a pre-design study on the feasibility of several reservoirs to store drinking water. Were Vancouver to be hit by an earthquake, many if not all water mains would be destroyed. If approved, construction of the first reservoir would occur during 1997-98.

The city of Vancouver is also improving its response capabilities for an emergency. Ensuring that emergency organizations can respond to a disaster is an important element in emergency planning and the city has addressed three areas of weakness. First, as noted above, Vancouver's water-distribution mains are vulnerable to disruption following an earthquake. The mains are constructed from cast iron, and the principal line bringing water from the Capilano watershed across Burrard Inlet passes over an alluvial fan (Munich Re, 1992). Consequently, damage to it would affect provision of water for consumption and firefighting. In response, the city has implemented a $40-million project to develop saltwater pumping stations to provide water for firefighting, in the event of such a disruption. The pumping stations are designed to withstand an earthquake up to 8.5 on the Richter scale; using fuel tanks they would be able to operate for up to five days without refuelling. Each station is equipped with a back-up generator, emergency food and water for operators, and other equipment allowing them to operate completely self-contained for many days, if required (City of Vancouver, 1996).

Second, a three-year project to develop a specialized, multi-disciplinary, heavy urban search-and-rescue team began in 1995. The team, which includes fire, police, engineering, and ambulance personnel, would use specialized training and equipment to extricate victims from collapsed buildings (City of Vancouver, 1996).

Third, the city continues to develop a volunteer-based emergency social-services program to coordinate provision of food, emergency shelter, clothing, and basic medical services to disaster victims. It hopes to have these services in place within the next few years (City of Vancouver, 1996).

### 8.2.5 Business and the Insurance Industry

*Claims Emergency Response Plans (CERPs)*
CERPs are the emergency plans (one for each province) set up by the property-and-casualty insurance industry to respond to claims resulting from all major natural disasters where multiple payments are expected. The activities of insurers as outlined in this series of ten provincial plans have been coordinated with emergency-response officials, and their effectiveness has been tested in several mock disasters, including the recent federal CANATEX 2 exercise discussed in section 8.2.2 (IBC, 1994). The plans allow for a coordinated response by the insurance industry to its customers following a disaster. Personnel are shared among the various companies, as assigned at the time by a provincial claims committee, and the plans allow employees closest to the disaster to determine the appropriate level of response. The Insurance Bureau of Canada (IBC) registers qualified claims personnel in each member company who could be evacuated to the emergency if necessary. Officers handle claims on a "worst-comes-first" basis.

*Emergency Preparedness for Industry and Commerce Council (EPICC)*
EPICC is a non-profit business group formed in 1991 to help B.C. businesses and crown corporations to recover from all types of disasters. Members sponsor research, seminars, and distribution of information concerning pre-emergency planning to the wider business community. A recent survey conducted by EPICC found that 60 government departments, crown corporations, and private enterprises spent close to $2 million on earthquake response and recovery plans (IBC, 1994d).

*Planning for Resumption of Business*
Planning for resumption of business has become a major business in North America, particularly along the west coast. Many organizations help businesses to prepare emergency plans to mitigate the effects of natural disasters and to minimize "downtime" following a disaster. For example, the Canadian Imperial Bank of Commerce has developed a wide range of emergency plans enabling it to resume operations soon after a disaster. The planning process involved identifying key units and establishing a centre for business-resumption operations for them.

### *8.2.6 Individuals*

When a disaster strikes, it is important for individuals to have their own emergency plan. While there is no legal requirement to do so, it is a prudent activity. A variety of organisations provide information and support to help people prepare for emergencies. Preparation can include setting up family emergency plans, purchasing home survival kits, ensuring a weeks supply of food and water is stored following the emergency, and obtaining training in first aid.

## 8.3 Warnings and Monitoring

Emergency planning must include provision of timely warnings for the public about upcoming hazards. In particular, weather hazards, floods, tsunamis, and wildfires are relatively slow and predictable, allowing time for warnings. Earthquakes, other geophysical hazards, and some severe storms, however, often strike with no warning.

In Canada, the federal government is chiefly responsible for monitoring the environment and warning citizens about impending disasters, except for tsunamis, which are a B.C. provincial responsibility; in general, the provinces and municipalities disseminate information provided to them by federal agencies.

### *8.3.1 Federal Government*

The federal government is the primary provider of environmental monitoring and emergency warning in the country. Environment Canada and Natural Resources Canada are responsible for ensuring that their provincial and municipal counterparts are warned of upcoming hazards in a timely manner.

*Environment Canada*
Environment Canada is the primary meteorological agency in Canada. It issues timely forecasts and warnings to enable Canadians to protect themselves from severe weather (Environment Canada, 1996). It issues and delivers scheduled public forecasts for nearly 200 regions and severe-weather warnings when required. Meteorologists in 17 Eco-Action Offices across Canada forecast significant weather, including severe events (Environment Canada, 1996).

The department has also, with Industry Canada, developed the weather-radio and weather-copy networks. These networks (which use radio and wire services, respectively) can get warnings to approximately 95 % of the Canadian population. An all-channel-alert (ACA) system, using crawler warning messages at the bottom of television screens, is currently in the pilot stage and, if successful, should be installed at cable stations across Canada in late 1997 (Environment Canada, 1996).

*Natural Resources Canada*
The Geological Survey of Canada's Canadian National Seismograph Network operates

nearly 100 seismographs across the country. These instruments detect more than 1000 earthquakes each year, most of which measure less than a magnitude of 3 on the Richter scale and are not felt by humans. The purpose of this monitoring is to alert essential government agencies of seismic activity so as to help protect the lives of Canadians.

The Canadian Forest Service provides national monitoring and forecasting reports on conditions related to fire – weather, behaviour, severity - and on fire-management criteria and indicators throughout the country. Using the Canadian forest-fire behaviour prediction (FBP) system, the Forest Service offers quantitative estimates of fire-spread rate, fuel consumption, fire intensity, and fire description. The system also gives estimates of the size of the fire area (Natural Resources Canada, 1996).

*Other Departments and Agencies*
Responsibility for warnings about tsunamis generally lie with the B.C. government. However, federal agencies rebroadcast warnings in their areas of jurisdiction. Through the Canadian Coast Guard Service, the Department of Fisheries and Oceans is responsible for rebroadcasting tsunami warnings received by the British Columbia Provincial Emergency Plan to all vessels operating in affected areas along the B.C. coast (Government of British Columbia, 1995). Similarly, on receiving a tsunami warning, the Vancouver Flight Service Station of Transport Canada rebroadcasts this message to alert all float aircraft operating in affected areas (Government of British Columbia, 1995), while CBC radio rebroadcasts these warnings to the public. Emergency Preparedness Canada alerts other federal departments of the upcoming tsunami.

### *8.3.2 Provincial Government*

Provincial duties in warning of natural hazards are primarily the broadcast of flood warnings through the ministry of natural resources or the ministry of the environment which monitor water levels in rivers. If a province receives a warning from Natural Resources Canada about a threat of forest fire, it then informs the public. Warnings are issued on a variety of media, depending on the severity of the hazard. Described below are some of the agencies that issue natural-hazard warnings, specifically in British Columbia, Alberta, and Ontario.

*British Columbia*
In British Columbia, the Water Resources Branch of the Ministry of Environment, Lands and Parks monitors water flow. Staff from both the Hydrology Branch in Victoria and regional water-management offices gather and assess information about snowpack and river flow. The Provincial Emergency Program issues tsunami warnings to federal departments, the RCMP, Canadian Forces, provincial emergency-preparedness co-ordinators, radio and television stations, and provincial ministries and agencies (Government of British Columbia, 1996).

*Alberta*
Alberta Environmental Protection issues warnings about forest fire and flood. The Forecasting Section of its Water Sciences Branch disseminates high-streamflow and flood advisories, while its Forest Protection division provides a variety of services, including a twenty-four-hour fire-reporting hotline, fire-hazard maps, and weather updates.

*Ontario*
The Ministry of Natural Resources issues flood warnings and fights forest fires. One of its main objectives is to protect human life, the resource base, and property from forest fires, floods, and erosion (Government of Ontario, 1996).

## 8.4 Summary

Activities to prepare for emergencies include writing and testing emergency plans, strengthening response capabilities, and providing timely warnings when possible. Such activities fall within the mandates of all levels of government; individuals and businesses can also participate. The federal Emergency Preparedness Act requires all departments to prepare and plan for future emergencies, but provincial authorities can manage most natural disasters. Consequently, all provinces have agencies for emergency planning and preparedness. Municipal governments, particularly for highly vulnerable cities such as Vancouver, also have programs. While there is no legal requirement to do so, it is wise for individuals and businesses to prepare emergency plans.

Natural-hazard warnings are provided by both federal and provincial agencies, depending on the type of hazard. Atmospheric hazards are monitored by Environment Canada, and earthquake hazards by Natural Resources Canada. Flood warnings issue from provincial agencies that monitor water levels. In British Columbia, the provincial government provides tsunami warnings to the public and relevant federal agencies.

## References

City of Vancouver. (1996). *Internet Home Page*, (http://www.city.vancouver.bc.ca).

Culter, N. (1994). Environment Canada, Weather and climate services. In: *Proceedings of a Workshop on Improving Responses to Atmospheric Extremes: The Role of Insurance and Compensation*. McCulloch, J. and Etkin, D. (eds.). Toronto, October 3-4.

Emergency Preparedness Canada (EPC). (1995). *Summary of Federal Emergency Preparedness in Canada*. EPC, Ottawa.

Emergency Preparedness Canada (EPC). (1994). *Canada's Emergency Preparedness and Response System*. EPC, Ottawa.

Emergency Preparedness Canada (EPC). (1991). *Joint Emergency Preparedness Programme (JEPP)*. EPC, Ottawa.

Environment Canada. (1996). *Main Estimates, Part III*. Department of Finance, Ottawa.

Government of Alberta. (1995). *Internet Home Page*, (http://www.gov.ab.ca).

Government of British Columbia. (1996). *FICO Internet Home Page*, (http://www.fic.gov.bc.ca).

Government of British Columbia. (1995). *British Columbia Tsunami Warning Plan*. Government of British Columbia, Victoria. June.

Government of British Columbia. (1994). *Emergency Program Management Regulation*. Government of British Columbia, Victoria. December.

Government of New Brunswick. (1996). *Internet Home Page*, (http://www.gov.nb.ca).

Government of Newfoundland. (1996). *Internet Home Page*, (http://www.gov.nf.ca/welcome.htm).

Government of Ontario. (1996). *Internet Home Page*, (http://www.gov.on.ca).

Government of Saskatchewan. (1996). *Saskatchewan Emergency Planning.* Government of Saskatchewan , Regina.

Government of Saskatchewan. (1995). *Saskatchewan Municipal Government, Annual Report 1994-1995.* Government of Saskatchewan, Regina.

Insurance Bureau of Canada (IBC). (1994). *Canadian Earthquake Exposure and the General Insurance Industry: A Proposal for Action.* IBC, Toronto. October.

Munich Reinsurance Company (Munich Re). (1992). *A Study of the Economic Impact of a Severe Earthquake in Lower Mainland B.C.* Munich Re, Toronto.

Natural Resources Canada. (1996). *Main Estimates, Part III.* Department of Finance, Ottawa.

# 9.0 Disaster Response and Relief

*by Lindsay Wallace*

## 9.1 Introduction

*Response activities – the third phase in the human-response cycle –should begin as soon as a disaster is detected. Those involved can mobilise and position emergency equipment; ensure that individuals are out of danger; provide food, water, shelter, and medical equipment; and bring damaged services and systems back into service. This chapter describes emergency responses maintained by the federal government, provincial governments, municipalities, voluntary agencies, business and the insurance industry, and individuals. There follows a section on co-ordination of all these responses and a summary.*

## 9.2 Federal Government

*Responding to National Emergencies*
Federal response to a natural disaster depends on the size of the disaster. In the most dire emergencies, the federal government would implement the *Emergencies Act* (the former *War Measures Act*), which gives it exceptional powers for limited periods. These powers would be required if and only if all other legislation is found too limited to meet the demands placed on the federal government. The act outlines the means whereby a national emergency may be declared and the regulations and orders that may be authorised to deal with it. The act also specifies the consultation that must occur with provincial authorities in order for the act to be invoked (EPC, 1995). The act includes safeguards and constraints on government actions in declaring and acting in a national emergency. It also contains provisions for compensating persons or organisations that suffer loss as a result of invocation of the act (EPC, 1995).
The act defines a national emergency as an urgent and critical situation of a temporary nature that seriously endangers the lives, health, or safety of Canadians and is of such proportions or nature as to exceed the capacity or authority of a province to deal with it. A national emergency would also be declared if such a situation seriously threatened the ability of the government of Canada to preserve the sovereignty, security, and territorial integrity of the country and could not be effectively dealt with under any other law of Canada (EPC, 1995).

The act specifies four types of national emergencies that could justify its invocation:

1. public-welfare emergencies, such as severe natural disasters or major accidents affecting public welfare, that are beyond the capacity or authority of a province to manage;
2. public-order emergencies that constitute threats to the security of Canada and are beyond provincial authority or capacity;
3. international emergencies, such as actions that threaten Canada's sovereignty, security, or territorial integrity;
4. war, including real or imminent armed conflict against Canada or its allies (EPC, 1995).

For the purposes of this study, only the first type of national emergency – related to public welfare – is of interest.

If a national emergency were declared, each federal department and agency would have certain responsibilities. For a public-welfare emergency, EPC would co-ordinate and manage many activities. It would help to execute the responsibilities of the fifteen departments and agencies listed below.

*Agriculture and Agri-food Canada (AGAFC)*
Once a national emergency is declared, AGAFC has five areas of responsibility:

- control and regulation of agricultural production, processing, and storage;
- equitable allocation and distribution of food and agricultural products to the population;
- domestic distribution of seed, feed, fertiliser, pesticides, and farm equipment to agriculture producers;
- provision of financing, seed, water, and equipment to farmers;
- pricing and allocation of strategic and critical food and agricultural materials.

*Canada Mortgage and Housing Corporation (CMHC)*
CMHC has three duties:

- control and regulation of existing real property required for residential purposes, including inventory, allocation, requisitioning, appropriation, and procurement of buildings for residential use;
- control and regulation of the rent, lease, or sale of property used for residential purposes;
- co-ordination and implementation of programs to construct, renovate, repair, or convert urgently required housing and related facilities.

*Environment Canada*
Environment Canada has two responsibilities:

- to place under the federal government's control all meteorological, limnological, and hydrological resources, facilities, and services in Canada, except those operated by the Canadian Forces;
- to provide increased meteorological, limnological, and hydrological support to the Canadian Forces if required.

*Finance*
The Department of Finance pays for proposed emergency measures. It does so through imposition of emergency taxes, financial moratoria, and other fiscal measures.

*Fisheries and Oceans*
The Department of Fisheries and Oceans (DFO) is responsible for:

- controlling all catching, landing, transporting, and processing of fish in collaboration with Agriculture and Agri-Food Canada;
- protecting Canadian fishing vessels, in collaboration with the Department of National Defence, and ensuring their safe havening in collaboration with the Department of Transport;
- requisitioning, procuring, or appropriating such vessels, gear, facilities, and resources as might be necessary to sustain the catching, landing, or processing of fish;
- determining the extent of damage to fishing fleets, landing facilities, and fish-processing plants and establishing the priority for their repair, replacement, or reactivation;
- co-ordinating and managing requests from other federal departments for use of

systems, craft, facilities, and services under its control.

*Health Canada*

Health Canada is responsible for:

- co-ordinating and ensuring provision of emergency medical, nursing, hospital, and public health services;
- in collaboration with provincial authorities, co-ordinating and ensuring provision of emergency social services, including emergency feeding, clothing, lodging, registration and inquiry, and personal services;
- controlling and allocating human resources in health care in conjunction with the Department of Human Resources Development;
- receiving and treating Canadian Forces casualties that exceed the capacity of the Canadian Forces medical facilities.

*Human Resources Development Canada (HRD)*

HRD is the federal agency responsible for welfare and employment services in Canada. As such, during a national emergency is responsible for:

- establishment of a register of human resources that would be used to identify useful persons in emergencies according to their skills;
- control, regulation, allocation, and movement of the civilian labour force, excluding members of the RCMP, regular members of the Canadian Forces, professional health workers, Human Resources personnel and such other persons;
- regulation and control of emergency conditions of work, rates of remuneration, occupational health and safety, and labour/management relations.

*Industry Canada*

Industry Canada would have two main areas of responsibility. First, it would control and co-ordinate industrial production of goods and services not controlled by any other department. It would do so in collaboration with the departments of Public Works and Government Services, National Defence, and Natural Resources. All activities, from extraction of raw materials to allocation and distribution of final output, would be controlled. Second, Industry Canada would direct, control, and regulate essential civil telecommunications resources, facilities, and services.

*Justice*

The Department of Justice drafts laws and administers areas of the justice system that fall within federal jurisdiction, such as the criminal code. In a national emergency, it is responsible for rapid development and processing of orders and regulations pursuant to the *Emergencies Act*, including declaring the national emergency. It is charged with determining whether measures taken pursuant to the act comply with the Charter of Rights and Freedoms and the principles of administrative and constitutional law. It provides advice to cabinet and to principal ministers and departments directly involved in the emergency response and provides legal advice on measures to ensure the continuity of constitutional government during a national emergency.

*National Defence/Canadian Forces*

The Department of National Defence (DND) supports the preparations for civil emergency planned by other federal departments and assist provincial and territorial authorities that request help. In a national emergency, it would mobilise troops and deploy them into the affected area. Personnel provide a variety of services, including manpower and civil protection.

In June 1996, DND set up a Disaster Assistance Response Team (DART). This team is capable of responding rapidly to a request for humanitarian assistance or disaster relief in Canada or abroad. DART is composed of approximately one hundred Canadian Forces (CF) personnel, including an engineering platoon, a medical platoon, an infantry platoon, a logistics platoon, and a communications detachment. DART can address the four most critical needs of emergency situations: medical care, potable water, engineering capabilities, and good communications. A CF CC-130 Hercules aircraft would move DART to a site near the emergency (Department of National Defence, 1996).

Despite DART, some questions have been raised – because of the closing of the CF base in Chilliwack – about the ability of the Canadian Forces to respond to a catastrophic earthquake in British Columbia (Howard, 1996). Troops would have to arrive from Edmonton, twelve hours away, which delay could seriously increase fatalities. Furthermore, several bridges might collapse; making Burrard Inlet and/or False Creek unnavigable and preventing a naval response from the Canadian Forces.

*Natural Resources Canada (NRCan)*
NRCan would control and regulate production, generation, processing, transmission, storage, sale, domestic distribution, export, and import of energy. It would do so in collaboration with the National Energy Board.

*Public Works and Government Services Canada (PWGSC)*
PWGSC has five areas of responsibility:

- co-ordinating acquisition and provision of supplies and equipment through extraordinary regulatory and funding powers;
- developing and implementing measures to regulate industrial production, through provision of advice and assistance to Industry Canada;
- controlling and regulating use of engineering and construction resources;
- providing support to other federal departments or provincial governments in acquiring non-residential accommodation;
- identifying contingency accommodation suitable for temporary use by emergency government agents.

*Solicitor General*
The Solicitor General is responsible for enforcement of extraordinary internal security regulations, as required, in accordance with available emergency powers.

*Transport Canada*
Transport Canada has two areas of responsibility. The first is co-ordinating and managing civil transportation equipment and facilities, including civil airports, ports, harbours, terminals, and canals. It is also responsible for controlling, regulating, and directing operation of all modes or systems of transport, other than those systems, craft, facilities, and services operated by or under control of the Canadian Forces, the Royal Canadian Mounted Police, the Department of Fisheries and Oceans, and Aboriginal peoples. Second, Transport is charged with provision, co-ordination, and insurance of civil aircraft and ships in support of national

and multinational reinforcement, evacuation, logistics, or other movements or operations.

*Treasury Board*
The Treasury Board Secretariat is responsible for the effective administration of federal departments; therefore it formulates and implements government-wide financial orders and regulations based on emergency legislative authority.

Invocation of the *Emergencies Act* does not, however, in any way reduce or impede provincial authority to act on their own territory. For example, in the case of a catastrophic earthquake in British Columbia, the B.C. government retains overall responsibility for management of the crisis, including emergency arrangements with all of its own ministries, agencies, and municipalities. Within the rest of the country the federal government would provide the B.C. government with a reference point for its emergency support requirements (EPC, 1995). Fortunately, the Emergencies Act has not yet been tested.

*Federal Involvement in Provincial Emergencies*
Most disasters fall within provincial jurisdiction. If a province or territory is unable to cope with an emergency, it can formally request federal aid. The federal Emergency Preparedness Act considers an emergency to be in provincial jurisdiction if a single province is affected and that province has sufficient capabilities to deal with them (EPC, 1995).

Ottawa must intervene in a provincial emergency if the emergency directly involves federal property, employees, statutory authority, or responsibilities. It would also automatically intervene if aspects of the national interest were affected. In such a case, there would be federal-provincial consultations between the designated leading organisations and the departments and agencies most directly involved to ensure smooth operation of response efforts (EPC, 1995).

When Ottawa is asked or compelled to intervene in a provincial emergency, the cabinet will assign a federal department to co-ordinate the collective federal effort – usually the department whose normal responsibilities are linked to the type of emergency. For example, Environment Canada would be the "lead" department in the event of a hazardous waste spill. The preceding section indicates the type of responsibilities exercised by each department.

Emergency Preparedness Canada monitors potential and actual emergencies across the country twenty-four hours a day from the Government Emergency Operations Centre in Ottawa. The centre helps the federal government to intervene effectively and quickly in provincial emergencies, should it be asked or compelled to do so. When federal response is required, EPC takes the leading role for a short period until a federal department is chosen.

## 9.3 Provincial Governments

As noted above, most national disasters occur in areas of provincial jurisdiction. Consequently, most provinces have an emergency-measures organisation to co-ordinate activities in an emergency for which federal help was not required. Such a body takes the lead only in situations where local authorities are unable to cope. This section describes disaster response in British

Columbia as an illustration of provinces' ability to respond to natural disasters.

### *9.3.1 British Columbia*

British Columbia has an extensive emergency-response system. The provincial government is responsible for operating emergency responses in unorganised areas, where there is no local government. Local governments are responsible for providing initial response to most emergencies occurring within their boundaries (Government of British Columbia, 1992). They may request assistance from other municipalities, private-sector agencies, the provincial government, or the local offices of the federal government. They themselves, however, retain responsibility for overall direction and control of response operations. In such situations, the province provides support, advice, expertise, or such other assistance as may be requested – similar to Ottawa's supporting role during a provincial crisis.

Under two circumstances, the province takes over emergency responses in areas not under its jurisdiction – if a catastrophe event has rendered local government incapable of responding, or if the emergency is such that local government cannot provide adequate direction and control and has requested provincial assistance (Government of British Columbia, 1992).

In a provincial disaster, each B.C. ministry and government corporation has a number of responsibilities. In this section we look at the role of nine ministries and six government corporations, all of which would, in an emergency, act under the supervision of the Provincial Emergency Program.

*Provincial Emergency Program (PEP)*
Within the Ministry of the Attorney General, the Provincial Emergency Program (PEP) maintains a twenty-four-hour-a-day capability to direct requests for emergency assistance to appropriate municipal, provincial, federal, or private agencies. It would also serve as the point of contact for requests for emergency assistance from and to the government of Canada. It would also organise and administer registered volunteers and temporary workers as requested or detailed in emergency response plans. It would also co-ordinate emergency responses by supporting ministries as requested or detailed in emergency response plans (Government of British Columbia, 1994).

*Agriculture, Fisheries and Food*
The mandate of Agriculture, Fisheries and Food is to advise farmers, aquaculturists, and fishers on how to protect crops, livestock, and provincially managed fish and marine plant stocks. It must also coordinate emergency evacuation and care of poultry and livestock and inspect and regulate food quality. Most important, it would identify food and potable water for use during the emergency and assist the Ministry of Health in inspection and regulation of food.

*Attorney General*
The B.C. Ministry of the Attorney General has several areas of emergency responsibility. It would advise local governments and provincial ministries and government corporations on legal matters relating to emergency orders, regulations, declarations, and contractual arrangements. It also prepares and implements orders relating to law enforcement and internal security through the local police force. It provides advice to local authorities regarding maintenance of law and order and would reinforce local police services. It also

arranges for security control of emergency areas, including traffic and crowd control. Search and rescue for missing persons on land and in inland waters is within its purview. The ministry also provides coroners' services, including temporary morgues, identification of the dead, and registration of deaths (Government of British Columbia, 1994).

*Environment, Lands and Parks*
Environment, Lands and Parks provides forecasts, bulletins, and assessment. It also provides technical services and planning staff at government operation centres in the case of floods and conservation officers to act as special constables to reinforce police forces in maintaining law and order and directing traffic. Dam-inspection services are another area of responsibility (Government of British Columbia, 1994).

*Forests*
The Ministry of Forests is responsible for dealing with wildfire in the province. In an emergency it provides personnel, equipment, supplies, telecommunications equipment, aviation support, and weather information.

*Government Services*
The Ministry of Government Services has three areas of responsibility – providing government aircraft and vehicles; arranging for leasing or purchase of emergency supplies and equipment; and – through the government communications office – co-ordinating the government's emergency information services.

*Health*
The Ministry of Health would be charged with seven areas of responsibility:

- provision of public health measures, including epidemic control and immunisation;
- co-ordination of ambulance services and triage, treatment, transportation, and care of casualties;
- arrangements for continuity of care for persons evacuated from hospitals or other health institutions and for medically dependent persons from other care facilities;
- provision of standard medical units – emergency hospitals, advanced-treatment centres, casualty-collection units, and blood-donor packs;
- inspection and monitoring of potable and safe water and food, with the assistance of Agriculture, Fisheries and Food;
- provision of debriefing for stress brought on by a critical incident and provision of counselling services;
- provision of support and supervision for physically challenged or medically disabled persons affected by an emergency.

*Municipal Affairs*
This ministry co-ordinates fire fighting through the office of the fire commissioner. The importance of this activity, were an earthquake to strike, has been discussed in Chapters 7 and 8.

*Social Services*
This ministry would provide six services:

- food, clothing, and shelter in private or congregated facilities;
- assisting in locating and reuniting of families;
- caring for children not accompanied by a guardian or custodian and for the mentally challenged;
- financial assistance or assistance in kind;
- clothing, food, shelter, registration, and information as required by emergency workers;

- assistance to local authorities in planning and operating emergency social services – feeding, clothing, lodging, registration and inquiry, and personal services (Government of British Columbia, 1992).

*Transportation and Highways*
This ministry is charged with ensuring that highways are clear of debris. It co-ordinates and arranges for transportation, engineering, and construction resources required by the provincial government (Government of British Columbia, 1994).

*British Columbia Ferry Corporation*
The B.C. Ferry Corp. arranges for priority loading for transport of emergency personnel, equipment, and supplies. If necessary, it would also provide ferries to serve as reception centres, hospitals, response centres, or other emergency facilities.

*British Columbia Hydro And Power Authority*
B.C. Hydro co-ordinates restoration of electric facilities, taking into account domestic, commercial, industrial, and government requirements. It would interrupt hydro services when they pose a threat to life or property. And it would conduct safety measures for its dams, including initiating warnings in the event of dam failures.

*British Columbia Rail Limited*
B.C. Rail is compelled to provide priority movement of emergency personnel, equipment, and supplies. At railway crashes and derailments it helps Transport Canada with rescue operations, removal of debris, and clean-up of hazardous material. Other responsibilities include providing rail cars for emergency facilities and providing specialised equipment.

*Other Government Corporations*
The British Columbia Systems Corporation provides technical advice and assistance on acquisition of telecommunications equipment systems and computers.

B.C. Transit co-ordinates public transportation, including school- and privately owned buses.

B.C. Buildings Corporation provides priority allocation of government buildings for operational accommodation, storage, or other emergency requirements. It would arrange for emergency rental or leasing of private buildings or other infrastructure and assess damage to government buildings.

### 9.3.2 Other Provinces

Other provinces have similar arrangements for responding to emergencies. Their ministries have mandates that parallel those of their B.C. counterparts.

One notable exception, however, occurs in Quebec, where civil-security response may take place at the regional as well as municipal and provincial levels. Provincial administrative regions correspond to regional health and social service boards, as well as regional directorates of government departments. The Regional Civil Security Directorate plans for civil security through a directorate composed of representatives from the ministries of Agriculture, Environment, Fisheries and Food, Municipal Affairs, Natural Resources, Social Services and Health, and Transport, as well as the provincial police and the Treasury Board. During a disaster, the directorate may form an organisation to mobilise representatives of these departments and agencies to support municipalities emergency responses (Government of Québec, 1994).

## 9.4 Municipalities

Municipal emergency-response organisations are the first to be activated. Local responses include use of fire, ambulance, and police services and implementation of municipal emergency plans.

The primary activity is implementation of municipal emergency plans. British Columbia requires local authorities to prepare plans respecting preparation for, response to, and recovery from emergencies and disasters (Government of British Columbia, 1994). Ontario does not require plans but encourages and assists municipalities in doing so.

B.C. municipalities may implement their plans without a declaration of an emergency, which invokes extraordinary powers of response, such as restrictions on travel or forced evacuations. A mayor or a regional chair can declare a local emergency for all or any part of the jurisdiction's area and must immediately advise the provincial attorney general and the public in the area. A state of local emergency is valid for seven days and may be extended with the approval of the attorney general or the lieutenant-governor-in-council for periods of not more than seven days each.

*Edmonton*

In order for emergency plans to be effective, response capabilities must be strong. Edmonton, for example, provides a number of emergency response services through different branches of the municipal government. The Fire/Rescue Branch provides firefighting and rescue services, including the fire medical responder (FMR), which helps firefighters with patient assessment and medical care. Emergency Medical Services (EMS) offers ambulance teams divided into Advanced Life Support (ALS) and Basic Life Support (BLS) systems. ALS consists of ambulances staffed with two paramedics; BLS ambulances have two emergency medical technicians (EMT-A). The branch also offers trained air medical escorts for patients being transferred between hospitals (City of Edmonton, 1996).

When dispatched to the scene of a medical emergency, EMS personnel assess injury/illness and provide medical treatment. If ALS care is required to stabilize the patient's condition, paramedics communicate with an emergency-department physician via their two-way radio for orders to administer medication or advanced procedures. The patient is then transported to the appropriate hospital, where EMS staff provide a verbal and written report to the receiving physician (City of Edmonton, 1996).

Edmonton also has a 9-1-1 emergency-response number that links the caller to the Emergency Response Communications Centre (ERCC). All information received by the dispatcher is keyed into a computer, which determines which fire and/or ambulance unit(s) should respond and from which station. After the unit(s) have been dispatched, the dispatcher provides instruction to the caller if there is a person who requires medical attention before personnel arrive at the scene (City of Edmonton, 1996).

Many other Canadian municipalities have response capabilities similar to Edmonton's. As discussed in Chapter 8, Vancouver has recently strengthened its abiliy to respond to an emergency by setting up saltwater pumping stations, a heavy urban search-and- rescue team, and a regional emergency-operations centre.

## 9.5 Voluntary Agencies

In the event of an emergency, at least three national voluntary agencies would assist: the St John's Ambulance, the Canadian Red Cross, and the Salvation Army.

The St John's Ambulance is a national, voluntary, not-for-profit agency founded in Canada over 110 years ago. Its mission is to enable Canadians to improve their health, safety, and quality of life by providing training and community service. Its work in an emergency would be carried out by "The Brigade" – uniformed volunteers who provide first aid at public events and deliver community health care. The brigade also provides back-up services for emergencies and disaster relief. It currently has 12,100 uniformed volunteers, including over 2,000 youths.

The Canadian Red Cross Society is a volunteer-based, humanitarian organisation founded in 1896. It provides disaster assistance to victims of emergencies in Canada as part of local emergency-response plans. It also provides help through partnership agreements with federal, provincial, and municipal governments (Canadian Red Cross Society, 1996).

In Newfoundland, emergency communications will be provided if necessary to the provincial government by the Society of Newfoundland Radio Amateurs (SONRA). SONRA is prepared to provide ham radio equipment and an operator anywhere in the province to assist the province's Emergency Measures Organization.

## 9.6 Business and the Insurance Industry

Businesses that have developed an emergency-response plan would implement it in time of emergency so as to protect their assets and minimise the amount of time that their business activities are interrupted. In the United States, some businesses have supported local emergency response by providing food to evacuees (Tucker, personal communication, 1996). There is no formal agreement for such provision, which tends to occur on an ad hoc basis.

As noted in Chapter 8, the insurance industry has developed a series of Claims Emergency Response Plans (CERPs) which allow for sharing of personnel among insurance companies in the face of a disaster. Teams of registered insurance personnel in the area would assist individual policy holders to file their claims as quickly as possible. Sharing personnel minimises the amount of time required for a claim to clear.

## 9.7 Individuals

According to Emergency Preparedness Canada (EPC), individuals should be prepared to do what is reasonably possible to protect life and property in the event of an emergency (EPC, 1995). In order to minimise the response required, individuals should take the time to protect themselves by implementing mitigation measures and establishing emergency plans for the home. During a disaster, many private citizens volunteer in the clean-up efforts.

## 9.8 Co-ordination

One of the most important aspects of disaster relief is efficient co-ordination within and among levels of government and private relief agencies. For example, when an emergency under provincial jurisdiction is mainly of local or regional concern, the regional director of EPC acts as primary contact between federal and provincial governments to co-ordinate federal assistance. This usually occurs during severe weather, floods, and forest fires.

Within provinces co-ordination is essential. For example, Saskatchewan Emergency Planning (SEP) receives support from ambulance operators, civil air search and rescue, fire departments, municipal police, the RCMP, and the Red Cross. SEP seeks to co-ordinate response efforts with these organisations (Government of Saskatchewan, 1996).

In the case of wildfires, where resources often need to be shared among provinces, the Canadian Interagency Forest Fire Centre coordinates the Mutual Aid Resource Sharing Agreement. This document provides for effective and efficient use of firefighting expertise and resources where they are needed and is often used by provinces to share firefighting personnel (Government of Alberta, 1996). For example, in 1996 Alberta sent over 300 firefighters and support staff to Ontario and Quebec.

## 9.9 Summary

Effective federal, provincial, and municipal capabilities to respond to emergencies are vital to minimizing casualties from natural disasters. All governments have assigned responsibilities internally. Which level of government leads emergency response depends on the severity of the disaster. Non-governmental organizations also support emergency responses. Succinct emergency planning by governments, businesses, and individuals can help ensure effective disaster response.

## References

Canadian Red Cross Society. (1996).

City of Edmonton. (1996). *Internet Home Page*, (http://www.gov.edmonton.ab.ca/city/).

Department of National Defence. (1996). *Main Estimates, part III.* Department of Finance, Ottawa.

Emergency Preparedness Canada (EPC). (1995). *A Summary of Federal Emergency Preparedness in Canada.* EPC, Ottawa.

Government of Alberta. (1995). *Internet Home Page*, (http://www.gov.ab.ca).

Government of British Columbia. (1994). *Emergency Program Management Regulation.* Government of British Columbia, Victoria. December.

Government of British Columbia. (1992). *Provincial Governments Emergency Management: A Strategy for Response.* Government of British Columbia, Victoria. August.

Government of Quebec. (1994). *Civil Security in Quebec, Basic Manual.* Government of Quebec, Sainte-Foy.

Government of Saskatchewan. (1996). *Saskatchewan Emergency Planning.* Government of Saskatchewan, Regina.

Howard, R. (1996). B.C. disaster-relief plans need work. *Globe and Mail, Metro edition,* August 6. p. A4.

Tucker. C. (personal communication). Emergency Preparedness Canada, 1996.

# 10.0 Recovery

*by Lindsay Wallace*

## 10.1 Introduction

*The fourth and final stage of response to a disaster is recovery from the physical and financial effects. Rebuilding can take months, if not years. It also requires that individuals receive the means to begin recovering, in the form of financial assistance and/or payouts from insurance. Costs of natural disasters may be borne by individuals, insurance companies, reinsurers, private businesses, and government. A study in Alberta of the distribution of compensation payments found that 11% of all recovery costs for three events originated in the provincial government's disaster-assistance program. Insurance companies paid over 66%, with the remainder coming from other sources such as business funds, personal funds, and bank loans (Wolsley, 1994). In this chapter we examine the recovery responsibilities – particularly vis-à-vis financial assistance – of the federal government, joint federal-provincial plans, the provincial governments, municipalities, and business and the insurance industry, and the final section examines crop insurance.*

## 10.2 Federal Government

Federal responsibilities for disaster recovery generally lie in two areas. First, Ottawa provides financial assistance to provinces affected by natural disasters. The provinces in turn pass the money along to communities through disaster financial-assistance plans of their own. Second, the federal government funds insurance schemes designed to protect farmers from financial hardships caused by crop losses induced by natural hazards (see section 10.6). This section discusses the roles of federal agencies in implementing financial assistance.

Emergency Preparedness Canada (EPC), aside from its duties discussed in Chapters 7-9, is also responsible for the Disaster Financial Assistance Arrangement (DFAA), whereby provinces can claim financial assistance from Ottawa for meeting the costs of major disasters. Since 1970, DFAA's average annual expenditure has been about $9 million (Peters, 1994).

Under the DFAA, the federal government on request provides financial assistance in accordance with a formula based on provincial/territorial population. Generally, payments are made to restore public works to their pre-disaster condition and to facilitate restoration of basic, essential, personal property of private citizens, farmsteads, and small businesses. Ottawa makes a contribution only when provincial expenditures exceed $1 per capita of population. Ottawa covers half of the next $2 per capita and three-quarters of the next $2 per capita beyond that. Finally, if provincial expenditures exceed this amount, the federal government pays 90% of the remainder.

This formula means that in the event of a large natural disaster, particularly in a province with a small population, Ottawa pays the larger part of the costs incurred. The EPC's regional director represents the federal government and makes arrangements for damage assessment, detailed interpretation of the guidelines, general surveillance of private damage claims, and development of joint federal-provincial teams to review claims for agricultural and public-sector damage. Since its inception in 1970, the DFAA has paid more than $210 million in post-disaster assistance to the provinces (EPC, 1995).

Floods are a recurring natural hazard and a frequent cause of property damage in Canada. The Federal Flood Damage Reduction program, discussed in Chapter 7, is a federal-provincial program to map floodplains and delineate areas of high flood risk with a view to minimising property damage. Once such areas are designated, no assistance is provided under the DFAA, unless a flood is much larger than the flood mitigated for (EPC, 1988).

After a disaster, the province requests assistance from the federal minister of defence. Federal-provincial assessment and appraisal teams review and assess public-sector damage, and insurance appraisers, private-sector damage. Together, these requests form the basis of the overall damage estimates (EPC, 1988).

Ottawa reimburses only eligible costs that meet the criteria in the federal guidelines. Eligible costs in the immediate post-disaster period include rescue, transportation, emergency health care, food and shelter, removal of hazardous material, containment of the disaster area, security, and communication. Post-disaster public-sector costs may include clearing of debris and wreckage, establishment of protective health and sanitation facilities, and repair to pre-disaster condition of roads, dikes, government and public buildings, and utilities (EPC, 1988).

For individuals, eligible costs include restoration and replacement of property, furnishings (including appliances), clothing, and small businesses (including farms) when an individual's livelihood has been destroyed. Individuals receive the provincial minimum wage for their clean-up efforts. Assistance for reconstruction of buildings will be given only once, unless action to avoid recurrence was not feasible (EPC, 1988).

Costs not paid for include anything that could be covered by insurance, vehicles, loss of income, normal operating expenses, and restoration of property owned by large businesses. For the provinces, costs of fighting forest fires are not covered.

There are many situations when government assistance to a large business or industry whose continued operation is vital to the economy of a community may be requested. Such assistance will be made only on an ad hoc basis (EPC, 1988).

In the event of a catastrophic earthquake, it has been estimated that federal assistance to cover losses to roads, bridges, hospitals, schools, and other infrastructure could amount to 90% of all uninsurable losses beyond the first $15 billion, or approximately $12 billion in the worst-case scenario (IBC, 1994d). This figure does not include compensation to policy holders whose insurance companies have become insolvent.

Occasionally, other departments are required to provide expertise to EPC to help administer the DFAA. Agriculture and Agri-food Canada advise and assist provinces and municipalities in determining damage estimates of farms and agricultural lands. They also advise EPC re estimation of agricultural damage and verification of claims for disaster financial assistance. The Canada Mortgage and Housing Corporation provides expert advice and assistance to provincial and municipal authorities concerning assessment of residential damage. It also helps EPC verify claims made under the DFAA.

## 10.3 Federal-Provincial Programs

Two other insurance programs are run jointly by Ottawa and the provincial governments, with financial participation by individual producers. The Gross Revenue Insurance Plan (GRIP) builds on crop insurance by offering producers revenue protection to complement the yield protection offered by the Crop Insurance Program. Through GRIP, producers receive a revenue guarantee for each crop, based on a percentage of their past production and a 15-year, indexed, moving average price. GRIP premiums are shared 33.33% by producers, 41.67% by Ottawa, and 25% by the provincial government. The prairie provinces have left GRIP (Agriculture Canada, 1996).

The Net Income Stabilization Account (NISA), another tripartite program, helps producers with financial management and planning by encouraging them to set aside money in good years for withdrawal in bad times (Agriculture Canada, 1996).

## 10.4 Provincial Governments

Provincial responsibilities for disaster recovery parallel those of the federal government. First, provinces transfer funding received through the DFAA to the municipal governments, through a municipal affairs ministry or the province's emergency-measures organization. Second, provinces deliver crop insurance, usually through agriculture ministries or crop-insurance boards or commissions (see section 10.7). As noted above, each province has some mechanism for transferring federal DFAA funds to municipal agencies or individuals. This section briefly discusses the programs in place in Saskatchewan and Alberta as an illustration of the types of provincial programs currently in place.

### *Alberta*

Alberta's disaster arrangements provide financial assistance following disasters that damage a large portion of the province. The guidelines are similar to the federal guidelines. Over the past ten years, the province has experienced eleven natural disasters, including the 1987 tornado in the Edmonton–Strathcona County area for which it paid $40.2 million to claimants (Wolsley, 1994). Program costs during that time have been approximately $228 million.

### *Saskatchewan*

In Saskatchewan, the Emergency Planning Branch of Saskatchewan's Ministry of Municipal Government, also known as Saskatchewan Emergency Planning (SEP), administers the Provincial Disaster Assistance Program. The program provides financial assistance to eligible claimants located in an area that has been declared eligible for assistance as a result of substantial loss or damage to uninsurable property caused by a natural disaster. A substantial loss is interpreted to mean approximately $1 million in the case of local government property; with private property, total damage in the area must exceed $25,000, or at least one individual must incur $5,000 damage to uninsured property (Government of Saskatchewan, 1995).

The program covers only uninsured damage, so it does not compete with insurance companies. It provides assistance only for restoring essential services and property to their pre-disaster condition. The municipal council must pass a resolution requesting that its area be designated eligible for assistance. When SEP receives this resolution, it reviews the circumstances. If it so designates the area, it sends application forms to municipal offices for distribution to eligible claimants. Once the municipality has collected the claims application forms, government-appointed adjusters inspect and assess the damage (Government of Saskatchewan, 1995).

There is no maximum amount of coverage for damage to a local government's property, but there is a maximum deductible of $1 million. Other eligible claimants are subject to the following deductibles: $500 plus 30% of the eligible costs in excess of $500 or $1,000 plus 30% of the eligible costs in excess of $1,000 in the case of livestock, feed, farm-soil erosion, or a small-business claim (Government of Saskatchewan, 1995).

## 10.5 Municipalities

Municipalities directly cover the costs of few disaster-recovery activities as they usually receive financial aid, and they are not, of course, involved in crop insurance. They are responsible for submitting claims to provincial governments' disaster financial authorities and using the funds to rebuild damaged infrastructure. They are also responsible for ensuring that their residents have access to government claim forms.

## 10.6 Business and the Insurance Industry

Business owners make claims to either their insurance company or the province, depending on the nature of the hazard. Similarly, individuals are responsible for making claims either to their insurance company or to the province, depending on their circumstances.

The insurance industry receives claims made by policy holders and pays out compensation depending on individual policies. Insurance companies also make claims to reinsurance companies for losses resulting from natural catastrophes and other reinsured losses. Reinsurance companies evaluate and pay the claims of insurance companies depending on reinsurance contracts (policies). The problem of defining natural-hazard events has caused arbitrations between reinsurers and insurers (see Chapter 4).

## 10.7 Crop Insurance

### *10.7.1 The Federal Government*

The federal government offers assistance as well through the crop-insurance and income-stabilisation schemes run by Agriculture and Agrifood Canada (AGAFC). The goal of this department is a healthy farm sector that is financially secure and environmentally sustainable and produces safe, high-quality food (Agriculture Canada, 1996c). AGAFC, in collaboration with provincial agriculture ministries, finances crop-insurance programs that seek to provide reasonable coverage for all agricultural commodities in all provinces. However, crop insurance is part of an overall income-stabilisation package. AGAFC also acts as federal reinsurer for provincial crop insurance.

The Crop Insurance Program provides production-risk protection to producers by minimising the economic effects of crop losses caused by natural hazards, such as drought, flood, hail, frost, excessive moisture, and insects. Ottawa is a partner in ten provincial crop-insurance programs. It pays into the programs when provincial insurance schemes meet the terms and conditions of bilateral Crop Insurance Agreements: premium rates must be actuarially sound, the provincial schemes must be self-sustaining, and estimates of probable crop yields must reflect actual yields produced.

Crop insurance costs the federal and provincial governments and producers an estimated $437 million per annum (Agriculture Canada, 1996b). Producers pay 50% of premium costs, with federal and provincial governments splitting the balance. Direct administration costs were $68 million in 1994-95, split between the two levels of government. The 1995 federal budget stated that approximately 20% of the federal contribution to administrative fees would be recovered from individual producers on a user-pay basis. Costs of the program are expected to rise in 1996-97 because of the higher insured values resulting from unseasonably high commodity prices (Agriculture Canada, 1996a).

Federal crop insurance was reviewed in 1995-96 by a committee composed of federal and provincial representatives as well as farmers. The body suggested that federal leverage in crop insurance is likely to become more limited and they made a variety of recommendations as to how this could be handled (Agriculture Canada, 1996b). In early July 1996, federal, provincial, and territorial ministers of agriculture endorsed the committee's recommendations (Saskatchewan Agriculture, 1996).

Federal crop reinsurance takes on part of the provinces' contingent liability when indemnities exceed accumulated reserves because of severe crop losses. Five provinces have reinsurance agreements with the federal government: Alberta, Saskatchewan, Manitoba, Nova Scotia, and New Brunswick (Agriculture Canada, 1996a). Each province contributes a maximum of 15% of total premiums in that province for the year to the federal fund, depending on the balance in the reinsurance fund. Before a reinsurance payment is triggered from the fund, crop-insurance indemnities must first be paid from a province's accumulated insurance-premium reserves. If these reserves are insufficient to cover all indemnities, then reinsurance funds make up a portion of the shortfall. The province is responsible for any shortfall up to 2.5% of the program's total liability, with the remaining shortfall funded 75% by the federal reinsurance fund and 25% by the province.

The committee also reviewed the reinsurance program. One discussion that resulted concerned the program's structure. There may be an opportunity for private-sector involvement. Producers generally feel, however, that private schemes might lead to unacceptable fluctuations in premiums because of reinsurers' need to cover risk margins, administrative costs, and profit (Agriculture Canada, 1996c). Moreover, some private reinsurers have suggested that the industry might be unwilling to act as a reinsurer because of the federal-provincial division of responsibilities. Private reinsurers that have contracts with the federal government would be unable to influence administration of the program, which is handled by the provinces (Ellis, personal communication, 1996).

### *10.7.2 The Provincial Governments*

Each province has companion programs to federal crop insurance. The Crop Insurance Review of 1996 found that there was no national consensus on crop insurance, with provinces preferring different approaches to managing production risk (Agriculture Canada, 1996c).

The volume of crop insurance written and paid out differs widely from province to province because of the varying size of the agricultural sector, differing participation rates, and the exclusion of beef, dairy, and poultry producers. The structure of crop-insurance organisations also varies. British Columbia, Newfoundland, and Prince Edward Island administer their programs through departments that mirror Agriculture and Agri-foods Canada. Alberta, Saskatchewan, Manitoba, and Quebec use crown corporations. In Ontario, Nova Scotia, and New Brunswick, boards or commissions tied to provincial departments of agriculture operate the programs (Agriculture Canada, 1996b).

The 1996 review found little interest in a single national program. Given the differences in crops and clients across the country, a national scheme would not necessarily be the best means of delivery (Agriculture Canada, 1996b). Several specific programs are discussed below – those in Saskatchewan, Quebec, Nova Scotia, and Newfoundland.

*Saskatchewan*

In Saskatchewan, the Saskatchewan Crop Insurance Corporation (SCIC) provides farm operators with protection against crop losses on insurable crops caused by uncontrollable natural causes. Over the past five years, approximately 47,000 Saskatchewan producers have enrolled each year. Coverage is available in low-, high-, and market-price options. Coverage options for each insurable crop are available at 50, 60, 70, 75, or 80% of the producer's long-term individual yield. Crop insurance offers a guarantee of production and quality. If the grade of harvested production falls below the designated grade for a crop, compensation is adjusted accordingly.

In 1995 Saskatchewan's Farm Support Review Committee recommended two-tiered crop insurance. The federal, provincial, and territorial ministers of agriculture endorsed this type of program in 1996. The national committee also thought a two-tiered model acceptable. Such a scheme offers basic coverage to producers at low cost and additional coverage at higher rates. Saskatchewan will change to a two-tiered model for the 1997 crop year (Government of Saskatchewan, 1996; Agriculture Canada, 1996b).

*Quebec*

The Quebec Agricultural Insurance Board (Régie d'Assurance Agricole) administers crop insurance in Quebec. Its mission is to ensure the financial stability of farm businesses by compensating for significant losses in income resulting from low prices or uncontrollable natural phenomena (Government of Quebec, 1996).

The objective of the programs sanctioned by the Crop Insurance Act is to compensate for losses in yield of eligible crops resulting from damage caused by uncontrollable natural elements. Individual risks covered include wild animals and birds, floods, excessive wind, rain, humidity and heat, frost, hail, uncontrollable insects and diseases, snow, hurricanes, and drought. Compensation is paid to the farmer when damage during the season affects more than 20% of total insurable yield. To calculate payment, the unit price listed on the certificate is multiplied by the difference between 80% of total insurable yield and actual yield. Salvage value and non-incurred expenses, if any, are subtracted from payments. The board determines a probable yield for farms based on 15% moisture and expressed in kilograms per hectare of Canada-pedigreed grade 1 and 2 seeds. Total insurable yield is calculated by multiplying yield by insurable area (Government of Quebec, 1996).

Participation is voluntary. Producers may reapply annually, provided they meet eligibility criteria. The insured value stipulated in the policy is a function of expected yield per insurable unit and a unit price usually based on production cost. Assessment rates are based on the actuarial principles used in the insurance sector. The financial position of each insurance fund and the historical loss index of the programs play a key role in setting assessment rates.

To be eligible, farmers must cultivate a minimum of four hectares of a given crop and use Canada-pedigreed grade seeds (foundation or registered). Pedigreed seed is not common in Canada, but using it, as opposed to the previous year's seed, increases the genetic strength of the plants and perhaps minimizes drought damage (Ellis, personal communication).

*Nova Scotia*

The Nova Scotia Crop and Livestock Insurance Commission administers crop insurance under the direction of the minister of agriculture and marketing. The commission makes available programs that assist farmers in years of reduced yields, lower revenue, and losses from insurable perils. The Crop Insurance Program was first made available in 1969. Its main objective is to pay out-of-pocket expenses for crop losses. Expenses such as seed, fertiliser, and spray are paid so that the farmer can continue farming. The commission administers eleven Crop Insurance plans, a Dairy Livestock Insurance program, and the Gross Revenue Insurance Plan (GRIP), covering grains and oilseeds. The Nova Scotia Crop and Livestock Insurance Act and the Crop Insurance Agreement between Nova Scotia and Canada govern these activities. The two governments each contribute half of administrative costs for Crop Insurance and GRIP, and the province covers administrative expenses for other programs administered by the commission (Government of Nova Scotia, 1996).

Crop Insurance plans deal with Blueberries, Corn, Forage Peas and Beans, Potatoes, Soybeans, Spring Grain, Strawberries, Tobacco, Tree Fruit, and Winter Grain. Each insured crop is guaranteed a specific yield based on the past yield records of each insured. When no historical records are available, a benchmark, either a provincial or an industry average, is used. When harvest yield is less than guaranteed yield, because of insurable perils, a claim payment is made. Crop insurance is designed to protect against crop losses resulting from unavoidable natural hazards beyond the control of the producer. It is not intended to cover losses resulting from negligence, misconduct, or poor farming practices. The insurable perils are drought, frost, wind, excess moisture, insects, disease, wildlife, winter injury, adverse weather, and pollination failure (Government of Nova Scotia, 1996).

Crop insurance plans offer the option of either 70% or 80% coverage. In the event of crop damage, the grower submits a notice of crop damage and a Crop Insurance representative inspects the damage. Claims are adjusted according to the time of the year when the loss occurs. The liability of the commission is the sum of all claim stages payable or the total dollar coverage of the crop, whichever is less (Government of Nova Scotia, 1996)

*Newfoundland*
In Newfoundland, the crop-insurance program provides production-risk insurance for turnips, cabbages, potatoes, and carrots. The feasibility of extending insurance to other crops is reviewed periodically. The program guarantees a producer a minimum yield, based on individual production history and specified coverage levels. Compensation for yield losses is currently based on the direct (cash) costs of production for the particular crop. The minimum acreage that can be insured is one acre, and all of the acreage of a particular crop must be insured if coverage is requested. The program is operated by the Newfoundland Crop Insurance Agency, under the Crop Insurance Act. The Canada/Newfoundland Crop Insurance Agreement establishes the cost-sharing rates – 25% for Ottawa, 35% for Newfoundland, and 40% for the individual producer. Administration costs are shared equally by the federal and provincial governments (Government of Newfoundland, 1996).

Canadian producers have experimented with buying futures and self-insurance as means of managing risk, but these activities are limited (Ellis, personal communication). There have been various discussions about creating producer-owned and -operated mutual insurance plans. Under such schemes, the provincial and federal governments would decide each year how much money they were prepared to allocate to crop insurance. Producers would pay the full cost of administration as part of their premiums, and costs would be controlled because farmers themselves would have a greater stake in a program's integrity. It was suggested that this area merits further study (Agriculture Canada, 1996b).

## 10.8 Summary

The federal and provincial governments provide financial assistance to municipalities, individuals, and occasionally businesses that have suffered financial losses as a result of natural disasters. They make payouts through the Disaster Financial Assistance Arrangements, and insurance companies pay claims to policy holders for eligible losses and in turn make claims on reinsurance companies. Federal and provincial governments and individual producers participate in a variety of programs of crop insurance.

## References

Agriculture Canada. (1996a). *Crop Insurance: Advice on Organisation and Administration. A report prepared for Agriculture and Agri-Food Canada as part of the 1995-96 crop insurance review.* Sussex Circle, March.

Agriculture Canada. (1996b). *Main Estimates, part III.* Department of Finance, Ottawa.

Agriculture Canada. (1996c). *Report of the Review of National Production Risk Management*

*Policy for Crops.* Crop Insurance Review Steering Committee, June.

Ellis, J. M. (personal communication). Agriculture Canada, 1996.

Emergency Preparedness Canada (EPC). (1995). *A Summary of Federal Emergency Preparedness in Canada.* EPC, Ottawa.

Emergency Preparedness Canada (EPC). (1989). *Disaster Financial Assistance: Manual to assist in the interpretation of federal guidelines.* EPC, Ottawa.

Government of Newfoundland. (1996). *Internet Home Page,* (http://www.gov.nf.ca/welcome.htm).

Government of Nova Scotia. (1996). *Internet Home Page,* (http://www.gov.ns.ca).

Government of Quebec. (1996). *Internet Home Page,* (http://www.gov.pq.ca).

Government of Saskatchewan. (1996). *Internet Home Page,* (http://www.gov.sk.ca/default.html).

Government of Saskatchewan. (1995). *Saskatchewan Municipal Government, Annual Report 1994-1995.* Government of Saskatchewan, Regina.

Insurance Bureau of Canada (IBC). (1994). *Insurance Bureau of Canada Position Paper: A Statement of Principles Regarding Insurance and Natural Hazards.* IBC, Toronto, February.

Peters, D. (1994). Emergency Preparedness Canada. In: *Proceedings of a Workshop on Improving Responses to Atmospheric Extremes: The Role of Insurance and Compensation.* McCulloch, J. and Etkin, D. (eds.). Toronto, October 3-4. pp. 5-2 to 5-5.

Wolsley, R. (1994). In: *Proceedings of a Workshop on Improving Responses to Atmospheric Extremes: The Role of Insurance and Compensation.* McCulloch, J. and Etkin, D. (eds.). Toronto, October 3-4. pp. 5-19 to 5-21.

# PART 6: SUMMARY AND CONCLUSIONS

## 11.0 Summary and Conclusions

# 11.0 Summary and Conclusions

## 11.1 Vulnerability to Natural Hazards in Canada

Geographical, political, economic, demographic, insurance, construction, and psychological factors all affect both the absolute cost of natural hazards to Canadians and the division of cost between and within public and private entities. However, we can analyse the various hazards to which Canadians are exposed, in terms of their impacts, their physical causes and their frequency of occurrence. For example, although these hazards occur throughout the year, summer probably represents the most vulnerable period when we regularly suffer the four most devastating hazards: floods, drought, hail and tornadoes. To these must be added the significant potential damage from earthquakes, severe winter storms and windstorms. Together these seven hazards require more detailed risk analyses in order to determine the vulnerability of Canadian society.

As climate changes due to human impact, it may be changes in the frequency of hazards or extreme events that has the greatest impact rather than the increase in the mean surface level temperature referred to as "global warming". It is the increase in the variance, rather than the increase in the mean, that poses the most immediate danger. For example we must address the question "How might extreme events change due to enhanced greenhouse warming?", by reviewing and summarising current literature on that issue. In some cases, prediction can reasonably be made regarding the consequences of climate change, while in other cases opinion is divided.

Conclusions on how climate change will affect the frequencies and intensities of extreme events is mixed. In a warmer climate, it seems likely that the number of convective events (e.g. thunderstorms with extreme rainfall, tornadoes and hail), heat waves, floods and drought will increase; while the frequencies of cold waves will become rarer. The relationship between the frequency and intensity of tropical cyclones and global warming is inconclusive. Table 3.1 is a summary of the current views on the future of extreme events as a result of climate warming.

The social and economic costs to Canadians from natural hazards are substantial, not only as a result of damages when events occur, but also due to adaptation and recovery. In particular, drought, flood and hail have had significant economic impacts, which we must understand in order to devise better policy tools to deal with them.

However, there have been almost no studies that provide such a summary, and this analysis is not at a stage where it can be attempted. Clearly, the importance of floods has been shown and highlighted by the Saguenay disaster. The costs of droughts can also be very large, if not so dramatic (drought is a slow onset disaster, as compared to flood which is a "fast onset" disaster). For example, Wheaton and Arthur (1989) estimated the cost of the 1988 drought at $1.8 billion (unadjusted), or 0.4% of real GDP. Other droughts of significance are: 1978/79 ($2.5 billion), 1980 ($2.5 billion), 1984 ($1 billion), 1985 ($50 million) and 1990 ($96 million).

It is likely that costs associated with hazards will increase in the future, as a result of climate change. However, although natural hazards and disasters are expensive, they are not inevitable; with appropriate planning to reduce vulnerability, their social and economic impact on Canadians can be reduced.

## 11.2 Scientific Support for Managing Natural Hazard Exposure

Incorporating concepts from meteorology has the potential to make occurrence definition more consistent, and therefore less subject to dispute. This would provide benefits to the insurance and reinsurance communities both in terms of dispute resolution and in having a clearer concept of what is covered by reinsurance treaties. If contracts included both a physically based, spatial description of the hazards covered and some stipulation regarding linkages between perils, it could make the definition of a loss occurrence more dependable.

The space-time proposal classifies occurrences by scale (synoptic or mesoscale) and physical links, and allows for fairly straightforward determination of the number of occurrences. By making the definition of an occurrence in this way, less confusion will arise in classifying losses. Further research is recommended to:

1. apply the space-time method to a series of case studies, covering all types of severe weather events; and
2. develop a set of sample contracts, in order to test the implications of this method on past and future incidences.

## 11.3 Validation of Computer Models of "Probable Maximum Loss"

How useful are seismic risk models, for example, how can they be critically examined? In this study we have examined seismic risk modelling in greater depth, for the purposes of model examination and assessment of model output. The steps outlined in a generic seismic risk model include the insurance inputs, the seismic hazard module, the vulnerability module, and the financial outputs.

The different seismic risk models available to the insurance industry have a similar structure. Each requires insurance input data including building inventory, insurance structure, and seismic event parameters. Each has a seismic hazard module which uses the seismic event data and building location in attenuation functions to estimate seismic shaking at a site. Each model then uses a vulnerability module to estimate the extent of damage at the site based on the site seismic shaking. Finally, each model has a financial module that calculates the potential insured losses given the extent of property and content damage, business interruption, and insurance structure.

However, the seismic risk models differ in their purposes, applications, secondary effects considered, attenuation and vulnerability functions, assumptions, sensitivities, and other more minor functions. The products also differ in services and support provided, and operation costs.

Other questions should also be considered, such as how often are databases updated?, what kind of support is offered by the modelling company?, how credible is the modelling company?

Further recommendations:

1. A similar analysis should also be performed for Eastern Canada.
2. A similar examination of the vulnerability and financial modules should be undertaken. The seismic hazard portion of the risk models should be studied in greater detail.
3. Landslide, liquefaction, inundation, and "fire following" modules were not addressed in this document and need to be evaluated in a similar manner.
4. Other risk models, such as Risk Engineers' EQCanada, should also be reviewed.
5. This analysis should be repeated for Wind Models.

## 11.4 The Changing Patchwork of Responsibility for Natural Hazards in Canada

Canada has developed a patchwork of publicly funded programs and private market services, encompassing four main types of response activities: mitigation (Chapter 7), preparation for an emergency (Chapter 8), response to a disaster (Chapter 9), and recovery (Chapter 10).

Physical mitigation is performed by all levels of government. Involvement of local governments is crucial to reducing the physical impact of natural hazards. Provincial governments can ensure that this occurs. Some individuals have taken preventive action in their homes and businesses, but financial incentives could increase these efforts. The property and casualty insurance industry faces a large, underfunded liability because of its earthquake exposure. Whether or not the federal government will respond positively to its request for reduced taxes while it builds a reserve remains to be seen. The insurance industry also awaits the response of the B.C. government to its request for separate policies for "fire following" earthquakes.

After mitigation, the second phase in the human-response cycle is emergency preparedness – development and practice of emergency plans to respond to natural hazards and monitoring of the geophysical and atmospheric environment to allow for timely hazard warnings. Responsibility for these activities rests with various agencies, as laid out in legislation, regulations, and by-laws, as well as by custom and practice.

Activities to prepare for emergencies include writing and testing emergency plans, strengthening response capabilities, and providing timely warnings when possible. Such activities fall within the mandates of all levels of government; individuals and businesses can also participate. The federal Emergency Preparedness Act requires all departments to prepare and plan for future emergencies, but provincial authorities can manage most natural disasters. Consequently, all provinces have agencies for emergency planning and preparedness. Municipal governments, particularly for highly vulnerable cities such as Vancouver, also have programs. While there is no legal requirement to do so, it is wise for individuals and businesses to prepare emergency plans. Natural-hazard warnings are provided by both federal and provincial agencies, depending on the type of hazard. Atmospheric hazards are monitored by Environment Canada, and earthquake hazards by Natural Resources Canada. Flood warnings issue from provincial agencies that monitor water levels. In British Columbia, the provincial government provides tsunami warnings to the public and relevant federal agencies.

Response activities – the third phase in the human-response cycle – should begin as soon as a disaster is detected. Those involved can mobilise and position emergency equipment; ensure that individuals are out of danger; provide food, water, shelter, and medical equipment; and bring damaged services and systems back into service.

Effective federal, provincial, and municipal capabilities to respond to emergencies are vital to minimizing casualties from natural disasters. All governments have assigned responsibilities internally. Which level of government leads emergency response depends on the severity of the disaster. Non-governmental organizations also support emergency responses. Succinct emergency planning by governments, businesses, and individuals can help ensure effective disaster response.

The fourth and final stage of response to a disaster is recovery from the physical and financial effects. Rebuilding takes months, sometimes years. It also requires that individuals receive the means to begin recovering, in the form of financial assistance and/or payouts from insurance. Costs of natural disasters are shared by individuals, insurance companies, reinsurers, private businesses, and government. A study in Alberta of the distribution of compensation payments found that 11% of all recovery costs for three events originated in the provincial government's disaster-assistance program. Insurance companies paid over 66%, with the remainder coming from other sources such as business funds, personal funds, and bank loans.

The federal and provincial governments provide financial assistance to municipalities, individuals, and (occasionally) businesses that have suffered financial losses as a result of natural disasters. They make payouts through the Disaster Financial Assistance Arrangements, and insurance companies pay claims to policy holders for eligible losses and in turn make claims on reinsurance companies. Federal and provincial governments and individual producers participate in programs of crop insurance.

This study has focused on out-of-pocket costs such as claims even though broader definitions for disasters would include fixed costs such as in-house legal and executive time spent, as well as external legal costs, and the avoidance of the loss of goodwill (measured by lost revenue – an opportunity cost) that would follow disputes. Consideration of these overhead, related out-of-pocket, and opportunity costs are now causing significant changes in management thinking in other industries.

The Canadian patchwork of responsibility has evolved in response to a myriad of local circumstances and higher level consultations. At no time has an overall assessment been made of responsibility for natural hazards in Canada – and perhaps no such assessment is necessary. What is needed is for each of the responsible parties to understand the full extent of their liability, especially in the event of a major urban earthquake and the probability of the increasing frequency of extreme weather events in response to climate change.

# APPENDIX A

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