Striking Back: An Assessment of Lightning-related Fatality and Injury Risk in Canada

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EXECUTIVE SUMMARY

Cloud-to-ground (CG) lightning is a common natural atmospheric hazard in Canada. Its significance to health and property is recognized in weather watches and warnings for severe thunderstorms that are issued by Environment Canada and in general public safety and emergency preparedness information provided by government agencies and non-government organizations. The importance of lightning is also reflected in support for the development of the Canadian Lightning Detection Network (CLDN), which was launched in 1998 and forms part of the larger North American and global detection systems.

While systems such as the CLDN allow meteorologists and other scientists to better understand, model and communicate information concerning the physical lightning hazard, equivalent mechanisms are not in place to monitor and evaluate trends in lightning-related injuries and damage in Canada. Such information is critical for baselining, understanding and mitigating the risks of lightning to the general public and sensitive industries, sectors and activities. A review of the literature revealed only three studies that have examined lightning-related casualty risks in Canada—the most thorough of these was completed by Hornstein in 1961.

Based on the literature review results and apparent lack of a recent and substantive national analysis, an empirical case study was conducted by Environment Canada (EC) to assess the fatality and injury risks associated with lightning. The study examined six distinct and readily available sources of mortality or morbidity information:

- National and provincial vital statistics (Statistics Canada, 1921-2003);
- Hospital admission data (Canadian Institute for Health Information, 1999-2003);
- Emergency room visitation data for Ontario (Canadian Institute for Health Information, 2002-2003);
- Property fire data (Council of Canadian Fire Marshals and Fire Commissioners, 1986-2001);
- Canadian newspaper reports (1986-2005); and
- American *Storm Data* (largely based on media reports) for U.S. states bordering Canada (U.S. National Oceanic and Atmospheric Administration, 1994-2005).

Summary statistics of casualty counts and rates, standardized by population, were developed and analyzed in terms of temporal, spatial, population and activity exposure patterns. The main findings are summarized below:

- Lightning kills and injures people in Canada every year. Based on an analysis of media reports, vital statistics, hospital admission and emergency visitation records, and fire loss data, the authors estimate that on average about 9-10 lightning-related deaths and 92-164 injuries occur each year in Canada.
- Lightning mortality has declined significantly over the past century. Vital statistics show that lightning mortality has fallen from a peak of 2.4 deaths per million population over 1931-35 to 0.11 deaths from 1999-2003. This observation is consistent with trends in other developed countries.

- The majority of lightning-related fatalities and injuries in Canada occur in Ontario. Over 90% of lightning deaths reported in vital statistics since 1921 have occurred in Ontario, Quebec, Saskatchewan, Alberta and Manitoba. With the exception of B.C., where few deaths have been recorded, the distribution of fatalities reflects current provincial population and CG lightning frequencies.
- Most lightning-related fatalities and injuries occur during the June-August summer season. Greater than 94% of lightning-related deaths and 74% of injuries reported in the media since 1986 occurred from June-August. The Thursday-Saturday period accounted for almost 55% of all fatalities and over 70% of all injuries, most likely related to higher rates of participation in outdoor activities.
- Most victims are male, less than 45 years old, and engaged in outdoor recreational activities when injured or killed in a lightning incident.
- Media reports used in the study were found to underestimate lightning mortality by 36% when compared to vital statistics. Morbidity was underreported by 20-600% relative to hospital statistics depending on the severity of injury included in the analysis.
- Fires ignited by lightning are important secondary sources of lightning-related casualties accounting for about 3 deaths and 15 injuries per year from 1986-2001.
- Although the relative risks may be small compared to chronic disease, motor vehicle collisions, etc., exposure to lightning and thus the potential risk of injury is very discrete and concentrated in terms of vulnerable activities, locations and time. This concentration makes the lightning hazard more 'potent' than annualized per capita estimates might suggest and, more importantly, allows one to target public risk-reduction strategies, information and programs.

The following recommendations are suggested based on the results of this initial investigation:

- Results from this study should replace current estimates of lightning fatalities and injuries used by Environment Canada and other federal departmental in various communications with the public and other stakeholders.
- National and regional lightning-related estimates should be shared and discussed with provincial emergency management colleagues and incorporated into existing and future EC-provincial or EC-municipal hazard information projects (e.g., http://hazards.ca/).
- EC should consider further development of the media report database to support CLDN operations and further research, including:
  - incorporation of detailed lightning information from CLDN for every injury or fatality incident;
  - support for regular, at least annual, updates of media reports; and
  - addition of a spatial GIS component to incorporate additional exposure-related data (e.g., population).
- In terms of continued research, the current health impact study should be expanded as planned to investigate the social and economic impacts associated with lightning-related property damage and service interruptions using a combination of data derived from media reports and sector-specific records. Further analysis of injury and fatalities at the storm level to discern additional finer-scaled risk patterns or

associations between lightning and exposure is also warranted. A major focus in both sets of studies should be on evaluation of risk or damage prevention measures, particularly those that relate to expanded or enriched use of the CLDN data by both public and private sector clients.

1.0 INTRODUCTION

Environment Canada issues approximately 14,000 warnings of severe weather each year (MSC, 2003). During the spring, summer and early autumn seasons, the bulk of these warnings are issued to alert the public of the development and imminent arrival of severe thunderstorms and the potential for damaging winds, heavy rainfall, large hail, and intense cloud-to-ground (CG) lightning.

With the development and implementation of the Canadian Lightning Detection Network (CLDN) in 1998, Canadians now have basic systems in place to detect and monitor each of these potentially deadly facets of severe weather. In fact, with several years of data, scientists are generating lightning climatologies (e.g., Burrows *et al.*, 2002) that parallel those for wind, rainfall, tornadoes and hail, and are developing methods to predict lightning occurrence as part of a severe weather forecasting program. Unfortunately, the equivalent systems are not in place to continuously monitor and evaluate trends in the impacts of severe weather in Canada—this is particularly evident for lightning-related injuries and damage. Such information is critical for baselining and understanding the risks of lightning to the general public and sensitive industries, sectors and activities (e.g., forestry). It is also essential for evaluating the effectiveness of monitoring and warning information and associated short- and longer-term responses (i.e., immediate emergency response through to education programs). By default, Environment Canada has relied upon relatively gross estimates of impact that are difficult to independently verify or are based on outdated information (e.g., 6 deaths and 60-70 injuries annually, EC, 2000; previously quoted 16 deaths and 100 injuries based on a national study by Hornstein, 1961). Relative to public health impacts, our understanding of damage is better in certain economic sectors like forestry (e.g., forested area burned from fires caused by lightning) and aviation, but composite pictures of national impact and trends remain elusive.

1.1 Project Goal

In response to this need, Environment Canada and university partners have begun developing an assessment of the impacts of lightning in Canada. The broad goal of the research is to improve our understanding of the impact of lightning on Canadians in terms of health, property damage, service interruptions and associated economic implications. This report summarizes progress made towards understanding the first and most important impact in this list—the health implications of lightning. In doing so, the extent to which our systems and activities are currently adapted to lightning-related risks will also become apparent, the basis for identifying and assessing future improvements/solutions.

The first section of the report introduces and characterizes the lightning hazard and profiles pathways to injuries and fatalities[1]. Studies that have estimated lightning-related injury risk in Canada and elsewhere are then reviewed leading into a case study where

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[1] Deaths, fatalities and morbidity are used interchangeably through the report as are injuries and morbidity. Casualties refers to the sum of all deaths and injuries.

multiple datasets and approaches are used to define new Canadian risk estimates. The report concludes with a general discussion and summary of results and recommendations for future applications and research.

1.2 Characterizing the Lightning Hazard

Physical characteristics

Lightning is a large static electrical discharge that develops most commonly within thunderstorms where convection and gravitational forces combine with an ample supply of particles to generate differential electrostatic charges[2]. When these charges achieve sufficient strength to overcome the insulating threshold of the local atmosphere then lightning may occur. In thunderstorms, this process results in an accumulation of positive charges towards the top of clouds and an accumulation of negative charges in the cloud base region. The built-up electrical potential is neutralized through an electrical discharge within or between clouds (in-cloud lightning), or between the cloud and ground (cloud-to-ground or CG lightning). Most CG lightning involves a transfer of negative charge from the base region of a cloud to a positively-charged surface feature. A flash occurs once a leader from the base cloud region meets an upward streamer emanating from the surface feature—the flash consists of one to several return strokes that transfer the main current of the discharge. Less frequently the CG flash emanates from the top or other positively charged region of the cloud and transfers a positive charge to a negatively-charged surface feature. Positive CG flashes often have a greater peak current, transfer more charge, and may travel further than negative CG flashes (Rakov, 2003). Positive CG flashes are also relatively more common during the cold season, during the dissipating phase of thunderstorms, and within severe thunderstorms (Rakov, 2003; Murphy and Conrad, 2005; Carey and Rutledge, 2004; Price and Murphy, 2002).

Lightning climatology

Historically, investigations into lightning climatologies have relied upon general weather observations of thunderstorm occurrence (e.g., Phillips, 1990). However, efforts within the past 15 years have had the advantage of new ground and space-borne lightning detection systems, tools and datasets that have allowed for more comprehensive and in-depth analyses. The CLDN, part of the larger North American (NALDN) and global network, is an essential component of this new monitoring infrastructure. An overview of the CLDN is described in Box 1. Data from the CLDN and similar systems have been applied to understand lightning frequency and occurrence from local to global geographic scales (Bentley and Stallins, 2005; Burrows *et al.*, 2002; Christian *et al.*, 2003; Clodman and Chisholm, 1996; Hodanish *et al.*, 1997; Murphy and Konrad, 2005; Orville *et al.*, 2002; Stallins, 2004; Tomas *et al.*, 2004).

[2] Lightning is also associated with other phenomena where these same forces occur, including volcanic eruptions and large forest fires.

Canadian lightning researchers, using cloud-to-cloud and CG flash density data for the 1998-2000 period, observed that southern Alberta, southwestern Ontario, and areas off the southern coast of Nova Scotia have the highest annual number of lightning days, while western British Columbia, the Arctic, and land areas east of New Brunswick have the fewest (Burrows *et al.*, 2002). When lightning occurs in Canada, it typically takes place during the warm-weather months (May to October) and during the day. Many of the observations by Burrows *et al.* (2002) are similar to patterns identified by Orville et al. (2002) in their study of a 3-year North American lightning dataset derived from the NALDN. The observations are also consistent with more recent analyses, including the map of recent mean CG flash density (2000-2004) provided in Figure 1 (Vaisala, 2006). In general, greater frequency of lightning days and higher flash densities in Canada coincide with more populous regions of the country. As the CLDN matures, longer and thus more representative datasets will facilitate greater insight into the physical characteristics and spatio-temporal patterns of lightning that will enable improved interpretations of injury risk.

BOX 1: <u>The Canadian Lightning Detection Network</u>

Information on the precise location, strength and timing of lightning is crucial to a wide range of operations that are vulnerable to direct hits or to fluctuations in electric power. By confirming that there is a mature thunderstorm in progress, the presence of lightning assists weather forecasters in issuing warnings to those at risk. For example, the aviation industry relies on such warnings to protect aircraft and ground crew, while forestry and parks services use them to determine areas where lightning-induced fires are most likely to occur, as early detection is critical to saving valuable timber.

A reliance on radar, satellite imagery and ground reports made lightning detection a challenging task, particularly in unpopulated areas, until the Canadian Lightning Detection Network came into being in 1998. Eighty-one sensors across the country, most of them located south of the treeline, form the Canadian half of a North American network that is the largest of its kind in the world, able to process more than 200 000 strikes per hour. The Canadian network not only detects ground strikes, but also is the first national network of its size with the capability to detect cloud-to-cloud lightning.

The cylindrical sensors, which stand over a metre high, determine the strength, polarity and timing of lightning from the electromagnetic pulse it produces. The pulse information is sent via a miniature satellite dish to the network control centre in Tucson, Arizona. There the information from many sensors in the network is integrated to determine the location of the strike, in some areas to within half a kilometre. The lightning location information is then transmitted to Environment Canada's weather centres, where it is mapped on a computer screen in real time. The whole process takes less than 40 seconds from start to finish. Every strike detected by the network is stored in a data archive, which can be used to produce flash-density maps showing lightning activity in Canada over a certain period of time.

<u>Source:</u> Excerpt from Environment Canada 2000. Network pinpoints lightning strikes, *Science and the Environment Bulletin*, September/October. http://www.ec.gc.ca/science/sandesept00/article6_e.html

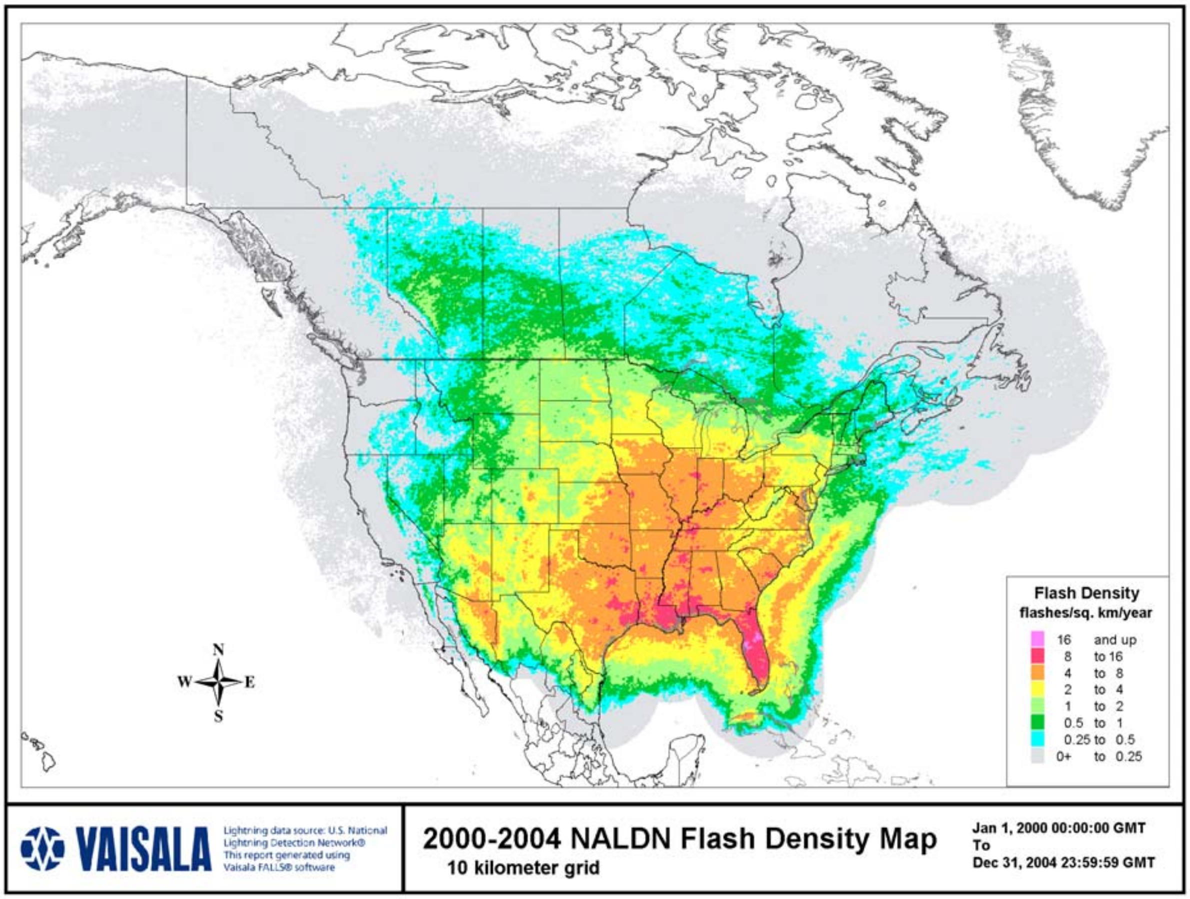


Figure 1. North American average annual cloud-to-ground lightning flash density, 2000-2004 (Vaisala, 2006).

2.0 LITERATURE REVIEW

A literature review was conducted to identify Canadian and international studies that had analyzed lightning-related fatalities and injuries. Additional clinical and epidemiological research was assessed to provide an overview of the etiology of injuries associated with lightning and information concerning the socio-demographic factors that influence exposure.

2.1 Incidence of Lightning Mortality and Injury

Lightning-related mortality and morbidity risks have been the focus of several studies in the international scientific literature. Study locations, timeframes, counts of deaths and injuries, mortality and injury rates (most often expressed per unit population) and primary data sources for many of these investigations are summarized in Table 1.

Most of the literature concerning lightning-related casualties refers to studies conducted for the United States (Duclos *et al.*, 1990; Lopez *et al.*, 1993, 1995; Lopez and Holle, 1996, 1998; Shearman and Ojala, 1999; Curran *et al.*, 2000; Cherington, 2001). Additional work was uncovered for Australia (Coates *et al.*, 1993), Canada (Hornstein, 1961; Bains and Hoey, 1998; Nguyen and Bailey, 2004), Netherlands (ten Duis, 1998), Singapore (Pakiam *et al.*, 1981) and the United Kingdom (Baker, 1984; Elsom, 1993, 2001). Pakiam *et al.* (1981), Carte *et al.* (2002) and Coates *et al.* (1993) make reference to casualty estimates from Austria, Germany, South Africa and Zimbabwe.

Data sources and reporting methods

While a variety of data sources are used to estimate lightning-related mortality and injuries, most researchers have relied upon government health statistics (death certificates, vital statistics, or hospital discharge data) and newspaper articles. Many American studies rely heavily on the US National Atmospheric and Oceanic Administration (NOAA) *Storm Data* database which uses a combination of media references and reports from law enforcement agencies, local government officials and others in documenting weather-related fatalities, injuries and property damage (NOAA, 2006). A similar composite database for lightning-related impacts is maintained by the TORnado and storm Research Organisation (TORRO) in the United Kingdom (TORRO, 2006). Only one study was found that did not rely upon historical observations or evidence of lightning strikes to humans. Szczerbiński (2003), relying upon theoretical principles rather than empirical observations, estimated that the risk of being struck directly by lightning for a person continuously exposed in the open would be once in 2000 years.

Regardless of source data, lightning casualties are reported and analyzed in different ways. National or state fatalities and injuries are most commonly reported as simple counts over study periods and less frequently as a rate per year standardized either by population or lightning incidence.

Fatalities

Despite differences in reporting methods, there is evidence of strong spatial and temporal variation in lightning mortality. Gross national values range from as few as 1 fatality over 40 years in Northern Ireland to over 20,000 deaths reported in the United States between 1900 and 1991 (Baker, 1984; Lopez and Holle, 1998). Annual mortality rates, normally expressed per million population, ranged from 0 in Alaska (1900-1991) to over 6 in the United States as a whole in 1901 (Lopez and Holle, 1998). Holle and Lopez (2003) estimate an annual mortality rate of about 6 per million population in less-developed nations (e.g., countries in southern Africa, South and Central America, Southeast Asia)

Contemporary fatality rates in most developed nations over the past 30 years are much lower, typically between 0.1 and 1 death per million, than those reported for the early to mid-1900s. Elsom (2001) observed a trend towards fewer lightning fatalities in England

and Wales over the past century and suggested it was partly due to the concurrent patterns of fewer people working outdoors in open fields, the expansion of urban areas that provide more structures to attract lightning away from people, improved weather forecasts that have enabled people to plan activities that avoid being outside during a thunderstorm, and improved responses by medical staff. In the United States, a ten-fold reduction in the population-weighted rate of lightning-caused deaths over the last century has been hypothesized to be the result of a decrease in the percentage of the population living in rural areas (Holle *et al.*, 2005). Adekoya and Nolte (2005) suggested that this decline is also the result of individuals being more aware of risks, greater adoption of appropriate precautions, and an improved medical response to lightning victims.

A few studies have standardized fatalities by lightning occurrence and limited results also indicate the presence of spatial patterns. Curran *et al.* (2000) estimated a rate of one death per 345,000 CG lightning strikes in the United States and Elsom (2001) reported a value of 1 death per 100,000 CG strikes in England and Wales.

Injuries

Injury and casualty counts and rates are reported less frequently and are less consistent across jurisdictions than fatalities which, by definition, should be easier to document and track. In general, more injuries occur than fatalities, with injury-to-fatality ratio estimates ranging from 1:1 (Pakiam *et al.*,1981) to 16:1 (Elsom, 2001). Trends toward higher injury-to-fatality ratios are also likely due to improved medical science and response among both health professionals and the public—in other words, many of those who would have been killed are now saved but still injured. These factors may also partially explain the disparity between reductions in injuries and fatalities as reported in a 1959-1990 study by Lopez and Holle (1996). No doubt the capacity and ability to identify, report and track injuries has improved over this period as well thus resulting in more injuries being included in the tally.

2.2 Canadian Estimates

Only three known studies have examined Canadian data. Hornstein (1961, 1962) provided the first thorough descriptive account of lightning deaths and damage in Canada. Until very recently his estimate of 16 lightning fatalities per year, based on Dominion Bureau of Statistics data for 1939 to 1958, was used by Environment Canada to communicate the potential impacts of the lightning hazard. More recently, a brief report in the Canadian Medical Journal noted that between 1991 and 1995, the death certificates of 27 Canadians listed ICD code E907 ("*lightning, excluding injury from fall of a tree or other object caused by lighting*") as the cause of death (Bains and Hoey, 1998). The third Canadian reference is an epidemiological study of electrical and lightning-related deaths among Canadian children and youth (ages 0-19) (Nguyen *et al.*, 2004). Over the 1991-96 study period, they identified 21 deaths (based on data from provincial/territorial coroners offices) and 606 injuries (based on Canadian Hospitals Injury Reporting and Prevention Program data) caused by electrocution. However, only

5 of the deaths and 9 of the injuries were due to lightning, yielding an annual lightning-related mortality rate of 0.01 per 100,000 children (ages 0-19) (Nguyen *et al.*,2004).

2.3 Underreporting

Underreporting and lack of standard casualty definitions are recurrent themes acknowledged in several of the international studies (Holle *et al.*, 2005; Curran *et al.* 2000, Shearman and Ojala, 1999; Lopez *et al.*, 1993; Coates *et al.*,1993; Duclos *et al.*, 1990) and appear to be more problematic for injuries than fatalities. Sources that rely on newspapers are limited by the coverage of papers relative to the geographic scope of the study, the "newsworthiness" or relevance of a particular lightning incident relative to other stories, the availability or limitations of electronic or catalogue searches, and the reliability of sources (e.g., public vs. emergency official accounts). Official government health agency sources may be constrained by misinterpretation of World Health Organisation (WHO) International Classification of Diseases (ICD) coding and reporting errors[3] (i.e., miscoding victim presentations), or improper assignment of place of death or injury (e.g., some sources report only on death by place of residence). Hospitalization records may be sample-based (i.e., only include a subset of hospitals) and by definition do not account for non-admitted victims whose injuries are treated at the scene of a lightning incident, in an emergency room, or by a family physician.

A few researchers have attempted to estimate the extent of underreporting by evaluating data from multiple sources. Analyses into the accuracy of *Storm Data* have been performed in comparison with state or federal mortality data. The general consensus of these studies is that the *Storm Data* underestimates the number of lightning related deaths compared with death certificate data. The exact figures vary from state to state but typically the mortality underestimation ranges between 17% and 33% (Holle *et al.*, 2005; Shearman and Ojala, 1999; Lopez *et al.*, 1993).

2.4 Injury Mechanisms and Factors Influencing Exposure

A brief review of the etiology of injuries associated with lightning is useful background to interpret the case results presented later in the report. Studies by health scientists and others have investigated lightning injuries and injury profiles at the individual and population scales. The former has lead to the development of several inventories or taxonomies of injuries while the latter yields important information about socio-demographic factors that influence exposure.

[3] Lewis (1997) has noted that without witnesses to the event it may be difficult to determine that a patient's injuries were the result of lightning

Table 1. Summary of published estimates of lightning-related deaths and injuries

Author	Timeframe	Location	Deaths and injuries	Annual mortality, injury or casualty rates per million population (unless otherwise stated)	Data Sources
Bains and Hoey (1998)	1991-1995	Canada	27 deaths	n/a	Death certificates (government)
Baker (1984)	1941-1980	England and Wales	263 deaths	7.0 million to one	Unknown
Baker (1984)	1951-1980	Scotland	9 deaths	17.3 million to one	Unknown
Baker (1984)	1954-1969	Ireland	7 deaths	n/a	Unknown
Baker (1984)	1941-1980	Northern Ireland	1 death	57.1 million to one	Unknown
Cherington (2001)	1989-1995	Rocky Mountains (Colorado)	39 deaths	n/a	Newspapers
Coates *et al.* (1993)	1824-1991	Australia	650 deaths	0.08 per 100,000 (1910-89) 0.01 per 100,000 (1980-89)	Newspapers, Australian Bureau of Statistics
Curran *et al.* (2000)	1959-1994	United States	3239 deaths	0.42 (0.0-1.88, Alaska-New Mexico) 1 per 345,000 CG strikes	US NOAA Storm data
			9818 injuries	1.26 (0.0-5.74, Alaska-Wyoming)	
Duclos *et al.* (1990)	1978-1987	Florida	101 deaths	0.09 per 100,000	Death certificates, autopsy reports, Florida Hospital Cost Containment Board, US NOAA Storm data, hospitals
			44 injuries[1] (1987)	0.54 casualties[2] per 100,000 (1987)	
ten Duis (1998)	1910-1995	Netherlands	602 deaths[3]	n/a	Unknown
Elsom (1993)	1975-1990	England and Wales	56 deaths	n/a	Office of Population Censuses and Surveys
Elsom (2001)	1993-1999	United Kingdom	22 deaths	0.05 1 death per 100,000 CG strikes	Tornado and Storm Research Organisation database (reports in journals, news media, voluntary thunderstorm observer network)
			341 injuries	1 injury incident per 12,000 CG strikes	
Hornstein (1961,1962)	1939-1958	Canada	320 deaths	1.1	Bureau of Government Statistics
Lopez and Holle (1996)	1959-1990	United States	2983 deaths	n/a	US NOAA Storm Data
Lopez and Holle (1998)	1900-1991	United States	20758 deaths	0.3-6.3 (1991, 1901)	Bureau of the Census and Public Health Service (mortality and vital statistics)
			8233 injuries	n/a	
Lopez *et al.* (1993)	1980-1991	Colorado	36-51 deaths[4]	n/a	Colorado Department of Health (death certificates), US NOAA Storm Data, newspapers, Colorado Hospital Association (discharge data)
			46-82 injuries[5] (1988-1991)	n/a	
Lopez *et al.* (1995)	1950-1991	Colorado	103 deaths	n/a	US NOAA Storm Data
			299 injuries	0.1 casualties[2] per million people per $10,000 km^2$	
Nguyen and Bailey (2004)	1991-1996	Canada	5 deaths (0-19 years)	0.01 per 100,000 children 0-19 years old	Provincial and territorial coroners offices, Canadian Hospitals Injury Reporting and Prevention Program data
			9 injuries(0-19 years)	n/a	
Pakiam *et al.* (1981)	1956-1979	Singapore	80 deaths	1.7 (1961-79)	Meteorological Services Singapore, report on Registration of Birth and Deaths, Ministry of Health, newspapers
Shearman and Ojala (1999)	1978-1994	Michigan	39-47 deaths[6]	n/a	US NOAA Storm data, Michigan Department of Public Health (death certificates, hospital discharge records)
			203-246 injuries[7]	n/a	

[1] estimated
[2] casualties are the sum of reported deaths and injuries
[3] estimate based on figure 1 in article
[4] varied by source (36-US NOAA Storm data, 51-Colorado Department of Health
[5] varied by source (46-Colorado Hospital Association discharge data, 82-US NOAA Storm Data)
[6] varied by source (39-US NOAA Storm data, 47-Michigan Department of Health
[7] varied by source (203-Michigan Department of Health, 246-US NOAA Storm Data)

Injury mechanisms

Several pathways have been identified through which lightning may directly or indirectly injure an individual (Lewis, 1997; Walsh et al., 2000):

1) *Direct hits*, most often to the head, result in the most serious injuries, and usually occur to people standing out in the open.
2) *Contact voltage* occurs when current enters the body via objects touching a person (e.g., golf club, umbrella, phone).
3) *Splash or flashover voltage* refers to a situation where lightning strikes an object (e.g., tree) and then arcs to an adjacent person. In some splash voltage cases the discharge results in multiple casualties.
4) *Step voltage* involves current striking the surface and fanning out through the ground. Depending on environmental conditions, the orientation of an individual, and distance from the strike, the path of least resistance may take the current from the ground through the body thereby causing an injury. Multiple casualties may also result from step voltage incidents.

Anderson (2001) speculated that a fifth mechanism exists in which a person may be electrocuted in the upward streamer phase of lightning development. He suggests that this may account for some of the injuries commonly attributed to splash and step voltage processes.

Many injuries associated with lightning are caused by secondary mechanisms. For instance, blunt injuries may be sustained by persons after being thrown by the force of the shock wave produced by lightning or by muscle contractions caused by the current (Zafren *et al.*, 2005). Rapid vapourization of water in vegetation from the intense, concentrated heat of a lightning flash may literally explode tree limbs and bark which may then become projectiles that can initiate blunt trauma. Even less direct but still relevant are injuries associated with fires that were ignited by lightning.

The clinical literature contains several references to the presentation, treatment, categorization and analysis of lightning-related injuries (e.g., Aslan *et al.*, 2005; Aslan *et al.*, 2004; Sommer and Lund-Andersen, 2004; Courtman and Wilson, 2003; Carte *et al.*, 2002; Duff and McCaffrey, 2001; Muehlberger *et al.*, 2001; van Zomeren *et al.*, 1998; Zack *et al.*, 1997). Based on a thorough review of the literature, Lewis (1997) developed an inventory of lightning injuries arranged by body system (Table 2). Of the injuries profiled in Table 2, the most severe are related to the cardiac system with cardiopulmonary arrest being the most frequent cause of death (Lewis, 1997; Zafren *et al.*, 2005). The short duration of contact with lightning current is often attributed by researchers as the reason why many other injuries, including paralysis, resolve within a short period without extensive intervention (Lewis 1997). Long-term or permanent physical injuries among lightning-strike survivors, although infrequent, include burn scars, hearing loss and cataracts (Lewis, 1997; Zafren *et al.* 2005). Psychological impacts (most commonly post-traumatic stress syndrome, depression, phobias, and irritability) have been identified in several studies, however, methodological limitations (i.e., failure to separate electrical from lightning injuries, lack of longitudinal assessments, lack of appropriate controls, small sample sizes, and limited range of assessments) question the validity or representativeness of findings (Duff and McCaffrey, 2001). Other studies have shown little or no long-term psychological functioning impact (Muehlberger *et al.*, 2001; Gatewood and Zane, 2004) thus, while psychological impacts have been reported, there is presently not a consistent psychological symptom profile for lightning victims.

Table 2. Lightning injuries to body systems (Lewis, 1997)

Body System	Types of Lightning-related Injuries
Integumentary system:	Linear, punctate, and partial- or full-thickness burns; keraunographic markings
Cardiac system:	Ventricular fibrillation; asystole; hypertension; tachycardia; nonspecific ST-segment and T-wave changes; prolonged Q-T intervals; premature ventricular contractions; myocardial infarction
Central nervous system:	Weakness; amnesia; confusion; intracranial injuries; immediate loss of consciousness; brief aphasia; paraplegia; quadriplegia; spinal cord damage; cold, mottled, pulseless extremities
Ears and eyes:	Tympanic membrane perforation; secondary otitis media; transient dizziness; temporary or permanent deafness; dilated and/or nonreactive pupils; transient blindness; corneal edema; uveitis; hyphema; vitreous hemorrhage; cataracts
Other injuries:	Myoglobinuria (rare); myalgias; hypothermia; blunt trauma (e.g., vertebral, skull, rib and extremity fractures)

Factors influencing exposure

Past research has revealed a number of situational and population characteristics that influence exposure. These factors, identified through analyses of those injured or killed, provide insight into the "when, where and what" features of lightning casualty incidents.

Temporal considerations

An individual's risk of being struck by lightning has been shown to vary by time of year, week, and day. Summer is the peak season for lightning occurrence in mid-latitude locations and, not surprisingly, is also when most lightning-related injuries and fatalities occur. The months of June to August account for nearly 70% of the total lightning strike incidents in the United Kingdom (Elsom, 2001) while most lightning fatalities in Australia occur between November and February (i.e., during the Southern Hemisphere summer) (Coates *et al.*, 1993). In the United States, casualties occur almost entirely between May and August with a monthly maximum in July (Lopez and Holle, 1995; Curran *et al.* 2000).

With respect to day-of-week patterns, Curran *et al.* (2000) reported that 24% more lightning deaths occur on Sunday than on any other day of the week in the United States, with Wednesday being the next most common. This most likely relates to the activity and exposure factors noted in the next section. Regarding time of day, the majority of casualties in the United States occur during the afternoon and early evening from 1200 to 1800 hours, again generally coincident with maximum thunderstorm development and lightning incidence (Lopez and Holle, 1995; Curran *et al.*, 2000).

Geographic, population and activity-related factors

Geographic and socio-demographic influences are interrelated at a variety of scales. At a macro level, the frequency of CG lightning occurrence and population density in particular regions intuitively play a significant role in exposure—more people and more lightning equates to greater potential that an individual might be struck. As illustrated in Figure 1, annual North American CG lightning flash densities are greatest in Florida and Texas—these two states also experience the greatest number of absolute lightning casualties each year (Adekoya and Nolte, 2005). Lightning injuries are also relatively frequent in other southern states, the Rocky Mountains, Midwest, and along the Atlantic coast where the greatest number of thunderstorms occur (Lewis, 1997). When normalized for population density, injury rates are highest in the Rocky Mountain and Plains states (Cooper *et al.*, 2001). Of the 27 deaths reported in Canada from 1991-1995, 11 occurred in Ontario, 6 in Quebec, 6 in the Prairies, 3 in the Maritimes, and 1 in British Columbia (Bains and Hoey, 1998). This pattern is consistent with lightning occurrence and population density in Canada which are both greatest in Ontario.

Changes in the proportion of population living in rural and urban areas also seem to be related to macro-level shifts in lightning casualties. Rural (urban) regions accounted for 76% (24%) of all lightning fatalities reported in the United States during the 1890s but only 46% (54%) during the 1990s (Holle *et al.*, 2005). This observation likely reflects changes in occupation and exposure (i.e., less time spent in unprotected rural areas) in addition to the influence of urbanization.

Several studies have observed patterns in the demographic characteristics of those struck by lightning, including gender and age. Typically, it is younger men who account for the majority of lightning strike victims. In the UK, Elsom (2001) reported that males were struck more often than women (65% male and 35% female) and that the average age was 30 years (median 26). Similarly, males accounted for 84% of lightning fatalities and 82% of injuries in an American study based on *Storm Data* for the years 1959-1994 (Curran *et al.*, 2000). Among the 27 lightning deaths reported in Canada from 1991-1995, men, 15-50 years of age, were much more likely to be killed (Bains and Hoey, 1998). In a study that investigated work-related lightning injuries based on data from the Census of Fatal Occupational Injuries (CFOI) (1995-2000), workers 20-44 years of age accounted for 67% of deaths and all but two of those killed were male (Adekoya and Nolte, 2005).

This population-level association between age or gender and casualties is founded in a social preference for particular activities that lead to increased outdoor exposure rather than any medical predisposition to injury. While Elsom (2001) noted in a UK study that 52% of lightning incidents affected people while they were indoors, none were fatal. Similarly, in other studies, the vast majority of fatal incidents occur in outdoor environments, a pattern that has held throughout the past century, but one in which the chief activities have shifted from being occupation- to recreation-based (Pakiam *et al.*, 1981; ten Duis, 1998; Holle *et al.*, 2005).

Different outdoor activities entail different levels of risk. In a Colorado study, the two activities that accounted for the most number of lightning victims were recreation (52%) and employment (25%) (Lopez and Holle, 1995). Specific to work, the most predominant work activities that have been reported are construction (25%) and material handling (e.g., loading and unloading) (12%) (Adekoya and Nolte, 2005). According to an analysis of *Storm Data* for the years 1959-1994, the activities most commonly engaged in while being struck by lightning were, in order: open fields, ballparks and playgrounds; under trees; water-related activities (e.g., fishing, boating, swimming); golfing; operating tractors, farm equipment and heavy road equipment; on the telephone; and touching a radio, transmitter or antenna (Curran *et al.*, 2000). The distribution of fatality locations/activities in the UK study by Elsom (2001) showed similar results.

3.0 A CANADIAN CASE STUDY

Based on the literature review results and apparent lack of a recent and substantive national analysis, a case study was conducted to assess the fatality and injury risks associated with lightning in Canada. The study examined six distinct but readily available sources of mortality or morbidity information: national and provincial vital statistics, hospital admission data, emergency room visitation data, fire loss data, Canadian media/newspaper reports and American *Storm Data*. The data and related analyses are described below in three sections: 1) analysis of official Canadian mortality and injury data, 2) analysis of Canadian media reports, and 3) analysis and transfer of U.S. lightning mortality and morbidity statistics.

3.1 Analysis of Official Canadian Mortality and Injury Data

Official government or other standardized sources of data serve as the basis for many of the international studies discussed in the literature review. As noted in the literature review (Table 1), many researchers investigating lightning-related fatalities utilize official vital statistics collected by government agencies or industry-recognized organizations. The official data used in the Canadian case study, summarized in Table 3, were obtained from Statistics Canada, the Canadian Institute for Health Information (CIHI) and the Canadian Council of Fire Marshals and Fire Commissioners (CCFMFC). The following sections review each data source, present summary statistics for fatalities and injuries, and analyze and interpret some of the main observations.

Table 3. Description of official sources of mortality and morbidity data used in case study

Data	Period	Source	Region	Completeness
Vital statistics – cause-of-death by gender	1921-2002	Statistics Canada	National and provincial (except 1950-64)	– based on ICD codes (E907) and place of residence – non-Canadians excluded
National Trauma Registry – admissions to acute care hospitals	1999-2003*	Canadian Institute for Health Information (CIHI)	National	– based on ICD-9 code (E907) and ICD-10 code (X33 victim of lightning) – data collected only for acute care hospitals
National Ambulatory Care Registry System – emergency room visits	2002-2003*	Canadian Institute for Health Information (CIHI)	Ontario	– based on ICD-10 code (X33 victim of lightning)
Injuries caused by fires ignited by lightning	1986-2001	Council of Canadian Fire Marshals and Fire Commissioners (CCFMFC)	National and provincial	– based on standard code of fires by source of ignition (CCFMFC 2002) – includes fires where response was from a government fire department – does not include forest fires that do not affect structures

*based on FY (April 1-March 31)

Fatalities based on vital statistics

Data for all deaths caused by lightning for the period 1921-2003 were obtained from Statistics Canada. The data, disaggregated by province and gender (except for 1950-64, 1999-2003), refer only to lightning-related deaths as defined by various editions of the International Classification of Diseases (ICD) code and its predecessors (WHO, 2006). Indirect or secondary fatalities, such as those caused by fires ignited by lightning, are excluded from this dataset. The provincial disaggregation is by place-of-residence and not by the province where the incident occurred. It is assumed for this analysis that, in most cases, the two are the same.

A total of 999 lightning fatalities were identified in the official vital statistics dataset between 1921 and 2003. Figure 2 illustrates the annual variation in deaths, the number of male and female victims, and the total population of Canada. Five-year running average counts and mortality rates are presented in Figure 3. As observed in studies for other developed nations, the number of fatalities in Canada has dropped substantially over the past century, from a maximum 5-year average of 26 deaths (1931-35) to a minimum 5-year average of 3.4 (1999-2003). Interestingly, the data suggest that deaths increased slightly during the mid- to late-1990s to about 4-5 deaths per year on average.

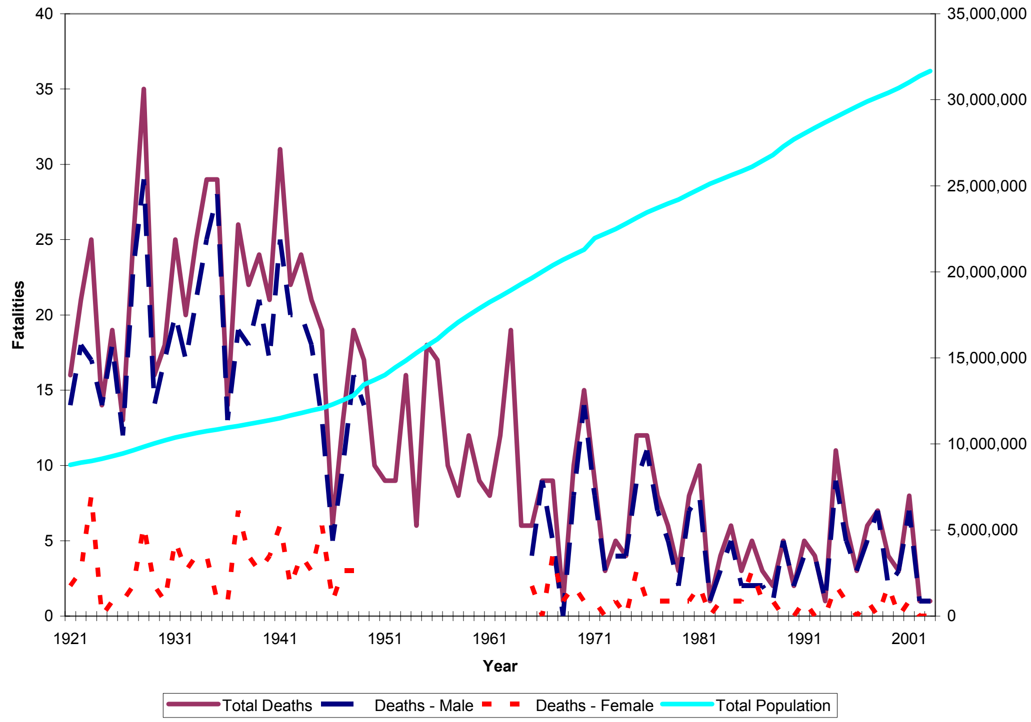


Figure 2. Lightning deaths in Canada, 1921-2003 (Statistics Canada, vital statistics)

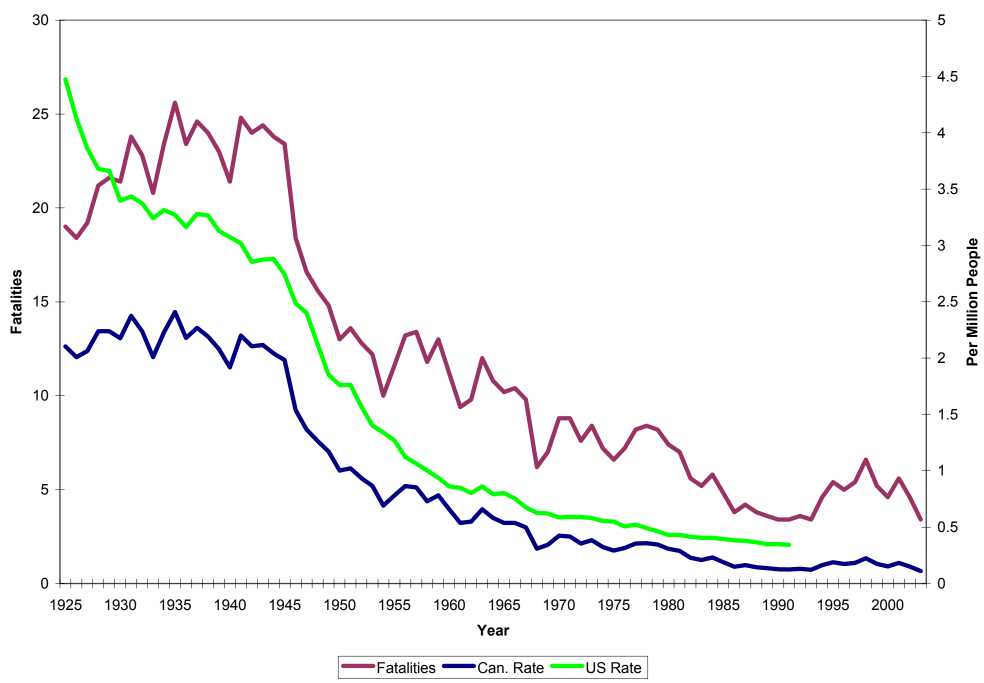


Figure 3. Five-year moving average of Canadian lightning deaths and Canadian and U.S. mortality rates, 1921-2003 (Statistics Canada, vital statistics; U.S. rates based on Lopez and Holle, 1998:3)

Since the downward trend in absolute fatalities is superimposed on a steadily increasing population, a steeper decline is observed for mortality rates than for fatality counts (Figure 3). Five-year average fatality rates per million population reached a maximum of 2.4 for the period 1931-35 while the lowest rate, 0.11, was observed for 1999-2003. U.S. lightning mortality rates based on similar vital statistics data, as reported in Lopez and Holle (1998:3), are consistently greater than those in Canada since 1930.

In terms of gender, about 84% of all lightning fatalities since 1921 (excluding 1950-64) were male and the remaining 16% were female. These relative proportions were similar at the beginning and end of the 1921-2003 period. Table 4 indicates the distribution of lightning fatalities by Canadian province (available until 1999) both in absolute and relative terms for two periods, 1921-99 and 1994-99. Over the full period of record, greater than 90% of all deaths occurred in Ontario, Quebec, and the three Prairie provinces (Saskatchewan, Alberta and Manitoba). No lightning mortality was reported in Canada's northern territories. Although the absolute numbers are different, a similar geographic distribution in lightning mortality is evident during the 1994-99 period.

Table 4. Distribution of lightning deaths by province (Statistics Canada, vital statistics)

	1921-99*		1994-99		2004	
	Fatalities	% of total	Fatalities	% of total	Population (thousands)	% of total
British Columbia	16	1.7	0	0.0	4,201.9	13.2
Alberta	107	11.6	5	13.5	3,204.8	10.0
Saskatchewan	133	14.4	2	5.4	994.3	3.1
Manitoba	78	8.5	2	5.4	1,170.2	3.7
Ontario	316	34.2	17	46.0	12,407.3	38.8
Quebec	206	22.3	10	27.0	7,547.7	23.6
New Brunswick	39	4.2	1	2.7	752.1	2.4
Prince Edward Island	2	0.2	0	0.0	137.9	0.4
Nova Scotia	24	2.6	0	0.0	937.5	2.9
Newfoundland and Labrador	2	0.2	0	0.0	517.3	1.6
Nunavut, Northwest, and Yukon Territories	0	0.0	0	0.0	103.5	0.3
CANADA	**923**	**100.0****	**37**	**100.0****	**31,974.4**	**100.0****

*excludes 1959-64, 2000-present period where provincial breakdown was unavailable
**numbers may not add to 100 due to rounding

Injuries based on CIHI data

For injuries, a few studies have analyzed hospital admissions data (Table 1) which are typically provided by public health authorities or hospital associations. For this case study, hospital admissions data from the National Trauma Registry (NTR) were obtained from the Canadian Institute for Health Information (CIHI)[4] for all reporting acute care hospitals during the 1999-2003 fiscal years (i.e., April 1-March 31). Since the literature acknowledges that many minor injuries go unreported, data were also requested from CIHI for emergency room (ER) visitation as documented in the National Ambulatory Care Registry System (NACRS). Unfortunately these data were only available for the province of Ontario for two fiscal years (2002-03). As with the fatality statistics, the NTR and NACRS data were extracted only for injuries that were ICD-coded for lightning.

The hospital admission and emergency room visitation data are compiled by fiscal year in Table 5. Between April 1, 1999 and March 31, 2004, acute care hospitals admitted 100 lightning victims. Five of these victims received major trauma while two others later died in hospital (to avoid double-counting, fatalities are not included in the injury tabulations). Two important observations are apparent from Table 5. First, there is considerable inter-annual variation in hospital admissions. Second, lightning-related emergency room visits occurred more frequently than hospital admissions. At 56, the two-year average for Ontario alone is 2.5 times greater than all reported admissions in Canada. If it is assumed that the geographic distribution of injuries is proportional to that of deaths over the 1994-99 period (Table 4), then an estimated 121 lightning-related emergency visits per year may have occurred nationally during 2002-03.

Table 5. Lightning injuries requiring emergency room treatment and admission to hospital, 1999-2003 (ICD-9 E907 and ICD-10 X33, CIHI 2006)

Fiscal Year	NTR Hospital Admissions (cases)*	NACRS Emergency Room Visitation (Ontario only)**
1999	33	n/a
2000	30	n/a
2001	7	n/a
2002	16	59
2003	12	52
Annual Average	**20.0**	**55.5**

*does not include those who later died in-hospital
**does not include those received in ER and later admitted to hospital

[4] CIHI is an is an independent, not-for-profit organization that works in collaboration with key stakeholder groups, including all provincial, territorial and federal governments, national health care agencies and service providers, to improve the health of Canadians and the health care system by providing quality health information (CIHI, 2003).

Injuries and fatalities based on CCFMFC fire statistics

In an effort to probe the significance of indirect casualties, specifically those related to property fires, data were acquired from annual reports of the Council of Canadian Fire Marshals and Fire Commissioners (CCFMFC). The reports contain detailed tables on fatalities, injuries, and estimated property damage values associated with fires in Canada. The data pertain to all incidents responded to by local government fire departments and include variables for injuries and fatalities, stratified by the source of ignition (igniting object). Within this category, lightning is classified as the only example of "no igniting object". Standardized reporting protocols and coding for all variables are documented in CCFMFC (2002).

Although a small proportion of all fires, the CCFMCF data presented in Table 6 suggest that lightning-ignited blazes are a significant overlooked component of lightning-related mortality and morbidity. At 2.9 deaths per year, annual mortality is of comparable magnitude to that reported in the vital statistics over the same period. Approximately 76% of adults killed were male—gender was unspecified for 12 children and one unknown victim. While no firefighters were killed in fires ignited by lightning, they comprised about one-third of all reported injuries. On average, 15.4 people were injured each year and approximately 80% of the victims were male (not including firefighters, children or unspecified victims).

Table 6. Deaths and injuries associated with fires ignited by lightning, 1986-2001 (CCFMFC, 2006)

	Fires ignited by lightning	% of all fires	Deaths	% of all fire deaths	Injuries	% of all fire injuries
1986	469	0.69	3	0.54	16	0.41
1987	595	0.89	1	0.19	17	0.44
1988	437	0.62	3	0.60	14	0.39
1989	563	0.84	6	1.20	29	0.77
1990	1125	1.67	2	0.43	18	0.48
1991	1194	1.75	0	0.00	19	0.55
1992	816	1.25	2	0.52	19	0.49
1993	574	0.87	3	0.72	24	0.69
1994	956	1.43	4	1.06	19	0.54
1995	2428	3.78	13	3.25	23	0.65
1996	408	0.68	3	0.80	7	0.22
1997	1157	2.06	2	0.48	25	0.79
1998	412	0.72	0	0.00	9	0.33
1999	362	0.66	4	1.03	2	0.09
2000	361	0.67	1	0.31	2	0.08
2001	387	0.70	0	0.00	4	0.17
TOTAL	**12244**	**1.21**	**47**	**0.70**	**247**	**0.47**

Limitations

As discussed in the literature review, official vital statistics and injury data are subject to several limitations. Most importantly for the intended application in this analysis, the data only provide a partial picture of lightning-related fatalities and injuries in Canada. This is primarily due to the limitations of the ICD code definition (i.e., only direct causes) but also, particularly in the case of morbidity, due to incomplete spatial or temporal coverage. Time and budget constraints limited analysis of less serious injuries that don't require ER treatment or hospitalization (e.g., family physician visits) which might contribute to a more complete assessment of health impact. As well, the vital statistics used in the case study are not disaggregated beyond year, province, gender and age. As such they provide little insight into activity patterns and finer-scaled geographic or temporal factors that contribute to exposure and impact. While further investigation using the underlying coroners' reports is possible, time constraints prevented their incorporation into the current analysis.

3.2 Analysis of Canadian Media Reports

Media reports were the primary source of data used in this case study to estimate fatality and injury risks associated with lightning in Canada. Media information can be a valuable source of quantitative and qualitative data about hazard extent and impact. Newspaper reports provide a wealth of data including a detailed history of specific hazard events (e.g., floods, tornadoes, smog days), affected property (e.g., broken levees, homes burned or flooded), and social impacts (e.g., injuries, deaths). These forms of data allow researchers to use newspapers to chronicle the occurrence of hazard events (Hewitt and Burton, 1971; Jones, 1993; Charlton *et al.,* 1995; Ibsen and Brunsden, 1996; Downton *et al.,* 2005; Tarhule, 2005), to estimate frequencies and return periods (Cutter *et al*., 2000; Downton *et al*., 2005; Schuster *et al.,* 2005), and to monitor trends in damages (Dore, 2003). Newspaper and media accounts provide the foundation for two national natural disaster databases; The Canadian Disaster Database published by the Department of Public Safety and Emergency Preparedness Canada and *Storm Data* published in the United States by NOAA.

Media reports are a valuable resource for hazard studies because they also provide a means to re-create the physical and social anatomy of a hazard event, usually long after it has occurred (Steinberg, 1997; Jones, 1999; Kerry *et al*., 1999; Fralic, 2003; Maher, 2003). Depending on the nature of the hazard, newspapers often provide sufficient information to develop a timeline of the event itself (e.g., flood stages, ice storm path), related impacts, and pre- and post-event emergency responses. For instance, Jones (1999) and Koshida *et al*. (1999) both used newspaper articles after-the-fact to re-create the climatological and social dimensions of the 1998 eastern Canada ice storm and the 1998 southern Ontario drought, respectively.

Data and methods

In this study, newspapers were used to identify deaths and injuries in Canada attributed to lightning. Factiva, an online searchable worldwide database of major newspapers was the primary source of media articles used in this study. The database provided comprehensive, up-to-date coverage of major daily Canadian newspapers (e.g., Globe and Mail, Toronto Star, Winnipeg Free Press, Calgary Herald), and it contained a considerable temporal archive (20+ years). Previous studies involving media analysis suggest that major daily newspapers may underreport lightning events (Lopez *et al.* 1993), particularly in rural and smaller urban areas. To address this issue, four additional online databases that provided links to various community newspapers were also used in this study (Toronto Star Group, Canada's Community Newspaper Association, Ontario Community Newspaper Association, and Quebec Community Newspaper Association). The length of archived material in community newspapers ranged from as little as seven days to as long as 21 years. Yahoo's and dmoz's newspaper web directories were also accessed to search newspapers not listed in the previous five databases.

Through the use of keyword searches in the various newspaper databases and archives, injuries and deaths were identified and recorded. Specifically, the term 'lightning', either individually or in conjunction with an impact (i.e., death, injury) or activity (e.g., fire, golf, camping) qualifier, was used to search the headline, leading paragraphs, and/or full text of published newspaper articles in each archive. The terms 'foudre' and 'éclair' were used to identify relevant articles when French language newspapers were part of the archived database.

The data from applicable archived media reports varied in detail, accuracy, and extent, however, each story and applicable derived information were input into a lightning incident database. Database variables or fields included casualty characteristics (i.e., age, gender), location (city and province), prevailing activity at time of incident (e.g., golfing, camping, working), and extent of injury where available. Deaths and injuries were included if the individual was directly struck by lightning; received contact, splash or step voltage; or if they incurred blunt trauma or other injuries related to the lightning flash. This includes deaths and injuries associated with lightning-induced fires if referenced in the article. Where possible, the source of information contained in the article (i.e., witness/victim account, police/fire/emergency official, etc.) was also recorded.

Results

Estimates of mortality and morbidity

The online newspaper databases used in this study permitted access to 460 searchable newspaper archives. Most of the newspapers were from the provinces of Ontario (207 newspapers), Quebec (67 newspapers) and Alberta (50 newspapers). The overrepresentation of Ontario in the newspaper sample is to be expected, as it has the largest population and the greatest number of published newspapers in the country.

The keyword search of online newspaper databases yielded 131 independent articles that documented 53 lightning-related deaths and 277 injuries between 1986 and 2005. Given the limited availability of searchable archives (and thus relevant stories), results prior to 1994 were not included in the analysis of trends or averages in total casualties. Annual estimates of injury and mortality for the 1994-2005 period are presented in Figure 4. It is estimated that on average, 3.5 people were killed and 16.4 people injured annually between 1994 and 2005. These figures translate into a national casualty rate of 0.65 and a mortality rate of 0.11 per million population. The substantial inter-annual variability (5-39 injuries) is partly attributable to a few instances of multiple injuries from single lightning incidents (e.g., one event in 1994 resulted in over 10 injuries).

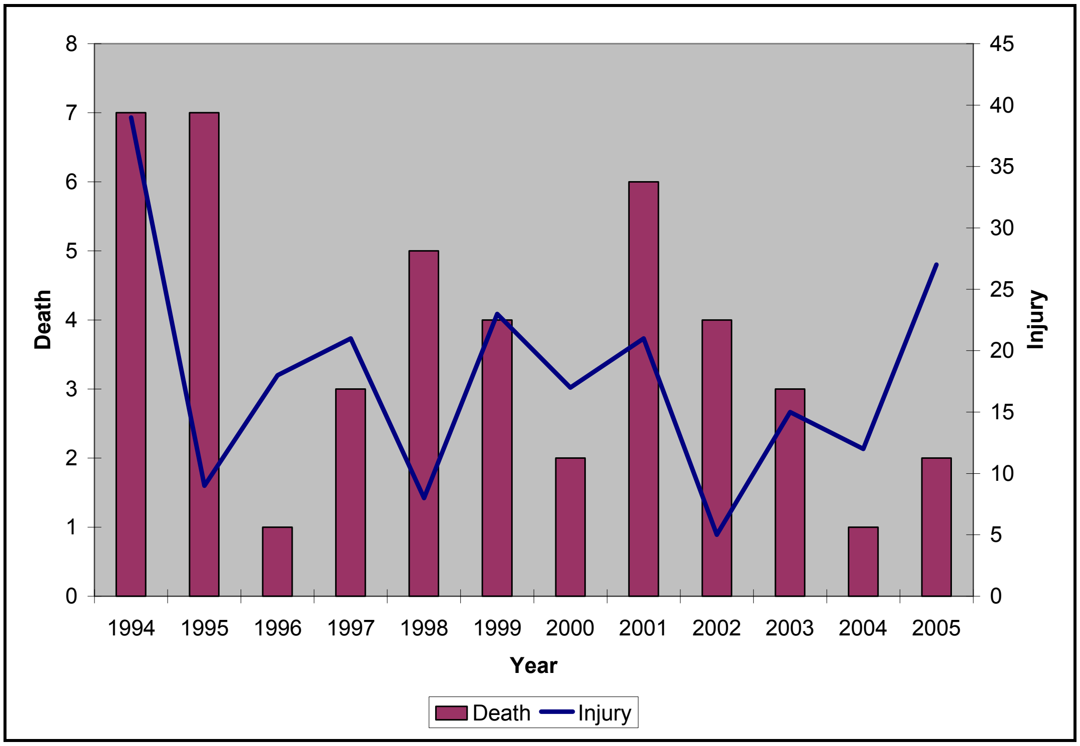
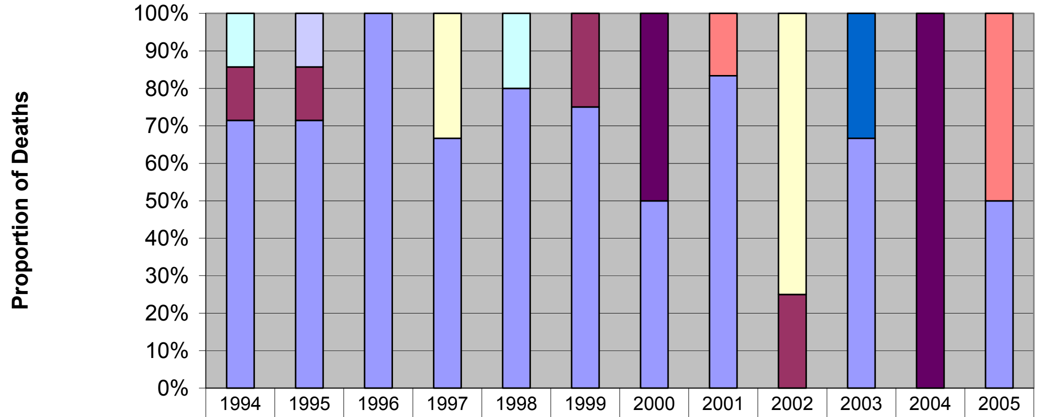


Figure 4. Media-based estimate of lightning-related deaths and injuries in Canada, 1994-2005

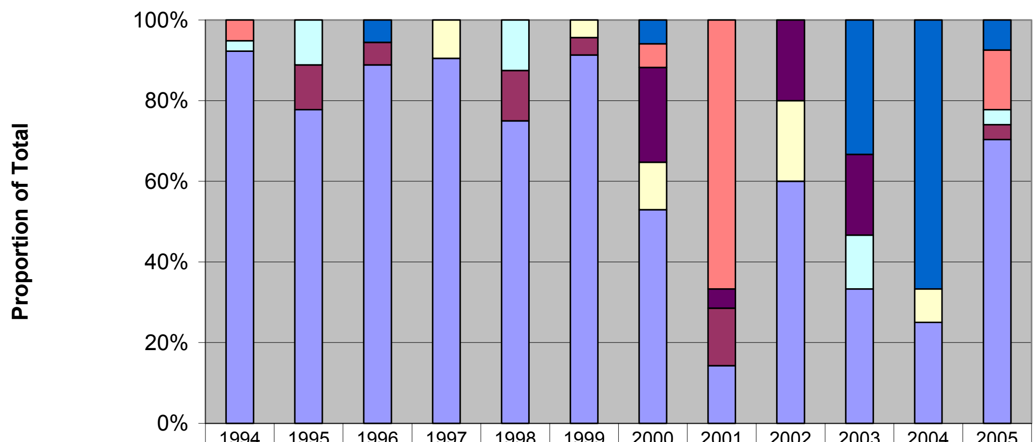
In addition to temporal variability in the number of lightning-related deaths and injuries, the media reports highlighted variation in the geographic distribution of casualties. Figures 6-7 illustrate the distribution of lightning-related deaths and injuries by province between 1994 and 2005. Most deaths and injuries occurred in Ontario, while very few or none were reported for the provinces of Newfoundland and Prince Edward Island or the Yukon, Nunavut, and Northwest Territories. The results seem consistent with the small populations and limited lightning activity observed in these jurisdictions; however, the low counts in Quebec (2 deaths, 21 injuries) and New Brunswick (1 death, 0 injuries), given historic lightning activity (see Figure 1) and population relative to Ontario, point to potential underreporting issues. This can be partly attributed to the limited extent of many searchable Quebec newspaper archives (often two weeks or less).



	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
New Brunswick		1										
Nova Scotia										1		
Quebec								1				1
Saskatchewan							1				1	
Manitoba	1				1							
British Columbia				1					3			
Alberta	1	1				1			1			
Ontario	5	5	1	2	4	3	1	5		2		1

Year

Figure 5. Provincial distribution of lightning-related deaths in Canada, 1994-2005



	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Nova Scotia			1				1			5	8	2
Quebec	2						1	14				4
Saskatchewan							4	1	1	3		
Mantoba	1	1			1					2		1
British Columbia				2		1	2		1		1	
Alberta		1	1		1	1		3				1
Ontario	36	7	16	19	6	21	9	3	3	5	3	19

Year

Figure 6. Provincial distribution of lightning-related injuries in Canada, 1994-2005

Population and activity-related characteristics

Socio-demographic information contained in the media reports suggest that the typical lightning victim in Canada is male and between the ages of 16 and 45. In total, 72% of deaths and 77% of injuries reported in the media were male—results that are similar to those documented in American and Australian studies (Lopez *et al.*, 1995; Coates *et al.*, 1993). Based on media reports where the age of victim was discernible, most deaths (66%) and injuries (78%) occurred among people under the age of 45.

Table 7. Age distribution of lightning-related deaths and injuries, 1986-2005

AGE	DEATHS		INJURIES	
	Count	Percentage of total*	Count	Percentage of total*
<16	6	11.3 (14.6)	12	4.3 (17.1)
16-30	10	18.9 (24.4)	21	7.6 (30.0)
31-45	11	20.8 (26.8)	22	7.9 (31.0)
46-60	8	15.1 (19.5)	10	3.6 (14.2)
> 60	6	11.3 (14.6)	5	1.8 (7.1)
Unknown	12	22.6	207	74.7
TOTAL	**53**	**100.0****	**277**	**100.0****

*numbers in parentheses refer to percentage of known deaths or injuries
**numbers may not add to 100 due to rounding

The use of newspaper articles in this study also permitted examination of the monthly and day-of-week distributions of lightning-related mortality and morbidity. As illustrated in Table 8, most lightning-related deaths (>94%) and injuries (~74%) occurred during the summer months, while no fatalities were reported during the October-April period. While total mortality was evenly distributed across the summer months, slightly more people were killed per lightning incident during June. Relative to fatalities, lightning-related injuries were reported in a greater number of months (7). Large peaks were apparent for both total injuries and injuries per incident during July when compared to other months.

The media reports also indicated that Canadians are more likely to be killed or injured by lightning on or near a weekend (Table 9). Relative to other days, more deaths occurred on Saturdays (26%) while injuries were most prevalent on Fridays (27%). The Thursday-Saturday period accounted for almost 55% of all fatalities and over 70% of all injuries, likely reflecting higher rates of participation in outdoor activities during weekends and holidays.

Table 8. Monthly distribution of lightning-related deaths and injuries, 1986-2005

MONTH	DEATHS			INJURIES		
	Count	% of total*	Per Incident	Count	% of total*	Per Incident
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	0	7	2.5	2.3
May	2	3.8	1.0	17	6.1	1.7
June	17	32.1	1.3	58	20.9	2.5
July	18	34.0	1.1	108	39.0	3.0
August	15	28.3	1.0	76	27.4	2.7
September	1	1.9	1.0	6	2.2	1.5
October	0	0	0	5	1.8	2.5
November	0	0	0	0	0	0
December	0	0	0	0	0	0
TOTAL	**53**	**100.0***		**277**	**100.0***	

*numbers may not add to 100 due to rounding

Table 9. Day-of-week distribution of lightning-related deaths and injuries, 1986-2005

DAY	DEATHS			INJURIES		
	Count	% of total*	Per Incident	Count	% of total*	Per Incident
Sunday	5	9.4	1.0	14	5.1	1.6
Monday	5	9.4	1.7	29	10.5	2.1
Tuesday	8	15.1	1.3	27	9.7	1.9
Wednesday	6	11.3	1.0	12	4.3	1.0
Thursday	9	17.0	1.3	64	23.1	4.9
Friday	6	11.3	1.0	74	26.7	3.2
Saturday	14	26.4	1.2	57	20.6	2.7
TOTAL	**53**	**100.0**		**277**	**100.0**	

Information was also obtained to determine the activities that the casualties were engaged in when they were struck by lightning (Table 10). Outdoor recreation pursuits accounted for over 70% of victims killed and over 62% of injuries, with camping and hiking being the most common activity. Golfing, picnicking and boating were also prevalent. Although the number of incidents was small, the results support findings from other studies that field sports, such as soccer and baseball, are often associated with multiple casualty incidents (Cherington, 2001). The location where the lightning incident occurred also informs our understanding of exposure. For those events where location information was available in the media reports, the bulk of fatalities (68%) and injuries (68%) occurred to people who were in open areas or to those taking shelter under trees.

Table 10. Distribution of lightning-related deaths and injuries by activity, 1986-2005

ACTIVITY	DEATHS			INJURIES		
	Count	% of total*	Per Incident	Count	% of total*	Per Incident
Golf	4	7.5 (8.3)	1.0	29	10.5 (11.3)	1.9
Camp/Hike	11	20.8 (22.9)	1.1	47	17.0 (18.4)	3.6
Picnic	5	9.4 (10.4)	1.7	11	4.0 (4.3)	2.2
Boating	8	15.1 (16.7)	1.1	18	6.5 (7.0)	1.6
Soccer	1	1.9 (2.1)	1.0	11	4.0 (4.3)	11.0
Baseball	1	1.9 (2.1)	1.0	28	10.1 (10.9)	9.3
Other Sport**	4	7.5 (8.3)	1.0	15	5.4 (5.9)	2.5
Work	3	5.7 (6.3)	1.0	41	14.8 (16.0)	2.3
In Home	4	7.5 (8.3)	2.0	24	8.7 (9.4)	1.6
In Shelter	1	1.9 (2.1)	1.0	7	2.5 (2.7)	3.5
Other	6	11.3 (12.5)	1.0	25	9.0 (9.8)	1.8
Unknown	5	9.4	1.0	21	7.6	1.8
TOTAL	**53**	**100.0***		**277**	**100.0***	

*numbers in parentheses refer to percentage of known deaths or injuries; numbers may not add to 100 due to rounding
**other sport includes cycling, equestrian, tennis

Limitations

While newspapers are a valuable source of hazard information, it is important to acknowledge that media analyses are subject to a number of limitations. Care must taken to consider bias in reporting when using newspapers, as the amount of print coverage tends to vary with an event's 'newsworthiness', which could be defined by the size of the event, where the event occurs (e.g., rural community, urban centre) (Ibsen and Brunsden, 1996; Tarhule, 2005), or the focus/readership of the newspaper (Dymon and Boscoe, 1996). The limited number of newspaper articles about lightning-related deaths and injuries in western and eastern Canada found in this study could be reflecting this bias.

Another limitation of media analysis is that access to and quantity of online information varies over time. Extensive online newspaper databases tend to capture newspapers with larger readerships, in part for economic reasons. As readership of non-archived newspapers increase or they are taken over by media conglomerates, online databases are often updated to reflect new newspaper sources. Such changes in quantity of newspapers available in an online database can influence the number of related articles, which can indirectly influence trend analyses. This pattern is partially reflected in the 131 newspaper articles about lightinginduced deaths and injuries used in this study. In each of the five-year periods since 1986, the number of deaths and injuries increased — 1986-1990 (7 deaths; 40 injuries), 1991 to 1995 (15 deaths; 69 injuries), 1996 to 2000 (15 deaths; 87 injuries) and 2001 to 2005 (16 deaths; 80 injuries).

3.3 Analysis and transfer of U.S. lightning mortality and morbidity statistics

Another approach to estimate and evaluate lightning-related injury and fatality risk is to compare and transfer results from neighbouring jurisdictions. U.S. National Oceanic and Atmospheric Organization (NOAA) *Storm Data* (NOAA 2006) were used in combination with population data (US Census Bureau, 2006) to develop lightning injury and fatality rates for all states bordering Canadian provinces.

Storm Data is available to the public in the form of an online searchable database that allows a user to search for casualties and property damage associated with particular meteorological hazards. Additionally, general weather and storm information is available, as well as a brief description of the incident. While *Storm Data* entries are primarily comprised of information gathered from newspaper clipping services, additional data from county, state and federal emergency management officials; local law enforcement officials; skywarn spotters; National Weather Service damage surveys; the insurance industry; and the general public are included where available (NOAA, 2006).

Provincial fatality and injury rates, based on the media analysis described in the previous section, are presented for the 1994-2005 period in Table 11. Beneath each provincial entry, comparable figures derived from *Storm Data* are noted for every border state. Entries are repeated where states border more than one province. Although they technically do not share physical boundaries, Prince Edward Island and Newfoundland and Labrador were associated with the state of Maine for the purpose of this analysis. The Yukon, Northwest and Nunavut Territories were excluded since no casualties have been reported for these jurisdictions in the vital statistics (1921-99) and no media reports were uncovered from 1986-2005.

With the exception of Manitoba and Ontario, state lightning fatality rates were generally greater than or equivalent to provincial estimates. Injury rates were much lower in all provinces, possibly owing in part to the additional non-media sources of information in the *Storm Data*. Variability in CG lightning frequency by state and province as shown in Figure 7 is another likely reason for the observed discrepancies.

Table 11. Fatality and injury rates in Canadian provinces (media analysis) and U.S. border states (US *Storm Data*), 1994-2005

PROVINCE/STATE	Fatality rate (per million population)	Injury rate (per million population)
BRITISH COLUMBIA	0.04	0.08
Washington	0.03	0.28
Idaho	0.39	1.68
Montana	0.56	1.85
ALBERTA	0.08	0.14
Montana	0.56	1.85
SASKATCHEWAN	0.17	0.66
Montana	0.56	1.85
North Dakota	0.13	1.04
MANITOBA	0.22	0.36
North Dakota	0.13	1.04
Minnesota	0.12	1.16
ONTARIO	0.17	0.80
Minnesota	0.12	1.16
Wisconsin	0.14	1.75
Michigan	0.11	1.06
Ohio	0.20	1.07
Pennsylvania	0.15	1.53
New York	0.05	0.90
QUEBEC	0.03	0.24
New York	0.05	0.90
Vermont	0.41	0.69
New Hampshire	0.07	5.15
Maine	0.20	4.37
NEW BRUNSWICK	0.00	0.00
NOVA SCOTIA	0.18	1.25
PRINCE EDWARD ISLAND	0.00	0.00
NEWFOUNDLAND & LABRADOR	0.00	0.00
Maine	0.20	4.37

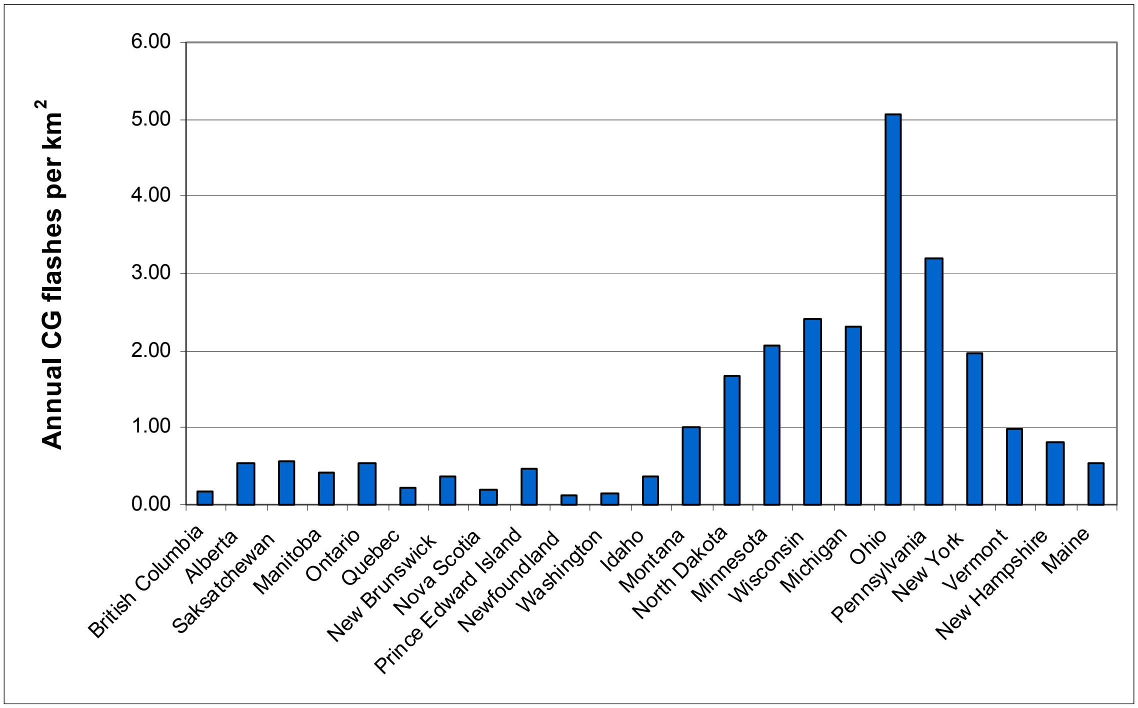


Figure 7. Estimated annual average CG lightning flashes per square kilometre for selected states and provinces, 2000-2004 (derived from Vaisala, 2006)

A crude method of accounting for variability in lightning occurrence is a simple proportionate weighting of state casualty rates by relative state-province lightning flash densities. For example, the estimated mean annual CG lightning flash density for B.C. observed in Figure 7 is about 17% of the density reported for the state of Montana. When this factor is applied to the Montana lightning fatality rate of 0.56 per million population, a new adjusted estimate of 0.10 fatalities per million is identified for B.C., somewhat greater than the 0.04 estimate derived from media reports. Table 12 lists the combined range of state-adjusted and original provincial values for both deaths and injuries that were determined through the analysis. When applied to 2005 population data and summed nationally, the transfer approach results suggest that approximately 1-5 people are killed and between 5-35 people injured in lightning incidents each year in Canada. Caution should be used in interpreting the specific results generated through this procedure since it assumes a simple linear relationship between casualty rates and lightning flash density. Overall, however, the results are consistent (i.e., similar magnitude) to those developed through the analyses of government statistics and media reports.

Table 12. Adjusted ranges of lightning fatality and injury rates in Canadian provinces based on combination of U.S. border state and Canadian estimates modified by lightning frequency data

PROVINCE/STATE	Adjusted fatality rate range*	Adjusted injury rate range*
British Columbia	0.04-0.18	0.08-0.79
Alberta	0.08-0.31	0.14-1.03
Saskatchewan	0.05-0.32	0.36-1.07
Manitoba	0.02-0.22	0.23-0.36
Ontario	0.01-0.17	0.11-0.80
Quebec	0.01-0.09	0.10-1.81
New Brunswick	0.00-0.14	0.00-2.96
Nova Scotia	0.08-0.18	1.25-1.65
Prince Edward Island	0.00-0.17	0.00-3.67
Newfoundland & Labrador	0.00-0.05	0.00-1.01

*Original US and Canadian casualty rates based on 1994-2005 data (Table 11)

4.0 DEVELOPING A COMPOSITE PICTURE OF LIGHTNING-RELATED CASUALTIES

4.1 Fatalities

Several sources of data were used in this study to estimate lightning-related fatalities and injuries, each with slightly overlapping characteristics (e.g., spatial and temporal coverage) which limit opportunities for direct comparison and aggregation. Estimates of average annual lightning fatalities from vital statistics (3.4) and the media analysis (3.8) based on 1999-2003 data fall squarely between the broad estimate of 1-5 deaths per year suggested by the transfer of U.S. casualty rates to Canadian provinces.

A composite picture of lightning-related fatalities, constructed using comparable timeframes, is presented in Table 13. The media-based data generally underreported fatalities relative to the vital statistics, by about 36% over 1994-2001, which is consistent with U.S. studies (Holle *et al.*, 2005; Shearman and Ojala, 1999; Lopez *et al.*, 1993). However, in 1995, there were more fatalities reported in the media than in the official statistics. Although information was not readily available that would permit comparisons of individual fatalities, it is reasonable to assume that the maximum number of fatalities reported by either source in a given year is the better estimate. Secondary fatalities associated with lightning-ignited fires are by definition excluded from both the vital statistics and, after reviewing the circumstances of each death, casualties reported in the media database. Thus it is possible to directly add the CCFMFC fatalities to the maximum of the other sources to obtain a more representative count of lightning-related fatalities. The resulting estimate of 9.5 deaths per year (1994-2001) translates into a fatality rate of 0.32 per million population.

Table 13. Composite estimate of lightning-related deaths in Canada, 1986-2001

	Media-based	*Vital statistics*	**Maximum**	**CCFMFC fire statistics**	**TOTAL**	**RATE (per million population)**
1994	7	11	11	4	**15**	0.52
1995	7	6	7	13	**20**	0.68
1996	1	3	3	3	**6**	0.20
1997	3	6	6	2	**8**	0.27
1998	5	7	7	0	**7**	0.23
1999	4	4	4	4	**8**	0.26
2000	2	3	3	1	**4**	0.13
2001	6	8	8	0	**8**	0.26
AVERAGE	4.4	6.0	6.1	3.4	9.5	0.32

4.2 Injuries

A composite picture of lightning-related injuries is more difficult given greater discrepancies in the reporting periods for various data sources. The summary provided in Table 14 allows for some comparisons though. As with fatalities, injuries associated with lightning-ignited fires may be added to either the media-based figures or the combined hospital admission/ER visitation counts. Based on the media data and fire statistics, 30.9 people on average were injured in lightning-related incidents each year from 1994-2001, an estimate that falls within the 5-35 range derived from the transfer of American injury rates reported previously. However, comparison with the CIHI hospital admission data reveals a gross underreporting in the media database—at least 20% over 1999-2003. When ER data are added for 2002-03, media-based counts underestimate injuries by almost 600%. The combined CIHI hospital admission and ER records yield an average lightning-related morbidity of 69.5 per year (2002-03) though this figure ignores injuries associated with fires ignited by lightning and only includes ER data for Ontario. About 11.4 injuries per year were reported in the fire statistics (1994-2001). Results from the media analysis indicate that Ontario accounted for 40% of national injuries during 2002-03 and about 70% of injuries over a longer timeframe (1994-2003). Assuming that these relative proportions hold true for ER admissions, one derives an inflated national estimate of 91.7-164.2 lightning-related injuries per year. This translates into an injury rate of 3.3-5.2 per million population.

Table 14. Estimates of lightning-related injuries in Canada, 1994-2003

	Media-based	CIHI NTR (hospital admissions)	CIHI NACR (Ontario emergency room visitation)	CCFMFC Fire statistics
1994	39	-	-	19
1995	9	-	-	23
1996	18	-	-	7
1997	21	-	-	25
1998	8	-	-	9
1999	23	33	-	2
2000	17	30	-	2
2001	21	7	-	4
2002	5	16	59	-
2003	15	12	52	-
1994-2003 average	**17.6**	**n/a**	**n/a**	**n/a**
1994-2001 average	**19.5**	**n/a**	**n/a**	**11.4**
1999-2003 average	**16.2**	**20.0**	**n/a**	**n/a**
2002-2003 average	**10.0**	**14.0**	**55.5**	**n/a**

4.3 Discussion

Care should always be taken when interpreting these estimates. They are derived from multiple sources using different protocols and definitions. Equally important, they are based on a relatively small number of deaths and injuries with large variation between years and among jurisdictions.

While the composite picture produces larger estimates of lightning-related fatality and injury risk than those based on a single source, the absolute and relative risks remain very small when compared to other causes of mortality (Table 15) or major trauma. Even the lowest mortality rate reported in Table 15, for deaths caused by influenza, is over an order of magnitude greater than lightning-related fatality rates estimated in this study. Similarly for morbidity, less than 0.5% of 9,313 major injuries in 2001-02 were caused by natural and environmental factors, including lightning (CIHI, 2003).

Although the relative risks may be small compared to chronic disease, motor vehicle collisions, etc., exposure to lightning and thus the potential risk of injury is very discrete and concentrated in terms of vulnerable activities, locations and time. This concentration makes the lightning hazard more ‘potent’ than annualized per capita estimates might suggest and, more importantly, allows one to target public risk-reduction strategies, information and programs. As well, when compared to other meteorological events, the average annual number of deaths and injuries related to lightning is significant. For instance, only about 2 people are killed in tornadoes each year in Canada (Etkin *et al.*, 2001). Similarly in the U.S., Lopez and Holle (1995) observed that lightning fatalities were more frequent than those attributed to tornadoes, floods, and hurricanes.

Table 15. Age-standardized mortality rates by selected causes, 2000-2003 (Statistics Canada, 2005)

CAUSE	Mortality Rate (per 100,000 population)			
	2000	2001	2002	2003
All causes of death	615.5	600.8	598.2	586.9
Cancer	180.4	178.7	178.2	175.6
Heart disease	152.0	143.1	138.6	133.3
Diabetes mellitus	18.9	19.3	20.9	20.5
Suicide	11.4	11.4	11.2	11.3
Motor vehicle accidents	8.6	8.3	9.2	9.0
Falls	4.3	4.6	4.6	5.0
Homicide	1.6	1.5	1.5	1.5
HIV/AIDS	1.6	1.3	1.2	1.3
Influenza	1.5	0.2	0.6	0.5

Source: Statistics Canada (http://www40.statcan.ca/l01/cst01/health30a.htm)

5.0 SUMMARY AND RECOMMENDATIONS

5.1 Summary

In summary, the following key observations result from the analysis:

- Lightning is a common meteorological hazard in Canada that regularly kills and injures. Based on an analysis of media reports, vital statistics, hospital admission and ER records, and fire loss data, the authors estimate that on average about 9-10 lightning-related deaths and 92-164 injuries occur each year in Canada.
- Lightning mortality has declined significantly over the past century. Vital statistics show that lightning mortality has fallen from a peak of 2.4 deaths per million population over 1931-35 to 0.11 deaths from 1999-2003. This observation is consistent with trends in other developed countries.
- The majority of lightning-related fatalities and injuries in Canada occur in Ontario. Over 90% of lightning deaths reported in vital statistics since 1921 have occurred in Ontario, Quebec, Saskatchewan, Alberta and Manitoba. With the exception of B.C., where few deaths have been recorded, the distribution of fatalities reflects current provincial population and CG lightning frequencies.
- Most lightning-related fatalities and injuries occur during the June-August summer season. Greater than 94% of lightning-related deaths and 74% of injuries reported in the media since 1986 occurred from June-August. The Thursday-Saturday period accounted for almost 55% of all fatalities and over 70% of all injuries, most likely related to higher rates of participation in outdoor activities.
- Most victims are male, less than 45 years old, and engaged in outdoor recreational activities when injured or killed in a lightning incident.

- Media reports used in the study were found to underestimate lightning mortality by 36% when compared to vital statistics. Morbidity was underreported by 20-600% relative to hospital statistics depending on the severity of injury included in the analysis.
- Fires ignited by lightning are important secondary sources of lightning-related casualties accounting for about 3 deaths and 15 injuries per year from 1986-2001.
- Although casualty counts and rates are most often reported annually and normalized by population, both exposure and the physical hazard are concentrated in space (geographic, demographic, activity) and time.

5.2 Recommendations

The following recommendations are suggested based on the results of this initial investigation:

- Results from this study should replace current estimates of lightning fatalities and injuries used by Environment Canada and other federal departmental in various communications with the public and stakeholders.
- National and regional lightning-related estimates should be shared and discussed with provincial emergency management colleagues and incorporated into existing and future EC-provincial or EC-municipal hazard information projects (e.g., http://hazards.ca/).
- EC should consider further development of the media report MS Access database to support CLDN operations and further research, including:
  - incorporation of detailed lightning information from CLDN for every injury or fatality incident,
  - support for regular, at least annual, updates of media reports, and
  - addition of a spatial GIS component to incorporate additional exposure-related data (e.g., population).
- In terms of continued research, the current health impact study should be expanded as planned to investigate social and economic impacts associated with lightning-related property damage and service interruptions using a combination of data derived from media reports and sector-specific records. Further analysis of injury and fatalities at the storm level to discern additional finer-scaled risk patterns or associations between lightning and exposure is also warranted. A major focus in both sets of studies should be on evaluation of risk or damage prevention measures, particularly those that relate to expanded or enriched use of the CLDN data by both public and private sector clients.

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