UNIVERSITY OF ALBERTA

THE HUMAN CONTEXT IN HAZARD MAPPING

BY

© **HILARY SANDFORD**

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Dedicated to
Roo and Piquita
and
James of Waterton
-for all they have done-

Abstract

Event maps and hazard maps are often thought to be the same thing while in fact, they are not. Event maps provide information for a specific physical activity (magnitude, spatial distribution and frequency of occurrence) while hazard maps incorporate information on an affected segment of the population or associated resources. This distinction has not been made clear in previous hazard mapping efforts. Thus, the first objective of this research involved the development of an event-impact classification that provides a human context for event mapping.

Through the collection and mapping of weather-event data for the province of Alberta, the usefulness of the proposed event-impact classification system (inferred/indirect, inferred/direct, specific/direct, specific/indirect) was assessed. The resulting maps provided information on both the physical characteristics of the event and on the affected segment of the population or resources.

The production of demonstration maps for each event-impact type identified a lack of appropriate data collected by those agencies normally responsible for collecting weather related information, principally Atmospheric and Environmental Services (AES), the Ministry of Agriculture, Food, and Rural Development, and the Ministry of Environmental Protection. These organizations focus on collecting information for specific tasks and often fail to consider the implications for other users.

The second objective of this research was to assess the incorporation of a human context in weather hazard mapping and to suggest improvements to data collection that would improve the production of hazard maps. Ultimately, the four demonstration event-impact maps were successful in incorporating a human context despite both practical and conceptual difficulties.

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Chapter 1
Introduction

"No matter where we live or what we do, we are all subject to hazards, to risks embedded in the environment" (Palm, 1990).

Every community is subject to the impacts of natural hazards - whether due to minor events, such as cold temperatures, and heavy rainfall, or more destructive occurrences such as tornadoes, avalanches, and earthquakes. As citizens, we accept environmental risks as tradeoffs for living in a place where we can find employment or enjoy a favourable climate but we often request some form of protection from more severe hazards through local government agencies.

Alberta Hazards

The province of Alberta is not usually affected by newsworthy hazards, such as earthquakes or tsunamis. Instead, Albertans feel the impact of less dramatic events, such as landslides, rockfalls, and avalanches in the mountainous or gullied regions of the province and the impacts of various meteorological events.

Meteorological events in Alberta often result in major economic losses in agriculture, forestry, transportation, and recreation, as well as having an impact (usually negative) on the life of the average individual (Alberta Advisory Committee, 1986). This economic vulnerability is not strictly due to the severity or frequency of individual weather events but is due to the magnification of the impact of these events through provincial reliance on these environmentally based economic sectors (especially agriculture) as sources of revenue (Alberta Research Council, 1986). For example, much of Alberta is subjected to severe convective processes (thunderstorms and associated events) during the majority of the growing season (Alberta Research Council, 1986) and, as a result, agriculture sustains large financial losses from hail, snow and heavy rain.

Hazard Mapping

The vulnerability of Alberta's crops to weather damage is of considerable concern both to the individual farmer and the Provincial Ministry of Agriculture, Food and Rural Development. In order for these parties to understand both the distribution and level of impact of meteorological phenomena, detailed mapping of both individual weather events and long-term climatic normals is required.

Sporadic attempts at hazard mapping have been conducted by various provincial authorities in Canada, but the resulting maps provide no information on the impacts felt by the affected communities. Since natural events are not hazardous unless they potentially affect a portion of the population, the incorporation of information on the affected population is necessary in order to create a true hazard map (White, 1974; Palm, 1990; Bryant, 1991).

The creation of severity zonation maps, or hazard maps, relies on the use of four factors to assess the loss potential of a natural hazard (UNDRO, 1979; Maybury, 1986):

1. the geographic distribution of the severity of the phenomenon
2. the number, spatial distribution and density of the population and/or property exposed to the effects of various natural hazards
3. the vulnerability of elements at risk when subjected to seasonal timing, intensity and distribution relationships of hazards
4. the effects of local conditions in modifying the severity of the event at a given location.

One of the realities of hazardous events that this list does not address is that natural events can have very different levels of impact, both over space and over time. As a result, classification of different levels of event impact becomes an important factor in event mitigation.

Hazardous events often do not impact all affected areas equally; for example, the same hail storm may deposit pea-sized hail in one community and cause little damage, while in a neighbouring community, walnut-sized hail might result in serious property damage. At the same time, not all populations will suffer the same amount of stress when subjected to an event of equal magnitude.

A classification method that can be used to group natural events according to the impacts of each event is proposed in this research. In a severe cold spell, the very young, the very old, and the very sick are the most vulnerable. This perceived variability in impact for the same event, both as a result of the events spatial variation in strength and by the affected communities level of preparedness, at an institutional level, creates a problem for hazard assessment. This type of complicated event has an **inferred** impact. At the other end of the spectrum, there are hazardous events which directly cause the resulting impact and while the impact is consistent throughout the affected area, the level of community preparedness has almost no influence on the resulting impact (for example, a person struck by lightning). These type of events have **specific** impacts. These two types of impact, inferred and specific, are variations on the pervasive-intensive distinctions made by Burton and Kates (1971) and Burton, Kates and White (1993).

Inferred/specific impact types can be further subdivided as to whether or not the effects of the event are **direct**, such as in the case of a tornado destroying a building, or **indirect**, where a bolt of lightning starts a fire which threatens humans and associated resources (Smith, 1992). These different levels can be combined to create an event-impact typology for mapping: **inferred/indirect, inferred/direct, specific/direct, specific/indirect**.

These event-impact types are easy to understand conceptually but whether or not these classifications can be used in traditional hazard mapping or if they enhance the dissemination of information, is not known. This project investigates the value of incorporating these event-impact classification types into traditional event mapping. Population distribution, transportation routes, crops, and forest cover can be mapped in concert with climatic data to produce severity maps which can be viewed in a human context. The resulting maps are easy to interpret and provide an indication of the areas of the province which are susceptible to specific severe weather events.

Objectives

The objectives of this research are:

1. to examine the practical realities of hazard assessment and to determine whether or not classifying events according to type of impact (inferred/indirect, inferred/direct, and specific/direct, and specific/indirect) contributes to the understanding and assessment of hazardous events.

2. to integrate hazardous event data, in this case climatic data, and information on the affected human population through mapping.

The first objective has two components: first, to attempt to assess specific weather hazards for Alberta and to determine if event-impact classification increases the usefulness of the resulting maps; and, second, to determine if the data that are currently being collected by climatic organizations, such as Atmospheric and Environmental Services (AES), and resource agencies, such as the Ministry of Agriculture, Food, and Rural Development or the Ministry of Environmental Protection, are useful for the assessment of provincial vulnerability to natural events. The second objective is intended to assess the human context in weather hazard mapping and to determine if suitable data are being collected.

Thesis Structure

This thesis is divided into six chapters. Chapter 1 has provided a general introduction to the project and objectives while Chapter 2 contains a detailed literature review, which defines the terminology and includes a discussion of the role of hazard mapping in mitigation strategies. In Chapter 3, descriptions of the seven main weather hazards experienced by the province of Alberta are given and the types and sources of climatic data are discussed. Chapter 4 introduces event-impact classification, defining the characteristics of indirect, direct, inferred and specific impacts. Variables are selected for the production of demonstration maps for each event-impact category. Chapter 5 examines the demonstration maps and the problems associated with the specific map combinations and, more generally, with the problems associated with the role of the event-impact categories. Chapter 6 summarizes the findings of this research and makes recommendations for further work.

Chapter 2
Hazards Research

The roots of geographical hazard research can be found in the human ecological studies of the 1920s which, under Harlan Barrows (1923), focussed on the study of human adjustments to specific natural environments (Caviedes, 1982; Smith, 1992). This human-environment tradition was the basis of Gilbert White's (1945) research on floodplain hazard that concentrated on the physical factors that affect human adjustments to floods (Saarinen, 1966; Whyte, 1986). The original human-ecology school began to encompass the hazard perception approach and this combined research increased in scope in the early 1960s. Hazard perception research continued throughout the early 1970s and focussed on the assessment of social, economic and behavioural variables and how the interaction of these variables might result in the suboptimal mitigation of hazards (Saarinen, 1966). The human-ecological perspective, which was prevalent throughout this early work on hazards, was arranged into a model, constructed by Robert Kates (1970), to show hazards-society interactions as a system dominated by negative feedbacks between vulnerability, impact, adjustment, and changing vulnerability and impact (Mather and Sdasyuk, 1991).

In the late 1970s, the human-ecological approach to hazards began to meld with the more pragmatic approach developed by civil engineers, and a joint perspective, though still dominantly behavioral, emerged. This combined approach was used in the assessment of many single-hazard situations and over time became utilized in complex, multiple hazard case studies (Gold, 1980). Emergency response plans, mitigation strategies, and structural modifications began to include perspectives from both human and physical geography.

By 1975, despite a large number of completed studies, the existing body of natural hazard research was found to be uncoordinated and still split between the technological and social science fields (White and Haas, 1975). In an attempt to remedy this situation, the Institute of Behavioral Sciences, at the University of Colorado, began to compile and archive existing hazard studies. Simultaneously, Gilbert White and his colleagues attempted to create an international dialogue on hazards research and to influence the direction of subsequent research through the International Geographic Union (White, 1974).

Soviet scientists pursued hazard research throughout the 1980s and acquired experience in the classification of hazards as discrete events. Japan, Norway, Switzerland, and the United States are some of the leading countries in hazard research and their concentrated efforts have led to a number of breakthroughs, both in the theoretical and pragmatic areas of hazards research (Mather and Sdasyuk, 1991). The United States, in particular, has made substantial progress in inventorying hazardous geomorphological events and has been one of the few countries to attempt multi-hazard mapping (Dow *et al.*, 1979; Cross, 1988).

Hazard Definition

At the core of hazard definition is the idea that natural events are physical processes that have the potential to damage individuals, property, and resources (Kates, 1971; Palm, 1990; Bryant, 1991; Mather and Sdasyuk, 1991; Smith, 1992; Burton *et al.*, 1993). When natural events occur in uninhabited areas they pose no threat, and only become hazardous when harmful interactions occur with populations, the activities of populations, and with the specific environments that humans value and need (Palm, 1990; Burton *et al.*, 1993). Some disasters, such as droughts, are not ultimately catastrophic to property; others, such as slow-rising floods, may effect property almost entirely (Drabek and Hoetmer, 1991). Most hazards, however, threaten both people and property.

A hazard is defined as a potential situation which will cause damage to people, property, and/or the environment (White, 1974; White and Haas, 1975; Oliver, 1975; Foster, 1980; Gold, 1980; Palm, 1990; Drabek and Hoetmer, 1991; Bryant, 1991; Burton *et al.*, 1993). The vulnerability of a population to a specific hazardous event is not entirely dependent upon the physical features of the event but is also strongly dependent on the socioeconomic vulnerability of the community (Heathcote, 1985; Whyte, 1986). The citizens of Edmonton, Alberta would be less susceptible to damage resulting from an extreme snowfall event as the infrastructure of the city is designed to cope with such an occurrence. Residents of Victoria, British Columbia, on the other hand, would find the daily functionings of the city crippled by a similar snowfall event due to both the lack of psychological or physical preparation.

Where both people and property are at risk, mitigation strategies usually place protection of people as the first priority and property losses as the second priority. By delimiting areas of potential property damage, emergency managers can identify threatened populations and property and can demonstrate the economic and public safety value of both community preparation and event-specifc mitigation strategies (Drabek and Hoetmer, 1991).

Because of the variability and complexity in natural and human environments, some phenomena can be both a hazard and a resource (a flood). This duality complicates the process of hazard planning because, on the one hand, there are benefits that can result from a natural event but, on the other hand, there is the possibility of extreme damage (White 1974b; Burton *et al.*, 1993). Preventing disasters from occurring altogether is, in many instances, neither technologically nor economically feasible (Drabek and Hoetmer, 1991). Ultimately, society accepts a compromise between exposure to the hazard and the economic and/or social benefits that accompany the hazard. Such a compromise may be expressed as that particular society's "acceptable level of risk" (Lowrance, 1976; Burton *et al.*, 1993). While determining the acceptable level of risk for a community is essentially a political process, an understanding of both the physical and socioeconomic parameters of this process is vital (Maybury, 1986).

Hazard Mitigation

Environmental hazards have existed since humans first inhabited the planet and the methods of preparation and mitigation have not changed substantially over time. 'Good fortune' is still heavily relied upon as a means of protection but four other strategies have also evolved (Hewitt and Burton, 1971; Foster, 1980; IDNDRC, 1987; Housner, 1989; Burton *et al.*, 1993):

1. preventing or altering the characteristics of a hazardous event
2. planning and building to withstand a hazardous event
3. identifying and avoiding sites where a hazardous event could occur
4. insuring against potential losses due to the occurrence of a hazardous event.

These four strategies can be utilized in concert but in practical situations, only one or two approaches are usually implemented (Foster, 1980). This haphazardness in emergency planning has proved to be moderately effective throughout the majority of human history because of a heavy reliance on a more primitive version of option three - relocating to a less hazardous area. However, human population levels have risen dramatically in the past one hundred years and this is forcing people to inhabit more and more hazardous areas (IDNDRC, 1987; Mather and Sdasyuk, 1991). As a result, avoiding natural hazards is much more difficult and the amount of physical damage and the associated costs of these events is continually increasing (Bryant, 1991).

Between 1960 and 1980 the number of worldwide major disasters increased five times (Degg, 1991). This increase resulted in a three-fold increase in economic losses while insurance losses increased by a factor of 4.8 (Munich Re., 1990). Every year North Americans experience loss of life and devastating damage to property and housing from a variety of hazards (Petak *et al.*, 1978). As a result of these types of impacts, the UN General Assembly, on December 11, 1987, adopted resolution 42/169 designating the 1990s as the International Decade for Natural Disaster Reduction. The principal objective of this resolution was:

> to reduce through concerted international actions, especially in developing countries, loss of life, property damage and social and economic disruption caused by natural disasters such as earthquakes, wind storms, tsunamis, floods, landslides, volcanic eruptions, wildfires, and other calamities of natural origins (UN, General Assembly Resolution 42/169, 1987).

Hazard mitigation strategies can be placed into two main categories: structural mitigation and non-structural mitigation (UNDRO, 1978; Drabek and Hoetmer, 1991). Structural actions include efforts to contain a hazard and to strengthen exposed buildings and structures against the physical stresses exerted by a disaster. Non-structural actions use the government's regulatory, taxing, spending and management powers to limit the damage potential to both people and property. Non-structural actions include land use planning, zoning and subdivision regulations, building codes, land acquisition and insurance (Drabek and Hoetmer, 1991).

The non-structural strategies are often used in risk assessment (the techniques used to determine a community's acceptable level of risk) and this assessment includes (Drabek and Hoetmer, 1991; Mather and Sdasyuk, 1991):

1. hazard identification, where the types of damaging natural events are inventoried
2. hazard delineation, where the areas affected by natural events are identified and
3. hazard zonation, where the affected areas are ranked according the frequency and the severity of the potential natural events.

The results of this initial assessment can be used to determine potential mitigation strategies and can be used in further risk analysis (IDNHRC, 1987; Drabek and Hoetmer, 1991; Mather and Sdasyuk, 1991).

Once potential hazards, impacts, and possible mitigation actions have been identified, an evaluation of risk must be conducted. Risk is the probability of a hazard occurring, (Kates, 1978; Palm, 1990; Smith, 1992) and the evaluation of risk is a socio-political process that involves bringing together available information about risks and hazards from expert and lay sources for the purpose of making policy decisions and designing appropriate responses (Mather and Sdasyuk, 1991). Risk and vulnerability mapping, or hazard mapping, is a procedure for locating areas with different degrees of hazard occurrence and susceptibility (Palm, 1990) and is an important source of information for risk evaluation. The combination of risk assessment and evaluation is termed risk analysis and together they form the basis for risk management decisions (Mather and Sdasyuk, 1991). Methods of formal risk assessment have developed over the past forty years as a tool to aid in public decision making and include environmental impact assessment, hazard delineation and hazard mapping (Mather and Sdasyuk, 1991).

Hazard Mapping

Methods for hazard mapping have existed for centuries but only became formal techniques as a result of the United States National Flood Insurance Program in 1968. This program has produced maps for all areas of the United States that are subject to flooding, based on a standard definition of a floodplain (Drabek and Hoetmer, 1991). Techniques also exist for mapping vulnerability to earthquakes and landslides, and while many states in the United States have embarked on multi-scale mapping for each of these events, comprehensive coverage for North America is still some years away (French and Issacson, 1984; Cross, 1988). Floodplain delimitation is possible with reasonable accuracy, given sufficient hydrologic data, but determining the exact area vulnerable to seismic activity may be extremely difficult; the definition of seismic risk on the basis of recorded history may be quite misleading unless it includes the history of the tectonic activity of the Quaternary. Many of the calculations of the frequency and magnitude of extreme events in meteorology, hydrology, and seismology assume a persistence of conditions which have prevailed over relatively short observation periods (i.e. the past 100 years) and usually assume no changes resulting from human activity which may be incorrect (Whittow, 1975).

There is a continuum in the classification of natural events in terms of the energy of the event and the frequency of occurrence, from low-magnitude, high-frequency events, such as hail or lightning, to high-magnitude, low-frequency events, such as earthquakes and tsunamis (Foster, 1975; 1980). These different types of hazardous events produce very different results; the effects of low-magnitude, high-frequency events are often at a much smaller scale and resulting in fewer deaths per event, while high-magnitude, low-frequency events are often catastrophic and can result in very high death tolls (Foster, 1980). This latter category has been the focus of the majority of disaster research efforts, primarily because protection of life is always a priority. High-magnitude, low-frequency events have been the subject of much research, and earthquake microzonation (Foster, 1980, 1988; Terwindt, 1983; Nakano *et al.*, 1986), flood plain mapping (Drabek and Hoetmer, 1991), hurricane impact zonation (Brinkman, 1975a, 1975b), and tsunami extent maps (Foster, 1975) have been conducted on differing scales and to varying degrees across North America. Low-magnitude, high-frequency events, on the other hand, are much more difficult to identify and classify; much of the hazard research has been confined to local municipalities creating case-specific plans (Drabek and Hoetmer, 1991).

Weather events can range from high-magnitude, low-frequency types (tornado) through low-magnitude, high-frequency types (summer thunderstorms). As a result, meteorological hazards are, as a whole, problematic from the points of view of hazard mapping and prediction, as they are the result of transient, sporadic weather patterns (Palm, 1990). The variability in causal factors has been one of the obstacles that has deterred many researchers from attempting to delimit and map the areas affected by weather events.

The maturing of computer cartography, as applied to hazard research, has increased the quantity and accuracy of risk and vulnerability mapping throughout North America. Improvements in hazard mapping should increase the dissemination of event information, expand existing databases, and foster further hazard analysis.

Chapter 3
Alberta Weather Hazards and Data

There are two primary types of meteorological events: first are those conditions that are constantly present and continually monitored while the second type are those events that deviate markedly from the average (Palm, 1990). These latter short-term, severe, and unusual weather patterns are more commonly the focus of statistical prediction and hazard mitigation strategies.

Alberta Weather Hazards

The province of Alberta is subject to seven main meteorological events (temperature, snow, wind, rain, hail, tornadoes, and lightning) that may cause damage to people and/or their property. Meteorological events vary in terms of frequency, impact severity and geographic location (Table 1). Within Canada, the weather related events that impact Alberta are rarely newsworthy (Table 2). The characteristics and effects of each of the seven types of hazardous events are distinct and each has positive and negative repercussions on both the population and the surrounding environment.

Temperature

Temperature is the one of the most commonly discussed weather variables and the directional trends of this measurement are monitored with great thoroughness. Most humans are preoccupied with high and low temperatures for the benefits that they provide; the extremes, however, both maximums and minimums, can be damaging to people and property. In theory, the relationship between mortality and temperature might be visualized as a U-shaped function with mortality rising sharply during extremely cold and extremely hot weather (Rogot and Padgett, 1976; Glass and Zack, 1979; Riebsame, 1985; Riebsame *et al.*, 1986).

High temperatures, especially when sustained over time, are an important factor in the outbreak of summer forest fires throughout the province of Alberta (Kiil *et al.*, 1977; Unland, 1992). Excessively warm conditions dry the forest litter layer, and lower the water table, depriving trees of essential moisture. The resulting dry conditions are vulnerable to lightning strikes, common during Alberta's summer months (Harrington and Flannigan, 1987) and which account for the majority of provincial forest fires (Kiil *et al.*, 1977).

Excessive heat has also been attributed to the aggravation of specific medical conditions. The serious short-term effects of excessive heat directly impact on the body's thermoregulatory mechanism and electrolyte balance (Ellis, 1972). Circulation ailments, such as high blood pressure and arteriosclerosis, are directly affected by high temperatures, due to the psychological and physiological stress imposed on the human body by heat (Quayle and Doehring, 1981; Riebsame, 1985; Riebsame *et al.*, 1986; Smith, 1992). The occurrence of cardiac arrest (Rogot and Padgett, 1976), strokes, cerebrovascular and respiratory disease, and diabetes also increases when the temperature exceeds 26.6°C and the overall death rate follows the same trend

Table 1. Impact of Meteorological Events in Canada*

Event	Impact	Location	Impact Threshold
Wind	building damage		55 km/hr
	inundation	Canada-wide	
	shipwrecks	Great lakes	
	injury/death	marine areas	
	oil spills	Canada-wide	
		marine areas	
Rain	flooding	lowlands	40 mm/hr
	landslides	mountain areas	
Freezing rain	power failure	Eastern Canada	12 mm/12 hr
	traffic accidents		
		Eastern Canada	1 mm/hr
Blizzard	death	Canada-wide	
	traffic accidents		wind-50 km/hr
	disruption	Canada-wide	
		Canada-wide	
Snow	accidents	Canada-wide	15 cm
	disruption	Canada-wide	
	avalanches	mountain areas	
Tornado	building damage		80 km/hr
	resource damage	Canada-wide	
	injury/death		
		Canada-wide	
		Canada-wide	
Hail	property/crop		10 mm diameter
	damage	Canada-wide	
Lightning	forest fires	Canada-wide	
	injury/death	Canada-wide	
	power problems	Canada-wide	
Frost	crop damage	Canada-wide	<0°C
	exposure	Canada-wide	
Heat	heat stroke	Canada-wide	
	crop failure	Canada-wide	
	water shortage	Canada-wide	<60% normal rain
	forest fires	Canada-wide	

* Source: Adapted from Newark (1983).

Table 2. Deaths due to Natural and Environmental Factors* in Canada and Alberta

	Year 1983	1984	1985	1986	1987	1988	1989	1990	1991
COLD	†131	148	141	106	101	98	117	119	117
	13	**22**	**9**	**9**	**13**	**14**	**19**	**27**	**19**
Frost bite	–	–	1	1	1	–	–	1	2
	–	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Chilblains	1	3	2	1	–	–	1	–	–
	–	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Hypothermia	78	98	92	66	71	76	90	97	106
	7	**17**	**9**	**8**	**11**	**10**	**14**	**20**	**19**
Unspecified	52	45	–	–	–	–	–	–	–
	6	**5**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
HEAT	9	3	6	11	9	19	5	7	2
	1	**–**	**1**	**1**	**–**	**–**	**–**	**3**	**–**
Heat stroke	3	3	2	7	9	7	3	5	1
	1	**1**	**–**	**1**	**–**	**–**	**–**	**2**	**–**
Heat exhaustion	1	2	–	3	–	10	–	1	1
	–	**–**	**–**	**–**	**–**	**–**	**–**	**–**	**–**
Heat fatigue	–	–	–	–	–	–	–	1	–
	–	**–**	**–**	**–**	**–**	**–**	**–**	**1**	**–**
LIGHTNING	4	6	3	5	6	2	5	2	5
	–	**1**	**1**	**1**	**2**	**–**	**1**	**1**	**1**
EXPOSURE	26	19	12	22	19	12	19	21	15
	8	**2**	**–**	**–**	**–**	**–**	**–**	**5**	**1**
STORM	2	2	13	4	28	3	–	–	–
	1	**–**	**–**	**1**	**25**	**2**	**–**	**–**	**–**

† Plain type shows Canadian statistics; bold type shows Alberta statistics.
* Source: Statistics Canada (1983-1991).

(Ellis, 1972; Ellis *et al.*, 1975; Ellis and Nelson, 1978; Rogot and Padgett, 1976; States, 1977; Tout, 1980; Rogot *et al.*, 1992).

Excessive cold can also pose a threat to segments of the human population and their property. Humans have been found to have a much smaller tolerance to extreme cold than to extreme heat (Giles *et al.*, 1990). As a result, hypothermia is a very real danger when the air temperature drops below 0°C and frostbite, while not usually life threatening, is a direct result of excessive cold (Geehr *et al.*, 1989). Numerous researchers have found that cardiovascular mortality is high in winter, particularly when the daily average temperature drops below 15.6°C; the lower the temperature drops from this threshold the greater the increase in mortality (Ellis, 1972; States, 1977; Hsia and Lu, 1988; Auliciens and Frost, 1989; Washburn, 1989). Fruit growers are very conscious of the damage caused by an early frost and civil engineers and highway maintenance workers prepare for cold temperatures (Harrison, 1985).

Snow

Recreational activities associated with snow (skiing, snowshoeing, tobogganing, winter camping) are enjoyed by a large number of North Americans. Snow is also an important factor in summer water availability. While these benefits are known, snow can also bring inconvenience and danger to the urban environment (Rooney, 1967; Dunne and Leopold, 1978). According to Cochrane and Knowles (1975), the extent of social disruption resulting from an urban snowfall depends on three physical factors (depth of snowfall, extremes of temperature, and strength of wind) and three social factors (level of community preparedness, the city size and industrial mix). Excess snow has significant economic impacts in the urban environment (Janz, 1968) but this in does not imply that rural areas are immune to snow hazard. Blizzard conditions (the combined hazard of heavy snow and strong winds) are dangerous to both urban and rural dwellers. However, snow can also threaten settlements, either urban or rural, by placing stress on physical structures, sometimes to the point of failure (Cochrane and Knowles, 1975).

Loss of human life is rarely associated directly with a heavy snowfall but snow has been an indirect factor in many deaths. Edmonton, Alberta received a record snowfall of 79.8 centimeters for the month of January, 1994 and three deaths in the city were attributed directly to this event. Two individuals died from cardiac arrest as a result of shovelling large quantities of snow from their driveways and another city resident died as a result of sliding off the snow-covered roof of his home (McConnell and Struzik, 1994). The most common cause of accident, as a result of heavy snowfall, is slipping, stumbling or losing balance while shovelling snow off a roof (Table 3); in fact, snow seems to result in an epidemic of fractures due to slippery surfaces (Ralis, 1981; Erikson *et al.*, 1988; McConnell and Struzik, 1994). The physical and psychological stress resulting from a blizzard or heavy snow event probably does precipitate cardiac deaths in many susceptible individuals but this particular explanation for cause of death is debated by epidemiologists (Faich and Rose, 1978; Glass *et al.*, 1979; Riebsame, 1985; Riebsame *et al.*, 1986; Geehr *et al.*, 1989).

Table 3. Sources of Injury as a Result of a Snowfall Event*

Injury	Percent Occurrence
Slips/Falls	40.9%
Car accident	21.7%
Falling object	15.2%
Chain-saw	8.0%
Handsaws/Axes	10.6%
Other	3.5%

* Source: Adapted from Geehr *et al.* (1989).

Wind

Strong winds are rarely considered to have positive repercussions, perhaps because the use of wind-generated power is not popular in Alberta. Instead, wind is seen as a potentially devastating weather agent. Despite this perception, the effects of high wind are rarely felt directly by humans. More often, wind that reaches gale force strength is responsible for building damage or collapse (Drabek and Hoetmer, 1991). Wind is often responsible for damage to resources, such the provincial forests, where trees can be stunted, blown over, or deformed by high winds (Harrison, 1985).

Rain

Rain has many benefits, from 'greening' vegetation to providing a valuable source of drinking water. Rain also causes potentially hazardous situations at both extremes with excessive rain creating an increase in traffic accidents and causing flooding whereas a lack of rain results in drought.

A study by Bertness (1980) found that car accidents increased in frequency by 100 percent during and immediately following a rainstorm, especially in urban environments. In rural areas, the frequency of automobile accidents did not increase as dramatically, but the severity of the accidents did increase dramatically during a rainstorm. Automobile accidents are the short-term consequences of rainfall events but the cumulative, long-term effects often cause the most widespread damage.

Flooding is an example of a serious cumulative effect of a rainstorm. In Alberta, flooding is usually confined to floodplains and to areas with soils that are characterized by very slow infiltration rates such as expansive or impervious clays. Urban storm runoff rates are normally much higher than rural areas due to the prevalence of asphalt which blocks water infiltration to the soil (Dunne and Leopold, 1978). While floodplains are relatively easy to identify and the frequency of flooding can be predicted from historical stream gauging records with reasonable accuracy, total rainfall is not necessarily indicative of flood potential (Harrison, 1985). The critical rate of rainfall and the cumulative totals that put a specific locality at risk are both important variables in determining flood hazard (Drabek and Hoetmer, 1991). The Severe Weather Branch of the federal Atmospheric Environment Service has determined that flood-prone areas in Alberta are generally threatened if rainfall exceeds 30 millimeters per hour (AES, 1990).

Drought conditions are rarely severe enough in Alberta to jeopardize human life but in the southern portion of the province, lack of rain often poses a serious threat to cash crops. On average, rainfall in southern Alberta is barely adequate for crop production, and natural variation is such that the rain received in the growing season can be as much as 30 percent below normal once every five years (Alberta Research Council, 1986).

Hail

Hail is one of the few weather events to occur in Alberta that does not have obvious positive effects on the impacted area. While hail is a form of precipitation that adds moisture to the soil, the damage by hail in Alberta is amongst the most costly in the world. Hailstorms occur in central Alberta (a region 130 km in radius from Red Deer) on an average of 61 days in the summer and inflict an annual average loss of 150 million dollars to crops, while property damage may approach 125 million dollars for a single event (Alberta Research Council, 1986; Lowey, 1993). While extensive urban damage is possible, hail hazard is defined primarily in terms of damage to crops (Changnon, 1972; Drabek and Hoetmer, 1991; Bourette, 1992). Hailstone size (which can range from only a few millimeters to more than 12 centimeters in diameter), number of hailstones, mass of ice, momentum, impact energy, and the dimensions of the hailswaths (which may be 30 to 240 kilometers long and 8 to 50 kilometers wide) are all characteristics of hailstorms which can be used to characterize the damage potential of a hail event (Brinkman, 1975; Smith, 1992).

Tornadoes

Tornadoes are one of the most violent and newsworthy weather phenomena to menace Albertans, and with increasing population density and urbanization, the probability of serious tornado damage is also increasing (Brinkman, 1975; Newark, 1988). Hage (1987) conducted a comprehensive historical study of Alberta's tornadoes and found that 700 tornadoes and 1000 destructive windstorms had occurred between 1910 and 1960, resulting in 116 deaths, 463 injuries, and the destruction of 1550 buildings, 2040 barns and/or ice rinks, and 5400 smaller buildings.

Kessler (1970) and Palm (1990) both describe the tremendous destructive potential of tornadoes as a result of the storm's ground speed (on average, 60 km/hr), the accompanying wind velocities (which can reach maximums of 300 to 420 km/hr), and sudden changes in barometric pressure. The meteorological conditions associated with tornado formation - high temperature, specific wind patterns in the upper atmosphere, and excess humidity - affect the seasonal, diurnal and geographic distribution of the hazard (Brinkman, 1975; Smith, 1992). These conditions usually occur during March through August in Alberta with 90 percent of the province's tornadoes occurring between June 1 and August 15 (McKay and Lowe, 1960; Hage, 1987).

Lightning

Lightning events affect both people and resources. In an average year, lightning causes more deaths than any other weather phenomenon (Palm, 1990). The National Science Foundation (1972) reported average yearly deaths in the United States to be 200 while Ebert (1988; 1989) calculated that 100 yearly deaths was the average. In Canada, the lightning death toll is considerably less, with five fatalities being the average during the 1980s (see Table 2). Regardless of the death toll, lightning casualties tend not to receive the same widespread publicity given to other catastrophic deaths because most lightning deaths occur as single events (Palm, 1990).

Property losses resulting from lightning strikes are usually confined to buildings and livestock while resource damage resulting from lightning strikes includes forest fires and loss of electrical power (Changnon, 1964; Ellis, 1972; Wrathall, 1985). Lightning events usually damage the environment but in the last decade, researchers have been investigating the beneficial effects that lightning-set fires have on both forest and grassland ecosystems; these fires often improve the overall ecological health of the region by removing the litter layer and thinning out species and individuals (Burton *et al.*, 1993).

Alberta Climatic Data

By inventorying natural events and determining their characteristics, comparisons can be made between individual occurrences (Burton *et al.*, 1993). For example, the magnitude, frequency, duration, areal extent, speed of onset, spatial dispersion, and temporal spacing of each event can be recorded and used to determine the relative threat to a community (Mather and Sdasyuk, 1991; Burton *et al.*, 1993). There are two main sources of climatic data for the province of Alberta: federal government agencies and information provided by provincial ministries. Each of these agencies uses different methods of data collection and data storage which are discussed below.

Federal Data

The majority of climatic data for Alberta is recorded by Atmospheric Environment Services (AES), a branch of Environment Canada. AES collects and stores data on many different weather events (Table 4) that differ in terms of the collection intervals (hourly, daily, and monthly) and the method of data storage (paper copies, computer disk, and CD-ROM). The method of data collection and the type of storage for specific events and locales are determined by AES.

Hourly Data

In most cases, hourly data are too fine a temporal resolution for practical use and would require many separate maps to accurately present the information in detail. Hourly data however can be useful as a supplement to other levels of weather information. For example, the usefulness of maximum and minimum daily temperatures would be greatly increased through the inclusion of hourly data because the duration of an extreme event can then be more accurately determined. Similarly, hourly hail data can be useful for determining the frequency and/or impact of hail events in a specific area. The number of ranked (3, 2, 1) hail events can be weighted and summed to provide a relative ranking for different areas of the province.

Mean annual snowfall is frequently used as an indicator of potential snow hazard because these data are usually the most readily available (Brinkman, 1975). However, hourly snowfall rates might provide a better measure of urban snow hazard since heavy snowfalls often start slowly and reach their peak several hours later.

Table 4. Atmospheric Environment Services Data*

Hourly	Daily	Monthly
Tornado	Maximum temperature	Frost
Waterspout	Minimum temperature	Thunderstorms
Funnel cloud	Mean temperature	Rain or Drizzle
Thunderstorms	Relative humidity	Freezing Rain
Thunderstorms-heavy	Precipitation	Hail
Rain	Total rainfall	Snow
Rain showers	Total snowfall	Precipitation
Drizzle	Total precipitation	Fog/Ice fog
Freezing rain	Snow on the ground	Smoke/Haze
Freezing drizzle	Thunderstorms	Blowing dust/sand
Snow	Freezing rain	Blowing snow
Snow grains	Hail	Wind >=28 knots
Ice crystals	Fog	Wind >=34 knots
Ice pellets	Ice fog	Snow on the ground
Ice pellet showers	Smoke/haze	Mean maximum temp.
Snow showers	Blowing dust/sand	Mean minimum temp.
Snow pellets	Blowing snow	Mean monthly temp.
Hail	Wind	Extreme maximum temperature
Fog	Maximum wind speed	Extreme minimum temperature
Ice fog	Wind direction	Date of maximum temperature
Smoke		Date of minimum temperature
Haze		Total rainfall
Blowing snow		Total snowfall
Blowing sand		Total precipitation
Blowing dust		Greatest rainfall
Dust		Date of greatest rainfall
		Greatest snowfall
		Date of greatest snowfall
		Greatest precip.
		Date of greatest precipitation

* Source: Atmospheric Environment Service (1990).

Daily Data

Daily observations are a more manageable level of data collection than hourly observations as the daily records usually provide an indication of the severity and frequency of a weather event while still remaining temporally coarse enough for mapping. As with hourly data, daily data can also be a useful supplemental source that provides insight into the duration of many events, especially temperature (e.g. if the mean temperature equals the maximum or the minimum then the duration of the warm or cold spell can be determined).

Another type of daily data is the "day with" category. While this level of data collection is of general interest, the "day with hail" category, for example, gives no indication of severity or duration, provides no site-specific information, and gives no indication of where the hail is falling. An improvement made to the "day with" category is the inclusion of labels. For example, the three labels of tornado events (tornado, waterspout, funnel cloud) are useful for determining the type of hazard associated with each event. One of the problems that persists in this category is that, according to standard weather observing procedure, recording of tornadoes must be made by AES weather station personnel hence an accurate count of these events is almost impossible to obtain. A similar situation exists for thunderstorm data; these event are reported whenever thunder is first heard at a weather station and the storm is considered to have ended 15 minutes after thunder is last heard (Alberta Environment Services, 1990). Approximately 2000 thunderstorms are in progress over the earth at any one time, but since isolated areas contain few observation stations, many of these storms may be missed (Brinkman, 1975). This complicates hazard mapping because lightning strikes are sometimes recorded along with thunderstorms but the difficulties associated with the thunderstorm recording procedures make this practice questionable (Pierce, 1970). Hailstorms are also recorded in the same manner as thunderstorms and tornadoes and because of the problems associated with this method of data collection, derived distributions based upon crop damage reports and insurance data (hail intensity distributions) have come into use (Lemons, 1942).

Comparing the damage potential of storms with crop distribution is also difficult because vulnerability is a function of crop type and season. However, a rough estimate of crop-at-risk may be obtained by comparing hail frequency distributions with the distribution of crop types. A more refined estimate of crop damage potential would require considering not only hail frequency and crop type, but also the timing of the hazard in relation to the more vulnerable stages of crop development (Brinkman, 1975).

Monthly Data

Monthly data, either alone or in combination with daily and hourly data, can be used to determine the hazard resulting from extreme temperatures. For example, if the maximum temperature for July was 15°C, then no heat hazard was likely posed to the community that month, whereas a maximum of 34°C would be indicative of a potentially hazardous heat event. The date of the extreme temperature is also recorded by AES and, again, is a useful data type.

If the extreme temperature in a month is at a dangerous level then the date information can be used in combination with daily and hourly data to determine the length of the potentially dangerous temperature event.

While the monitoring of extreme temperature events can be done using monthly data, this level of data aggregation is not useful for many other weather events. Monthly data give no indication of the sequence of weather events and no indication of the rate of occurrence, both of which are important characteristics for determining the hazardousness of many events. Some of the monthly categories (total snowfall, total rainfall) are only useful for assessing events which become more threatening over time - cumulative hazards such as snow and rain.

The generalization inherent in monthly categories is evident when examining "days with blowing snow". This category records incidents where snow could have been blowing but not have reached white-out conditions and serious blizzards with white-out that were more than an inconvenience. This coarse type of categorization greatly impairs the usefulness of a resulting hazard map. A parallel situation exists with the monthly category "number of days with hail" which provides a summary of the hail season but gives no indication of when the hail season began and ended. Again, there is no way of accurately locating hailstorms; monthly hail data only indicate storm events in a broad regional context with no labels as to whether the affected area is residential, agricultural or industrial land.

Provincial Data

Sources of Alberta climatic data are not restricted to the federal AES. Data for three types of events (lightning, wind and tornadoes) are collected by specific government agencies and specialized provincial departments of AES.

Lightning

The Alberta Forest Service and TransAlta Utilities record lightning strike data for the province. Through a network of approximately 150 fire-watch towers and several dozen remote lightning detectors, the number of lightning strikes and associated fires are monitored throughout the province (AES, 1992). Because this information is primarily used for short-term fire prevention and suppression, the lightning data are not available on floppy disk. Written records do exist but are not readily available for research projects other than studies specifically directed at fire prevention.

Wind

The Severe Weather Branch of AES collects data on strong winds in Alberta. All events which exceed 50 km/hr are recorded and written comments regarding damage are included in the record. Wind data are, again, not available on either floppy or CD-ROM but can be obtained from the annual reports of the Severe Weather Branch.

Tornadoes

Because of the highly localized nature of tornado events and the method of collection, only a strongly anthropocentric record of occurrences exist. A number of researchers, notably Dr. Keith Hage, have compiled (Hage, 1987) media reports of tornadoes for the province and these records are thought to be fairly complete. The Severe Weather Branch of AES also records tornado sightings, provides severity rankings and includes damage and injury statistics. Neither the media compilations or the annual reports of the Severe Weather Branch are available on either floppy disk or CD-ROM nor do they use standardized measurement units for damage types making this information very difficult to compile into a generalized hazard map.

Data Storage

At the federal level, hourly and daily data on temperature and rainfall are available on CD-ROM. Unfortunately, the data collection for intervals that would be most useful for hazard mapping (monthly) are not available on CD-ROM. However, temperature and rainfall data, along with all snow and hail data, are available on floppy disk.

The province of Alberta does have a central agency, AES, that records potentially dangerous weather phenomenon. Unfortunately, the collected data are not generally applicable to hazard mapping. The lack of computer databases for some of the weather information (winds and tornadoes specifically) and the inconvenient data format (which requires time consuming extraction processes) makes the analysis of the data for hazard mapping purposes extremely frustrating.

Chapter 4
Hazard Mapping

Hazardous weather events occur almost everywhere in the world with varying degrees of severity. The most common technique used to monitor these events is through different forms of hazard mapping. Significant progress has been made in developing new techniques for mapping hazards with the majority of the advances realized in numerous Soviet studies (Mather and Sdasyuk, 1991). Japan is also well advanced in hazard mapping and has developed a systematic methodology (started in the late 1940s) for recording hazard damage in a series of large-scale maps covering all of Japan. The United States, Switzerland, and Norway have also produced hazard survey maps, or event maps (Cross, 1988; Mather and Sdasyuk, 1991).

Event Mapping

Event maps are used to display information showing the spatial distribution of a hazard and the frequency of occurrence for a specific event. Event maps are usually quite rudimentary, providing the user with only a basic understanding of the spatio-temporal characteristics of an event for a region. An example, lightning incidence for Alberta, July 1977 is shown in Figure 1.

Weather events can be measured for different temporal intervals and, as discussed in Chapter 3, these intervals provide varying levels of information and degrees of usefulness. Epidemiological studies have shown that the daily average temperature is the most "useful" level of information for determining trends in mortality that are associated with temperature extremes (Rogot and Padgett, 1976) while Changnon (1967) confirmed that the "day with hail" category can provide useful information for both analysis and mapping.

Event-Impact Classification

Hazard maps attempt to incorporate the social implications of extreme events in the assessment of the hazard (Mather and Sdasyuk, 1991). Very few true hazard maps have been constructed and utilized; this could be due to difficulty in obtaining socioeconomic data or difficulties in assessing the impacts of hazardous events. The system of event-impact classification that has been proposed here, combined with an assessment of data utility for each type of event-impact map, will hopefully alleviate some of the difficulties that are associated with hazard mapping.

Hazardous events often do not seem to impact all affected areas uniformly or equally. At the same time, not all populations will suffer the same amount of stress when subjected to an event of equal magnitude. This variability in impact from the same event, as a result of the event's spatial variation in strength and by the affected communities' level of preparedness, is characteristic of an **inferred** impact. **Specific** events, on the other hand, are events which are directly attributable to the resulting impact and, while the impact is consistent throughout the affected area, the level of community preparedness has very little ameliorating effect on the resulting impact. These two extremes of impact, inferred and specific, can be further subdivided as to

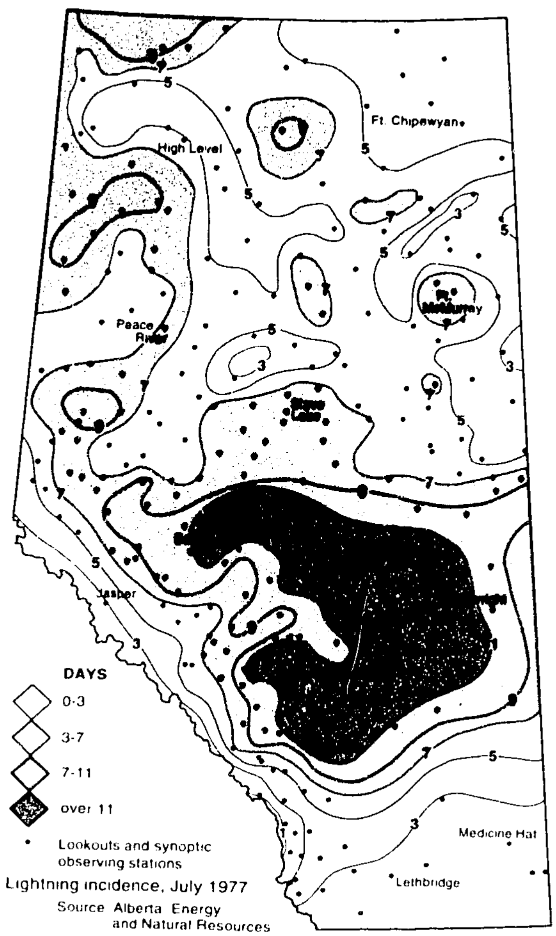

Figure 1. Lightning incidence for Alberta, July 1977. This map is typical of event maps produced by various types of government agencies.

whether or not the effects of the event are **direct**, such as in the case of a lightning bolt striking a person dead, or **indirect**, where a lightning bolt starts a fire which threatens a nearby community (Smith, 1992). These different levels can be combined to create combined event-impact types: **inferred/indirect, inferred/direct, specific/direct, specific/indirect** (Table 5). These categories provide a framework for event-impact classification and mapping. Hazardous events cannot be rigidly assigned to just one of these new groupings; the characteristics of a natural event may fall into more than one category depending upon the type and severity of the resulting impacts. The following detailed discussion of the proposed hazard types highlights this point.

Inferred/Indirect

This category of event-impact is the most difficult to conceptualize. An event such as extreme heat is hazardous to a population only when the temperature exceeds a specific threshold - approximately 26°C (Rogot and Padgett, 1976). Extreme heat can occur over a large area of the province but the impacts may not necessarily follow the same pattern; the hazard is not directly attributable to the heat because not everyone that experiences the extreme temperature is negatively impacted. The disparity between the event distribution and the distribution of effects characterizes an **inferred** event; an occurrence may threaten a population but preparation for an inferred event is difficult due to the unpredictability of the effects. Within this category, not only are the distributions of event occurrence and impact difficult to link, but the effects of the event are also difficult to define. High temperatures are known to increase the incidence of heart attacks and strokes but a physician would rarely be able to attribute an individual heart attack or stroke directly to a heat wave. This type of event may influence the health of a population but an **indirect** effect is in no way causal.

Extreme heat and extreme cold can both be inferred weather hazards and both of these occurrences can have indirect effects on a population. Normally the effects of these types of temperature fluctuations are health-related; an increase in heart attacks, strokes, arthritis, and asthma are the indirect result of exposure to extreme temperatures (Rogot and Padgett, 1976; Rogot *et al.*, 1992). Extreme heat places the human body under great stress and becomes dangerous to that segment of the population that is unwell; conditions such as angina and high blood pressure can be aggravated by the exposure to extreme heat (Rogot and Padgett, 1976; Smith, 1992). Extremely cold temperatures also put the human body under stress as well as placing people at risk to ice-related accidents (Geehr *et al.*, 1989; Smith, 1992). Conditions such as arthritis and anemia are also aggravated by cold temperatures (Erikson *et al.*, 1988).

Excessive snowfall can also be categorized as having inferred/indirect impacts. Snowfall is an event that is classified as inferred, again, because the impacts of the event can vary considerably, usually as a function of the level of preparation of a community and the overall health of the population (Heathcote, 1985). The impacts of snow hazard are often indirect; a cardiac arrest may be precipitated by the exertion of snow shovelling but the actual cause of death is arteriosclerosis, not excess snowfall (Faich and Rose, 1979). Difficulties in

Table 5. Event-Impact Classification Categories

	INFERRED Impacts vary over space	SPECIFIC Impacts are consistent over space
DIRECT Impacts are directly attributable to the event	EXAMPLES HAIL - crop damage WIND - crop damage SNOW - injury from slippage TEMPERATURE - hypothermia	EXAMPLES TORNADO - damage/injury AVALANCHE - damage/injury EARTHQUAKE - damage/injury LIGHTNING - damage/injury
INDIRECT Difficult to link the impacts directly with the event	EXAMPLE SNOW - cardiac arrest due to exertion from shovelling RAIN - flooding TEMPERATURE - health complications WIND - blizzards, wind chill	EXAMPLES LIGHTNING - lightning-induced forest fires EARTHQUAKE - broken gas mains igniting

connecting snowfall with the resulting damage and/or injury are characteristic of events with inferred/indirect impacts.

Wind can also be classified as having inferred/indirect impacts. Wind can act as an inferred agent because a large region of the province may experience high winds but the impacts vary greatly within that region. Because of this regional variation, prediction of the possible impacts and the development of mitigation strategies to alleviate the hazard are very difficult. This type of inferred event can also have indirect effects on a population. Wind has inferred event-impacts because a hazardous wind usually only results when strong winds occur with extreme cold creating a potentially dangerous wind chill. The resulting wind chill conditions are responsible for many of the cases of hypothermia and frostbite that are reported in the province (see Table 2).

Rain is a common weather occurrence in Alberta and rarely results in a hazardous situation. Large areas of the province often experience the same rain event but flooding may only occur in a few regions. Rain is not usually the direct cause of damage in the province; instead, when damage does result, a combination of rain and other factors is usually to blame (Bertness, 1980). Attributing property damage directly to the rain event is not feasible; instead, the damage is the result of soil type, antecedent soil moisture, and the geomorphology of the area, all combining to create a flood prone situation (Dunne and Leopold, 1978).

Inferred/Direct

This category also involves **inferred** events or events which Affect large portions of the province with differing levels of severity. A number of weather events fall under the category of having inferred impacts but, unlike the previous category, this category involves those events which are the **direct** cause of a hazardous situation. An example of an event which produces inferred/direct effects would be strong winds. Strong winds resulting in death and injury have the characteristics of an inferred/indirect event but when damaging wind occurs in an agricultural setting, the effects become direct. The Alberta Research Council (1986) cites wind as a principal cause of much of the crop damage experienced by southern Alberta farmers during the growing season.

Damage to crops can also be directly attributed to hail (Brinkman, 1975):

1. breaking or bending of the plant stem either killing or rendering the plant unharvestable
2. defoliating the plant leading to a reduction in yield
3. directly damaging the harvestable portion of the crop (e.g. grain kernels).

Hillaker and Waite (1985) found that crop loss and damage resulting from hail is usually highly concentrated in just a few major hail days per year. This direct damage, combined with wide variation in the effects of a hail event characterizes hailstorms as inferred/direct.

Snow is always categorized as inferred because large regions of the province experience a wide range of impacts that can be either indirect or direct. The indirect effects have been previously discussed, with the majority of the impacts manifested as injury and death resulting from existing health conditions aggravated by a snowfall. Snowfall also has direct effects on humans. As with the indirect impacts, snowfall tends to affect humans through injury and death, instead of having serious impacts on property. Geehr *et al.* (1989) found that there were a number of effects felt by humans as a direct result of snowfall. The majority of direct effects of snowfall are related to slippage (see Table 4), from falling on the pavement to sliding off a roof (Ralis, 1981; Erikson *et al.*, 1988; Smith, 1992).

Temperature is also an inferred hazard that can have direct impacts on portions of an affected population. Extremes, either maximum or minimum, can be very dangerous to human health, especially if measures have not been taken to protect against these effects. Hypothermia, frostbite and chilblains (a surficial inflammation) are common injuries that are the direct result of extremely cold temperatures and, in Alberta there are, on average, thirteen deaths a year as a result of these conditions (see Table 2). At the other end of the scale, extreme heat results in heatstroke, heat exhaustion, and heat fatigue with varying degrees of severity but while all three of these impacts cause injury to a population, they are not responsible for many deaths in either Alberta or Canada (see Table 2).

Specific/Direct

This category of event-impact involves **specific** events or those events which occur in distinct areas that can be easily delimited. Specific events normally involve the movement of surficial materials as these events tend to occur in well defined paths. Weather events do not often have specific impacts because the atmosphere is constantly in motion which prevents an event's impact from following a distinct path. One atmospheric event that is classified as specific is a tornado. The path of a tornado can be tracked, and the destruction of property and the loss of life or injury can be **directly** attributed to the occurrence and passage of the tornado.

Lightning is another atmospheric event which can be classified as specific. Like a tornado, a lightning event leaves behind evidence that is unique and directly attributable to a lightning occurrence. When lightning strikes injure either a human or an animal, the resulting burn or death is the direct result of the lightning event. Direct impact is characteristic of many specific events.

Specific/Indirect

The final category of event-impact is specific/ indirect. This is a rare category of occurrence with respect to weather hazards, with lightning being one of the few events having the potential to have indirect impacts. Lightning is a **specific** event because the effects are fairly uniform throughout the affected (albeit, small) region. Often a lightning strike does not result in direct injury or death but, instead, is the causal agent for property damage. The majority of forest fires in the province of Alberta are the result of one or more lightning strikes but the damage to the forest resources are only **indirectly** linked to the strike itself; the forest and surrounding communities are impacted by the resulting fire.

Hazard Maps

The proposed categories for the impacts of hazardous events are not rigid; many hazardous events have the potential to belong to more than one category. Despite this looseness, these categories do provide a framework for grouping the impacts of hazards and they do complement the traditional grouping of events according to their medium of origin (Table 6) as discussed by Eagleman (1983). A hazard map for each entry of the proposed event-impact classification was selected and used as the basis for a discussion of the problems involved in hazard mapping.

Inferred/Indirect Hazard Map: Extreme Heat

The effect of extreme heat in Alberta has an inferred/indirect impact on the older portion of the population. More specifically, this portion of the population is highly vulnerable to extreme heat because the incidence of high blood pressure or arteriosclerosis increases with age (Rogot and Padgett, 1976; Hsia and Lu, 1988; Washburn, 1989).

Information on the numbers of people in Alberta who suffer from either high blood pressure or arteriosclerosis is difficult to obtain. Instead, information from the 1986 Canada Census was used to identify the number of males and females over the age of 45 and determined their corresponding geographical location. Numerous biometeorology studies have found that the the vulnerability of a population to extreme temperature increases with age and reaches a peak for individuals over the age of 60 years (Ellis, 1972; Hsia and Lu, 1988; Washburn, 1989). While obviously not all people over the age of 45 suffer from either arteriosclerosis or high blood pressure, this age group is a reasonable choice for predicting potential vulnerability during a province-wide heat wave (Ellis, 1972).

'Extreme heat' is a difficult to define as there has not been agreement on the threshold temperature for this classification (Riebsame, 1985). Critical temperatures have been determined for specific epidemiological studies but these thresholds have not been recommended for other locales (Newark, 1983; Riebsame, 1985; Washburn, 1989). One of the difficulties of setting a threshold value for extreme heat is that 'extreme' is dependent upon the 'normal' range of temperature for any area. Much research (see Ellis, 1972) has been done to determine how a population acclimatizes to the temperature range of an area and the human regulatory system has been found to adjust to extremes, both high and low, in temperature, if allowed a period of adjustment. The critical factor in reducing metabolic stress is this period of temperature adjustment (Ellis, 1972). A mean temperature of 32°C over several days normally has little effect on a healthy individual acclimatized to high temperatures whereas such an extreme may be fatal to individuals accustomed to norms of 27°C (Clarke, 1972). While the human body will be placed under stress during a sudden rise in temperature, the associated complications felt by the body takes time to manifest themselves and, thus, there is a time lag between the onset of heat

Table 6. Natural Hazards by Originating Medium*

Meteorological	Crustal Processes	Surficial Processes
Snow	Earthquake	Avalanche
Blizzard	Volcanic eruption	Rockslide
Extreme cold	Tsunami	Landslide
Extreme heat		Erosion
Drought		Expansive soils
Flooding		Shifting sand
Fog		
Frost		
Hail		
Lightning		
Tornado		
Tropical cyclone		
Windstorm		

* Source: Adapted from Eagleman (1983).

and the health-related impacts (Kutschenreuter, 1959; Oechsli and Buechely, 1970; Ellis, 1972).

For one week in August, 1992, the majority of Alberta was under the influence of a heat wave. The temperatures began to climb into the low 30°s and while this would not fall into an extreme temperature range for the majority of the epidemiological studies conducted in the United States, the Edmonton Journal labelled the phenomenon as a "heat wave" (Unland, 1992). The temperatures rose into the low 30°s in the northern portion of the province on August 12 and this trend continued southwards through August 16. The maximum temperatures occurred on August 13 and, on that day, extreme temperatures were experienced over the largest area by the greatest number of people. Newspapers issued warnings not to leave children or pets unattended in automobiles as the temperatures inside cars rose to over 100°C in a matter of minutes (Williams, 1992). No deaths were reported as the direct result of the high temperatures instead, the impacts were non-lethal and felt province wide (Unland, 1992).

In order to determine what portion of the population over the age of 45 years was affected by the heat wave, both sets of data (population and temperature) were used to create a hazard map. Maximum temperature data from one hundred and thirty seven AES weather stations recorded during the week of August 12, 1992, along with their associated geographic coordinates (latitude and longitude), were used to produce maps. A raster-based software package (Terra Firma; Eyton, 1994) was used to process the data and create a temperature surface which was then used to plot 1°C contours (isotherms) on a map for each day of that week. The isotherms ranged from a weekly low of 14°C to a high of 36°C. Because there was such a range in temperatures in the province, the isotherms were divided into three classes (14°C-22°C, 22°C-30°C, and 30°C-36°C) which were then shaded, according to cartographic convention, light grey, dark grey and black, respectively (Cuff and Mattson, 1982).

The population data were obtained from Statistics Canada using the 410 provincial subdivisions; centroids for each subdivision were given in latitude and longitude. The provincial subdivisions ranged from having less than 10 residents over the age of 45 years to more than 100,000 in that age group As a result, the population data were classified on a logarithmic scale and symbols were assigned to each population class (Cuff and Mattson, 1982) using the Postscript page description language. The symbols associated with each population level were plotted as an overlay on the temperature distribution at the centroid of each provincial subdivision.

The resulting maps (Figures 2 to 5) provide specific information on the maximum temperatures (contour lines), the hot, warm and cool zones of the province (black, dark grey and light grey tones), the distribution of the population over the age of 45 (symbols), and the number of individuals over the age of 45 (type of symbol) for the province on specific days during the heat wave. This combination not only provides information on the magnitude of this four-day heat wave but also on the relative number and distribution of the vulnerable older portion of the population.

Maximum Temperature and Population - Day 1

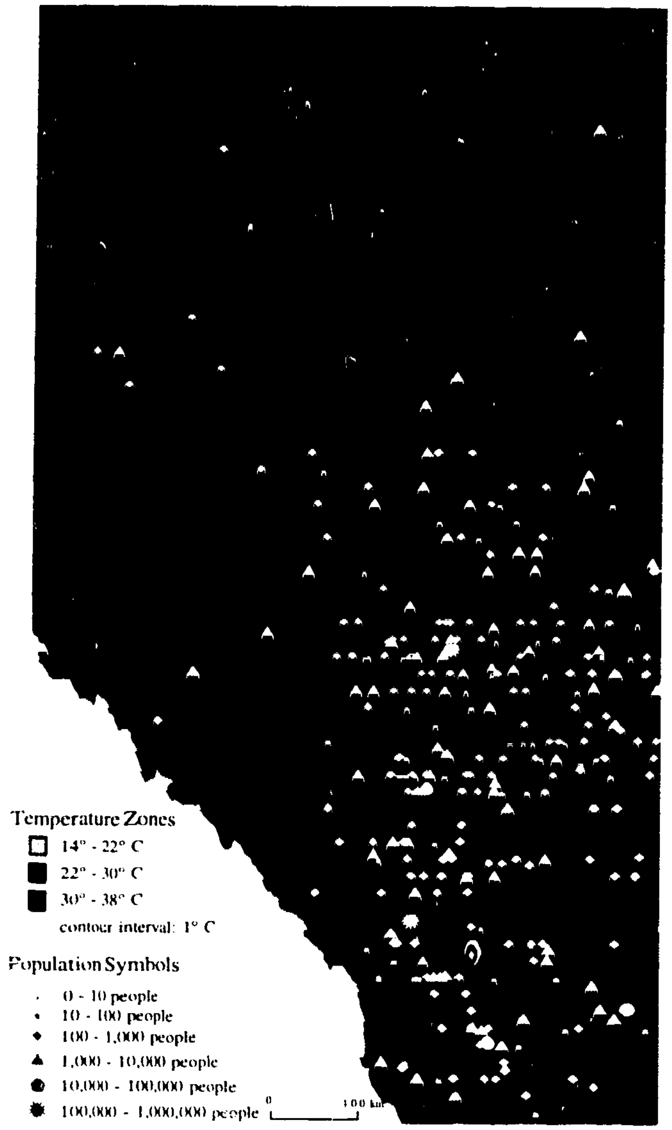

Figure 2. The distribution of maximum temperature over Alberta on August 12, 1992, the first day of a provincial heat wave, as an example of the inferred/indirect event-impact classification category.

Maximum Temperature and Population - Day 2

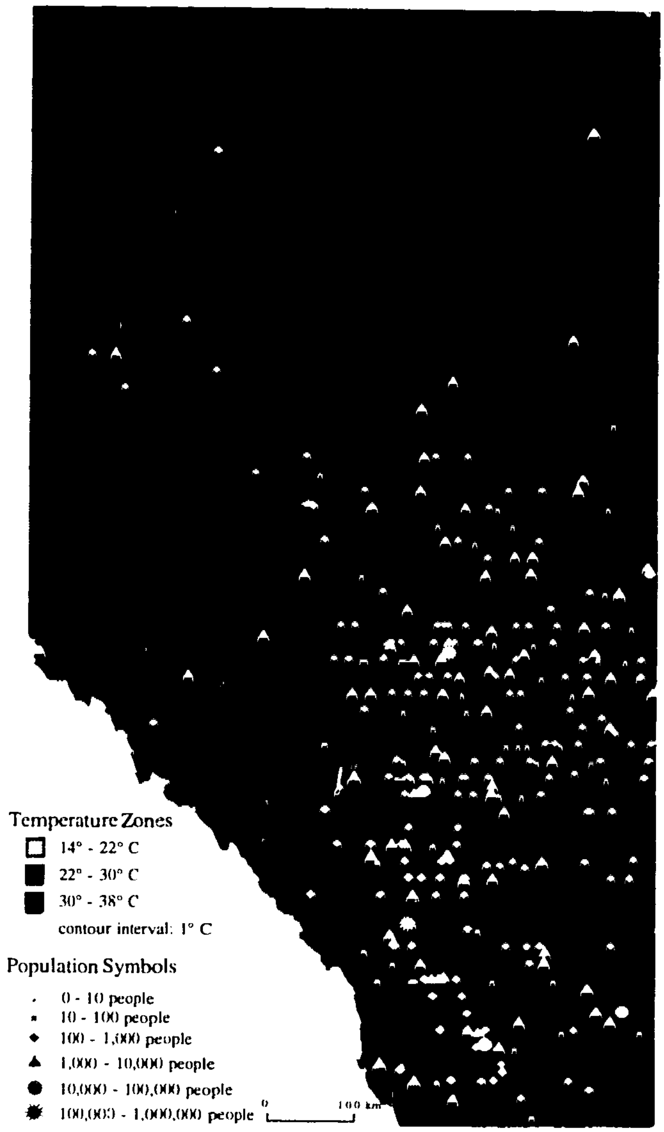

Figure 3. The distribution of maximum temperature over Alberta on, August 13, 1992, the second day of a provincial heat wave, as an example of the inferred/indirect event-impact classification category.

Maximum Temperature and Population - Day 3

Figure 4. The distribution of maximum temperature over Alberta on, August 14, 1992, the third day of a provincial heat wave, as an example of the inferred/indirect event-impact classification category.

Maximum Temperature and Population - Day 4

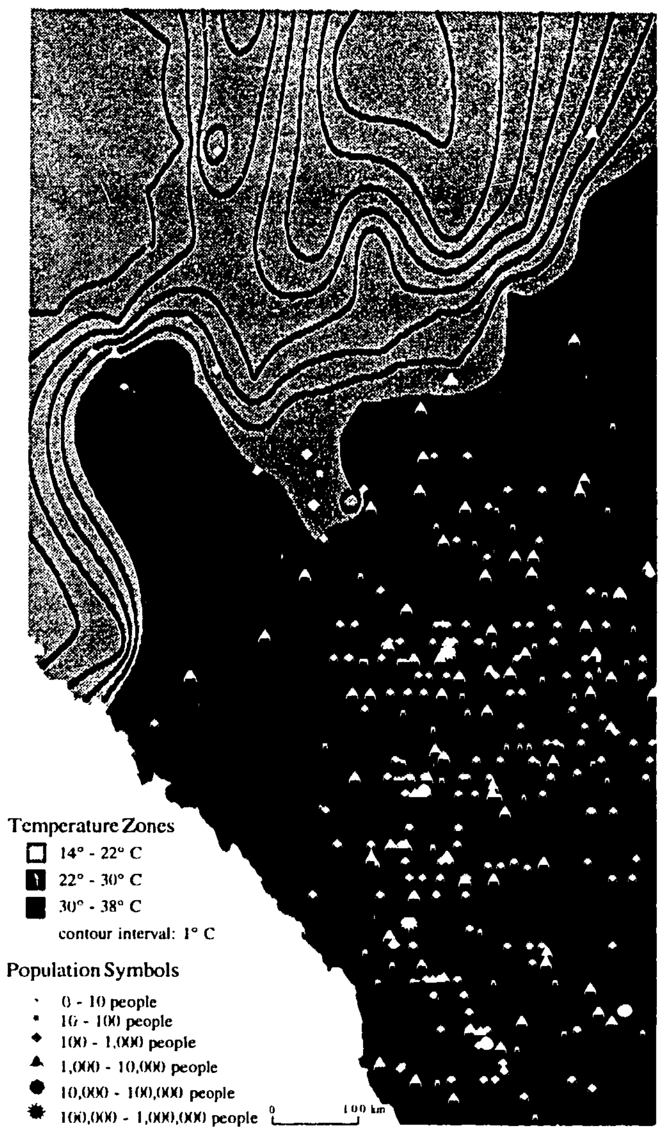

Figure 5. The distribution of maximum temperature over Alberta on, August 15, 1992, the fourth day of a provincial heat wave, as an example of the inferred/indirect event-impact classification category.

Inferred/Direct Hazard Map: Hail

A single hailstorm can vary in severity from one area of the province to another. In one region, the hailstorm may deposit golf-ball-sized hail, while in a nearby community the hail may only reach the size of a pea. This spatial variation is characteristic of an inferred event. While a hailstorm is an inferred event, the resulting effects are direct; when hail falls, the resulting damage is directly attributable to the hailstones.

Information on crop damage is collected by both private insurance companies and by the provincial Hail and Crop Insurance Department of the Ministry of Agriculture, Food and Rural Development. This information is extensive in content and resolution, and, for the purpose of this demonstration map, unwieldy. Instead, the general boundaries of the Provincial White Zone (the area of the province in which commercial cultivation is permitted) were used to delineate the spatial extent of vulnerable crops. The Provincial White Zone was digitized as a series of polygons from a 1:1,500,000 map of Alberta (Alberta Forestry, Lands and Wildlife, 1992). These polygons were then shaded, grey for Provincial Green Zone and black for the Provincial White Zone.

Fourteen years of data on provincial hail events, recorded as monthly totals of the number of days with hail for the period 1977-1990, were obtained from AES. These data were then averaged, creating a fourteen-year normal for the number of days of hail experienced at each recording station. The fourteen-year normal, along with the stations geographical coordinates (latitude and longitude) were used to create a provincial distribution of "days with hail" using the multiquadric surfacing program in Terra Firma (Eyton, 1994). This surface was used to create a contour map of the fourteen-year normals.

The information on provincial crop distribution, represented as black polygons, was overlain with white isolines of the "day with hail" normals to create a hazard map for the inferred/direct event-impact. This map (Figure 6) provides information on the frequency and distribution of hail events over a fourteen-year period within the agricultural regions of the province that are the most susceptible to damage.

Specific/Direct Hazard Map: Tornadoes

Tornadoes are the most notable catastrophic events to occur within Alberta (McKay and Lowe, 1960; Newark, 1988). Tornado events are dangerous because of the severity and consistency of the resulting impacts; once a tornado touches down, the damage in all exposed areas is comparable. The severity of tornadoes resulting in extensive damage to humans, their property and/or resources makes a tornado a classic example of an event with specific/direct event-impacts.

If a tornado occurs in the middle of an uninhabited portion of prairie, shrubs may be uprooted and the grass may blow down, but the overall severity will be minimal. A tornado only becomes dangerous when humans and/or their resources are placed in jeopardy. A tornado passing through an urban centre can damage homes, cars, business, roads, and bridges and possess the

Hail Days and Crops

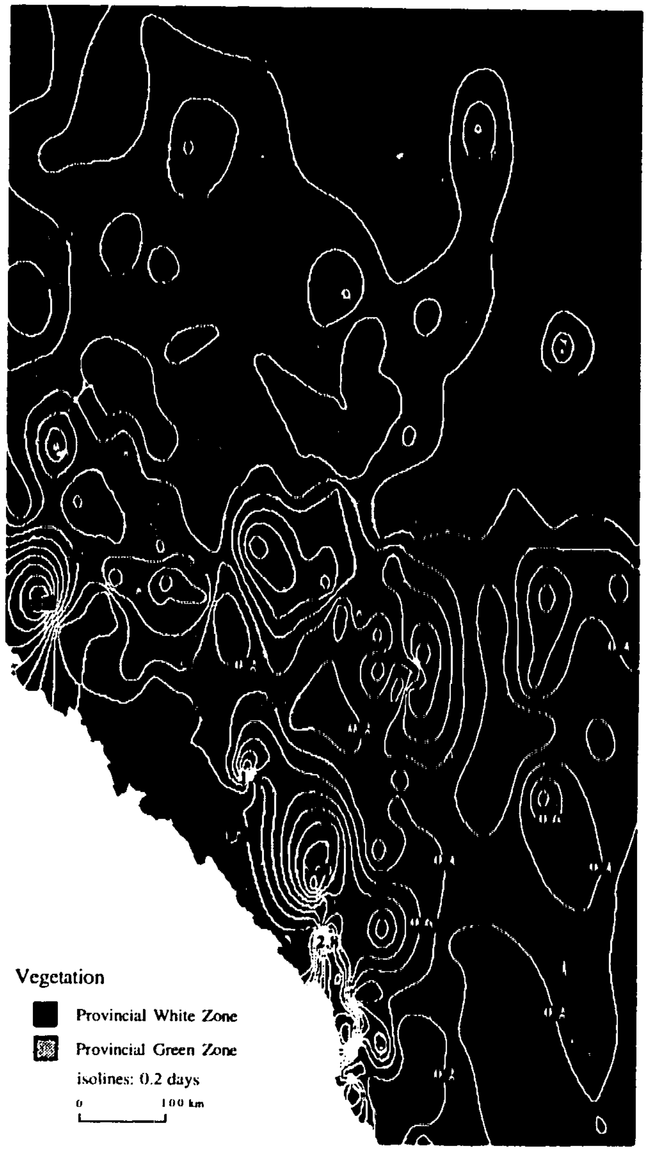

Figure 6. The distribution of fourteen year hail normals over Alberta and their relationship to sensitive agricultural areas as an example of the inferred/direct event-impact classification category.

potential to take many lives. As a result, the population distribution is the most significant variable to map in combination with the frequency of tornado events (Smith, 1992).

There is no specific segment of a population that is more susceptible to the impacts of a tornado. Instead vulnerability increases in areas where the concentration of both humans and their property is high; with more people exposed to a tornado, the severity of potential impact increases. In order to visually present tornado vulnerability, the distribution of population density across the province can be overlaid with the recorded incidents of tornadoes.

The 1986 Census of Canada contains values of the population density in all provincial subdivisions. A surface of these data was created (Terra Firma) and this information was contoured. The contours represent a value of 300 people per square kilometer. Areas with a population density of less than 300 people per square kilometer were shaded light grey and darkened as the density increased. This map, exhibiting both contours and gray tones, provides the human context for the mapping of tornado occurrences.

Tornado sightings have been recorded by the Severe Weather Branch of AES since the early 1980s. Each tornado record includes the name of the nearest town, the provincial region, the time and date of the sighting, and a ranking of the severity of the event (Table 7). These rankings specify the type of tornado that was sighted and provide an indication of the maximum wind speeds (Fujita, 1973). Each AES tornado recording sheet includes space for the observer to record any associated damage or to note any event peculiarities. Unfortunately, the inconsistency of the comments makes them of limited value for anything other than anecdotal notes.

Tornado event rankings and geographical coordinates were the only variables used to map tornado distribution. These tornado data were not surfaced; instead, each observation was assigned a symbol based upon the associated severity ranking and this symbol was plotted at the location of a sighting. The symbols for the Fujita severity rankings of tornadoes were modified to range from F1 to F6 to avoid the use of 0 as a symbol.

The final map (Figure 7) presents information on both the tornado events, by plotting the exact location of each sighting (symbols) and by recording the ranked severity of the event (type of symbol), and on the density characteristics of the population at risk (gray tones and contours). This combination of information shows areas of the province which are frequently impacted by tornadoes and at risk due to high population densities.

Specific/indirect Hazard Map: Lightning

Alberta is subjected to frequent and moderately intense convective processes during the summer months. These convective storms are usually responsible for summer rains, hailstorms, thunderstorms, and lightning events. Of these four events, lightning is the only weather event that can have specific/indirect impacts. As with tornadoes, when

Table 7. The Fujita Tornado Severity Scale*

Severity Rankings	Wind Speed (km/hr)
F0	64 - 116
F1	117 - 180
F2	181 - 252
F3	253 - 330
F4	331 - 417
F5	418 - 509

* Source: Adapted from Fujita (1973).

Tornado Events and Population Density

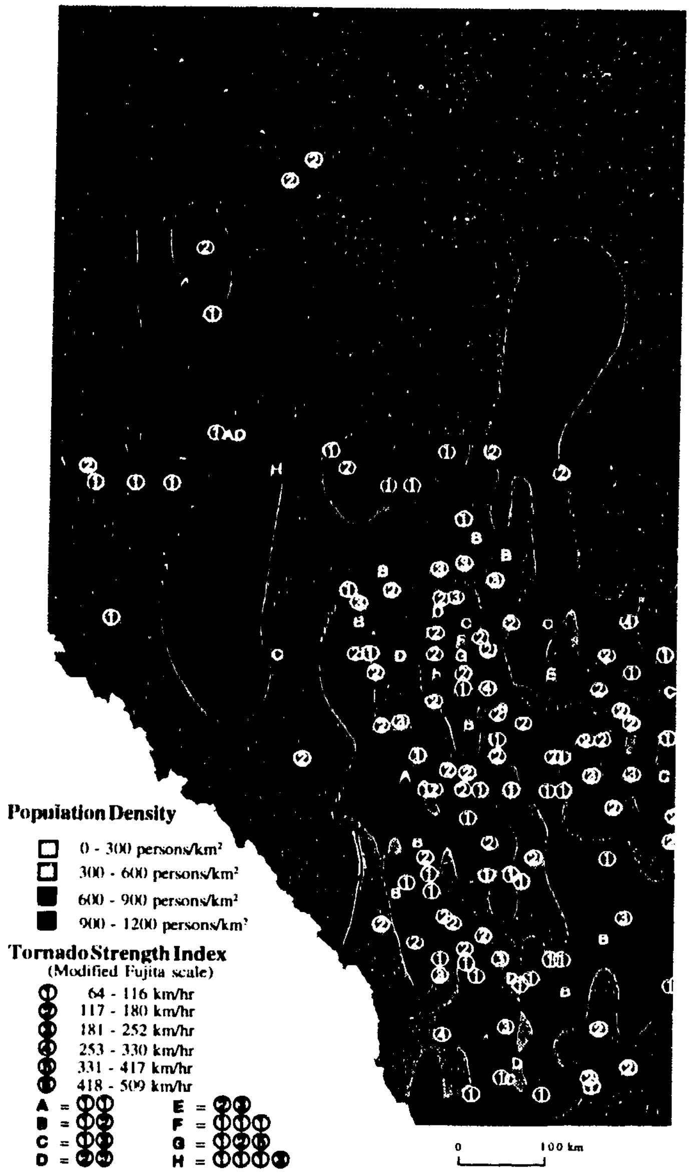

Figure 7. The distribution of nine years of tornado events in Alberta and their relationship to densely populated areas as an example of the specific/direct event-impact classification category.

lightning strikes, damage always results. The damage can range from a burned patch of grass to a forest fire. This specific impact is most commonly associated with direct damage, such as a person being killed while fishing or a single tree being stripped and burned, but the effects of lightning can also be indirect. If lightning strikes and starts a forest fire the effects are direct but if that forest fire then spreads and threatens the safety of a nearby community, the impact becomes indirect. The lightning is not the threat but instead the associated fire places the population at risk.

Lightning events are recorded by Alberta Forest Service and TransAlta Utilities (AES, 1992). Lightning strikes are extremely frequent over the majority of the province during the summer months and, as a result, the resulting database is large. Unfortunately, lightning records are not available in computer-compatible format, making access to this information difficult. Instead, a government of Alberta publication of event maps (Alberta Energy and Natural Resources, 1977) which displays, month by month, the distribution and frequency of lightning strikes was used as the source lightning data.

The lightning frequency map for July, 1977, was selected from this publication (see Figure 1) and the contours of the number of days with lightning were digitized. This lightning frequency information was then surfaced to create a nearly exact digital replica of the 1977 paper map.

In order to include a human context in the lightning event map, the boundaries of the Provincial Green Zone and the Provincial White Zone were digitized as polygons. The Provincial Green Zone was then shaded black and the Provincial White Zone was shaded gray. This created a two-toned vegetation surface upon which to overlay the existing lightning contours.

The resulting map (Figure 8) displays information on forest cover (shaded regions) and information on the number of days of lightning (white contours). This map identifies areas that are susceptible to lightning-induced forest fires and provides the basis for determining which communities are at risk.

Maximum Temperature and Population - Day 4

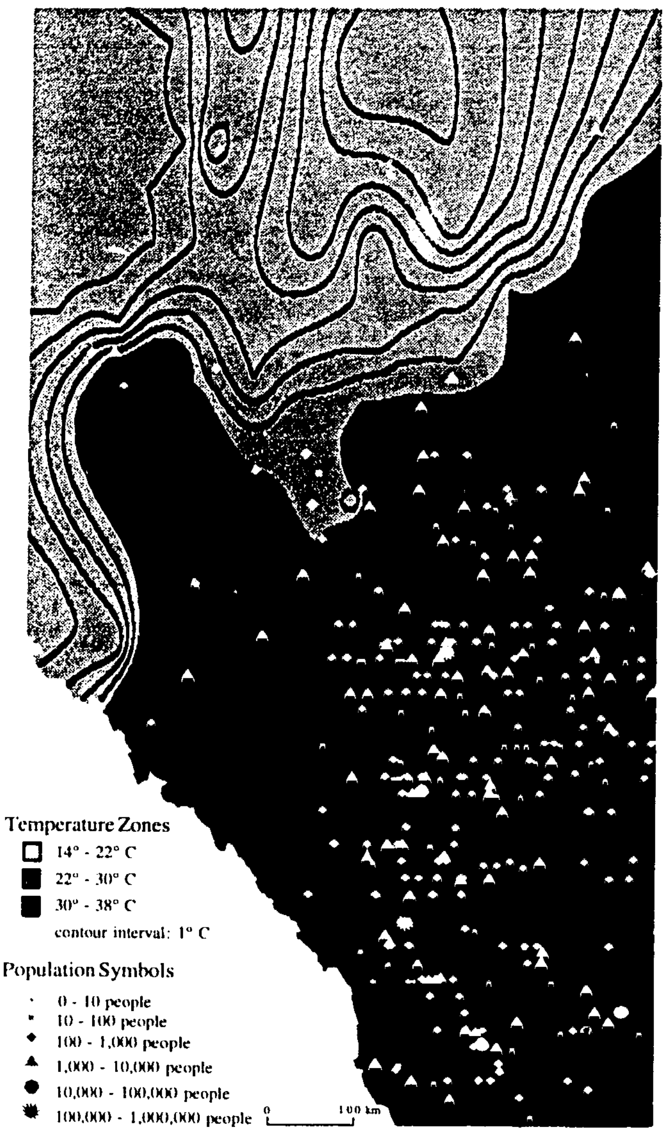

Figure 8. The distribution of days with lightning in August, 1977 in Alberta and their relationship to areas vulnerable to forest fires as an example of the specific/indirect event-impact classification category.

Chapter 5
Discussion

The mapping of hazardous events in terms of frequency of events, spatial distribution and, occasionally, magnitude or strength is relatively common and has often been labelled as 'hazard mapping'. Accepting a definition of a hazard as an event that has negative impacts on humans and associated property and/or resources, then this type of mapping is more accurately labelled 'event mapping'. In order to create a hazard map, human context in the form of socio-economic variables must be combined with physical variables representing the event. This process is feasible, though not flawless, in theory but in practice numerous practical difficulties are encountered. Accurate data collection, data availability, and data accuracy hindered the production of the demonstration maps for the four proposed event-impact classifications.

Demonstration Maps

Demonstration maps for each event-impact category were generated as black and white graphics in order to avoid colour production costs. The purpose of the demonstration maps was not to create cartographically correct maps but was instead to assess the value and limitations of the event-impact classification.

Inferred/Indirect Hazard Map: Extreme Heat

A series of four maps (see Figures 2 to 5) was created to demonstrate the inferred/indirect impacts that extreme temperature can have on the older segment of a population. The four maps clearly show the progression of a 'heat wave' over the province of Alberta during the week of August 12, 1994. By displaying three zones of temperature (high, medium and low) and overlaying this information with symbols showing total population over the age of 45, these maps provide a clear indication of those regions of the province that have a large number of older people who are subjected to extreme heat. Even with rudimentary temperature and population data, it was possible to portray the impacts of an event and to provide a human context for assessment.

Difficulties associated with this map arise from two main sources, impact definition and data availability. In the case of extreme heat, the impact experienced by a population is very difficult to predict and quantify. Epidemiologists understand that there is a link between temperature extremes and mortality but have found that determining the segment of the population that will feel negative effects from extreme heat is a very difficult task. The total number of people over 45 years of age was selected as an appropriate group of people who might be at risk from extreme heat. This is obviously a generalization. Ideally, the number of individuals who suffer from cardiac circulatory conditions would be a more meaningful segment of the population to use as the basis for a vulnerability map. Unfortunately, comprehensive information on the number of people suffering from arteriosclerosis or high blood pressure and their geographic location within the province is not available.

Previous epidemiological studies examining the effects of temperature extremes on human health have used emergency room statistics to determine which segments of the population were affected and how these effects were manifested (Faich and Rose, 1978; Ellis *et al.*, 1975; Giles *et al.*, 1990). Emergency room statistics for a representative sample of Alberta hospitals for August 13, 1992 might be obtainable but because hospitals are located in areas of urban concentration, hospital records would be heavily biassed and would not give complete information on the provincial situation.

The fundamental problem arising from this discussion is that the measurement of a population's health is not feasible. For example, not all people over 45 years of age suffer from heart disease, not all people suffering from heart disease register their problem with the Ministry of Health, and finally, not all people who suffer consequences on a specific day of extreme heat report to their local emergency facility.

Determining the limit where high temperatures become critical is very subjective. Some individuals may start to experience negative effects when the temperature rises above 22°C while more heat-tolerant individuals might not feel any effects until temperatures are well over 30°C (Clarke, 1972). Temperature-sensitive people may have air-conditioning installed, which can also act as an alleviating agent (Rogot *et al.*, 1992). All of these factors make it difficult to generalize what constitutes hazardous heat.

Inferred/Direct Hazard Map: Hail

An inferred/direct hazard map was created with the variables of hail frequency and agricultural crop distribution. The resulting map (see Figure 6) provides an indication of regions that support agricultural activity while also displaying regions that are subject to frequent hail storms. The agricultural information places the hail frequency data into a human context; cropped areas at risk from summer hailstorms are easily identified.

One of the problems highlighted by this map is that the spatial variation of impacts characterizing inferred events is difficult to map. The primary source of this difficulty is the absence of accurate, complete and consistent data on the magnitude or severity of the event. In the demonstration map, the event data used was the number of hail days during the month of June. The underlying assumption is that the more frequent the hail, the more severe the resulting damage. Research by Hillaker and Waite (1985) does not substantiate this assumption. Instead, they found that the majority of crop losses in the American Midwest corn belt occurred during one or two major hail events in a season.

Actual hail damage, as recorded by both provincial and private insurance companies, might be a more appropriate database for identifying hail-sensitive areas. These hail-damage data, combined with hail frequency contours, would create a more informative map. Unfortunately, crop damage by hail is extensive in Alberta and the value of individual claims can reach millions of dollars. This information, available from the Hail and Crop Insurance Branch of the Ministry of Agriculture, Food and Rural Development, was too detailed for the production of generalized maps.

Another type of hail event data might also improve the utility of the demonstration map. In the last nine years, the Severe Weather Branch of AES has started to collect information on the size of falling hail stones. This information would provide an indication of storm severity and would greatly improve the resulting map. One of the problems associated with Severe Weather Branch data is that much of the information is submitted by volunteers or solicited, by telephone, from people who experienced a specific storm (AES, 1992). This type of data collection, while usually quite reliable, does not guarantee objectivity or accuracy.

Specific/Direct Hazard Map: Tornadoes

The map demonstrating the specific/direct event-impact category (see Figure 7) was difficult to create. Unlike the previous event-impact demonstration map, the specific/direct map presents information not just on event distribution and frequency but also incorporates information on event magnitude. The demonstration map presents these three components clearly and incorporates useful information on population density despite problems associated with the data.

Tornadoes and population density were the variables used to create the map and both of these variables presented problems. The surface of population density data was used to create density contour lines, from less than 300 people per square kilometer to 1200 people per square kilometer. While this technique creates an easy to interpret density measure, it does not produce a true density distribution (Cuff and Mattson, 1982). Population density is a ratio measure which is calculated for each provincial census subdivision. The centroid of the subdivision is used as the geographic coordinates of the density values in the surfacing algorithm. The centroid may or may not be the area of population concentration and if the subdivision center is not the population center, the surface is generalized and does not give a true indication of the population distribution.

Tornado data are also problematic for this mapping exercise. Tornado events are recorded by employees of the Severe Weather Branch of AES or through lay reports of sightings. Unfortunately, if a tornado occurs outside a populated area or occurs at a time when there are no observers, the event can go unrecorded. As a result, tornado data are incomplete and heavily biased (in terms of both location and frequency) towards populated areas. While the purpose of this exercise was to determine the hazardousness of an event, the utility resulting from the inclusion of a human context will be reduced if the event data are biassed or incomplete.

Another problem associated with tornado data is that, while the collected information is intended for hazard assessment, the accompanying commentary is not. Each tornado event is assigned a ranking based on the Fujita severity scale, ranging from F0 to F5, corresponding to the speed of the tornado wind. This type of ranking is useful from a meteorological point of view but lacks corollary damage descriptions. Information on the wind speed associated with tornado events does indirectly provide a means for assessing structural damage but this measurement in no way provides information on loss of life, injury, or property damage. As a result, the AES tornado data provide information on the frequency with which tornadoes affect a population but do not indicate degree of impact.

In an effort to alleviate this problem, the Severe Weather Branch of AES provides space on all tornado recording forms for observer comments. These comments are intended to provide case-specific information to supplement the rankings. Unfortunately, comments are not always included and those that are provided vary in detail. This is compounded by the absence of a standardized measurement unit for damage. Some observers comment on the estimated monetary value of the overall damage while others just report "barn damaged" or "injuries". This type of reporting makes quantitative comparison impossible.

Specific/Indirect Hazard Map: Lightning

The demonstration map for this category, lightning days and forest cover (see Figure 8), while the weakest of the hazard maps presented in this research, does nevertheless present event information within the context of the affected population. The lightning strike contours present information on event frequency and distribution and the Provincial White Zone, while rudimentary, does provide the boundaries of the vulnerable resource. Primary weaknesses in this map are the result of an inadequate or inaccessible database.

Lightning is a common phenomenon in Alberta (Harrington and Flannigan, 1987) and is responsible for the majority of summer forest fires (Kiil *et al.*, 1977). The frequency of provincial lightning strikes, both in urban and rural areas, has led to the introduction of remote lightning detection devices that record all strikes within a specified recording area. These devices have produced substantial databases on lightning events. Lightning strike data are recorded by AES and by TransAlta Utilities (AES, 1992) but have yet to be placed in a digital format. As a result, the current database of lightning strikes is difficult to analyze. The demonstration map therefore relied on older data manually collected and recorded by AES. This information, while accessible and accurate, is not as complete in spatial resolution as the new, less accessible, data.

Information on the number of forest fires that are the direct result of lightning strikes is also collected but is not available as a digital database. This data would provide another level of information on the indirect hazard posed by lightning. In order for the map to accurately portray the indirect hazard of lightning events, lightning set fires that threaten populated areas would have to be recorded and mapped. This level of data collection is not presently conducted in Alberta and this type of information would have to be pieced together from newspaper reports.

Each demonstration map showed that the incorporation of a human context in traditional event mapping is not only possible but also creates clear and usable products. The maps also illuminated numerous difficulties associated with event-impact mapping. Differences in data collection types, data availability, and data accuracy all presented fundamental difficulties to the mapping of hazards.

Event-Impact Classification

Risk assessment is still an incomplete methodology. In particular, there is no systematic means for taking into account the independent contextual factors that influence the risk resulting from natural events (Mitchell, 1988; Mather and Sdasyuk, 1991). One of the principal objectives of this project was to create and test a scheme for grouping natural hazards according to their impacts in an attempt to include a human context in traditional event mapping.

The event-impact categories are a method for grouping hazards that serve as a supplement to the traditional method of grouping of natural hazards (Eagleman, 1983). An earthquake, for example, is traditionally labelled as a crustal process. This categorization is useful because it provides insight on the characteristics associated with events of this type. When an earthquake is viewed in terms of impacts felt by a population the effects can be classified as either specific/direct impacts (when a building collapses and kills the inhabitants) or specific/indirect (when the gas mains rupture and cause a life threatening fire). By viewing an event in terms of the resulting impacts, potential mitigation strategies become much clearer. The classification developed in this research produces a methodology for visualizing the types and range of impacts that a specific event may have and thereby improves a community's ability to plan and protect.

The event-impact types, although intended to be a classification tool, also provide a framework for hazard mapping. The characteristics, both spatial and relational, of each event-impact category provide information that is used in the design of hazard maps. For example, events with specific impacts, such as tornadoes, can only be mapped as point observations whereas events that have inferred impacts can be mapped as a surface. Events that have direct impacts can also be mapped as point or area observations whereas events that have indirect impacts, such as heat or lightning-induced fires, are much more difficult to present spatially. Ultimately, the proposed classification provided a clear method for grouping and mapping individual events by their impacts.

Chapter 6
Conclusions

The principal objective of this research was to develop an event-impact classification and to determine if this system contributed to the understanding and assessment of hazardous events. Data for events were chosen to represent the four event-impact categories (inferred/indirect, inferred/direct, specific/direct, and specific/indirect) and data for each event were obtained from both federal and provincial agencies.

Maximum temperature data for a 1992 heat wave were surfaced and contoured to represent an event with inferred/indirect impacts, while fourteen-year hail normals were calculated, surfaced and contoured as an example of an event with inferred/direct impacts. To produce a map representing the category of events with specific/direct impacts, tornado frequency for the last nine years was calculated, ranked, and mapped. Finally, lightning days, representing specific/indirect event-impacts, were digitized from a 1977 Alberta Energy and Natural Resources publication, surfaced and mapped.

While these events were representative of each of the four impact categories, they only provided information on the characteristics of a specific natural event. In order to convey the hazard associated with each of these events, information on the impacts felt by the human population had to be integrated into the event map. The human context for the inferred/indirect impacts proved difficult to quantify because it is not possible to obtain an accurate measure of a population's 'health' - the operative factor in determining human vulnerability to high temperature. Integrating the affected portion of the population with inferred/indirect hail information was much easier to accomplish. While not completely accurate or representative, the Provincial White Zone provided the basis for visualizing the impacts of hail on the agricultural sector. Areas with high hail frequency that are zoned for agriculture can be assumed to be more at risk to damage than areas located outside this zone.

Tornado events, ranked according to the Fujita severity scale, were overlaid with population density. The density measure was generalized during the surfacing procedure but nevertheless provided a human context for the specific/direct impacts of the tornado events. The human impacts of the final event-impact category, specific/indirect, were more difficult to present. Lack of appropriate and accessible data on lighting induced forest fires limited the inclusion of a human context. For the purpose of this demonstration, the general distribution of forest cover was used to represent areas that might suffer from the specific/indirect impacts of lightning.

The demonstration maps for each event-impact category provided insight into both the positive and negative features of the proposed event-impact classification system. The majority of the negative aspects were the result of inappropriate, inaccessible or inaccurate data in the early stages of the event classification process. No measure of a population's health can easily be generated. Crop-hail insurance information is scattered between the provincial Ministry of Agriculture, Foods and Rural Development and private insurance firms, and all of it is far too specific to be useful at a province-wide scale. The collection method for tornado events does not result in an objective data-set and does not include a standardized method for reporting event-specific comments. Finally, information on lightning strikes is unavailable in a digital database, making it unwieldy in the development of computer generated maps. Information on lightning induced forest fires is also available but no indication of community vulnerability is incorporated. The only method of obtaining vulnerability information would be a province-wide newspaper search but this would not provide accurate or complete information.

The demonstration maps highlighted various problems associated with the collection and quality of event data. This does not, however, undermine the usefulness of the proposed event-impact classification. Instead, the event-impact categories proved to be useful, both as a method for analyzing the impacts of hazards and as a framework for mapping.

The proposed classification system provides the tool necessary to assess the potential impacts of an individual event and in so doing, accentuates the need for specific mitigation strategies. This is a valuable addition to the traditional method of grouping natural events by their originating medium. The classification system also provides a framework for hazard mapping decisions; by examining the properties of event-impacts, the most appropriate mapping techniques can be determined. Hazards with inferred impacts are characterized by a spatial variation of the effect. This type of data does not lend itself to point representation; instead the information can be surfaced to show the variation over space. Conversely, those events which result in direct impacts do not lend themselves to surfaces and instead must be represented by point observation symbols.

This research has shown that no one method for mapping hazards exists. Instead there are a variety of different possible approaches with each one having merit. Examining and considering the impact of an event is a useful strategy, in terms of a hazard mapping methodology and from an event mitigation perspective. What this strategy offers is the opportunity for interdisciplinary research on important problems confronting the physical scientists who understand the characteristics of an event and the social scientists who study the impacts felt by humans (Riebsame, 1986).

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