2008
20th International Lightning Detection Conference
21-23 April • Tucson, Arizona, USA
2nd International Lightning Meteorology Conference
24-25 April • Tucson, Arizona, USA

A Review of Lighting Impacts in Canada

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1.0 Introduction

Approximately 14,000 warnings of severe weather are issued each year by Environment Canada (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. Surprisingly, very little information exists that documents the number of casualties and amount of damage attributable to lightning in Canada—valuable knowledge that could be used to improve the effectiveness of monitoring and warning systems.

In response to this need, Environment Canada and university partners have undertaken an assessment of the impacts of lightning in Canada. The first phase of activity established an updated estimate and profile of lightning-related casualties (Mills *et al.*, 2008a) while the second phase evaluated the extent of property damage, service interruptions and associated economic implications (Mills et al., 2008b). A brief synthesis of this research is presented in the following sections.

2.0 Fatality and Injury Risk

A literature review conducted by Mills *et al.* (2008a) revealed very few estimates of lightning-related injury and fatality risk in Canada. The most comprehensive evaluation, completed almost 50 years ago by Hornstein (1961, 1962), produced annual average figures (16 deaths, 100 injuries) that are still commonly quoted by Environment Canada and other agencies. Aside from Bains and Hoey (1998), who identified 27 lightning fatalities from 1991-1996 using death certificates, and an evaluation of electrical and lightning injuries for the under-19 cohort by Nguyen et al. (2004), little Canadian research has been published since Hornstein's original work.

In light of this void, Mills et al. (2008a) completed a national empirical analysis of lightning-related injuries and fatalities. Several distinct but readily available sources of mortality or morbidity information were utilized in the assessment: national and provincial vital statistics, hospital admission data, emergency room visitation data, fire loss data, and Canadian media/newspaper reports. Additional background on each source is specified in Table 1. The combination of media-based data with traditional government or official agency sources facilitated an evaluation of underreporting and exploration of the spatiotemporal and socio-demographic characteristics of lightning casualties. However, only overall risk estimates will be discussed in detail in this paper.

Table 1. Sources of mortality and morbidity data used in the empirical analysis

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[a]	Canadian Institute for Health Information (CIHI)	Ontario	– based on ICD-10 code (X33 victim of lightning)
Injuries and fatalities 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
Media reports of injuries and fatalities	1994-2006	460 daily and weekly Canadian newspapers	National	– incidents derived from qualitative interpretation of specific articles – *Factiva* online searchable worldwide database used to access 20+ year archive of articles in major daily Canadian newspapers – Four online databases provided links to community newspapers with archives ranging from 7 days to 21 years

[a]based on fiscal year (April 1-March 31)

2.1 Fatalities

The most consistent and long-term source of Canadian fatality data is vital statistics collected by provincial health agencies and summarized by Statistics Canada. Canadian vital statistics refer only to lightning-related deaths as defined by various editions of the International Classification of Diseases (ICD) code and its predecessors (WHO, 2006). Historic vitals data are presented in Figure 1 and illustrate the significant drop apparent in Canadian lightning fatalities over the past century—a trend that has been observed in the U.S. and most other developed countries.

Prompted by potential concerns over underreporting of lighting casualties, Mills et al. (2008a) complemented the vital statistics with data derived from annual reports of the Council of Canadian Fire Marshals and Fire Commissioners (CCFMFC, 2002) and a separate analysis of media reports. The CCFMFC information suggests that up to 13 deaths per year are attributable to fires that were ignited by lightning—an important indirect or secondary source of fatalities that are by definition excluded from vital statistics and many international studies.

A database of media reports of lightning-related fatalities was developed using *Factiva*, an online searchable database of major international and Canadian newspapers (e.g., Globe and Mail, Toronto Star, Winnipeg Free Press, Calgary Herald), and 4 additional online community newspapers (Toronto Star Group, Canada's Community Newspaper Association, Ontario Community Newspaper Association, and Quebec Community Newspaper Association). Keyword searches of the 460 daily and weekly newspapers were applied to archives with lengths ranging from as few as seven days to over 20 years.

Fatality counts identified using each source of information for the comparable period 1994-2001 are presented in Table 2. With the exception of 1995, the annual number of fatalities reported in the media was less than that recorded in the vital statistics. For the purposes of developing a national estimate, the maximum of either the vital statistics or media count was added to the indirect fatalities reported by CCFMFC. This yielded an average of 9-10 lightning-related deaths per year and an annual fatality rate of about 0.3 deaths per million population.

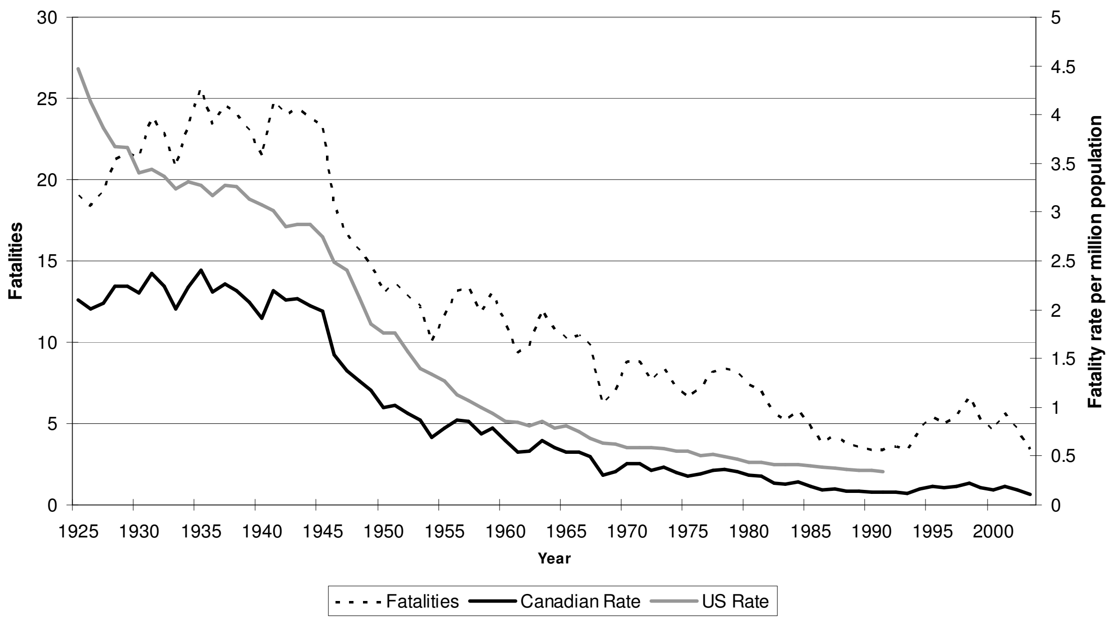

Figure 1. Five-year moving average of Canadian lightning deaths and Canadian and U.S. mortality rates, 1921-2003 (Statistics Canada, vital statistics; U.S. rates based on Lopez and Holle, 1998, p.3)

Table 2. Composite estimate of lightning-related deaths in Canada, 1994-2001 (Mills et al., 2008a)

	Media-based	*Vital statistics*	**Maximum of media, vitals**	**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

2.2 Injuries

Mills et al. (2008a) used 4 sources of data to develop an estimate of lightning-related injuries. Admission data from the National Trauma Registry (NTR) were obtained from the Canadian Institute for Health Information (CIHI) for all reporting acute care hospitals from 1999-2003. 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 one province (Ontario) and just two years (2002-03). The NTR and NACRS data were extracted only for injuries that were ICD-coded for lightning. As in the case for fatalities, these official government sources of information were augmented with estimates of indirect injuries caused by lightning-ignited fires (CCFMFC, 2002) and figures derived from analysis of media reports.

A summary of annual lightning injury counts derived from each data source is presented in Table 3. Relative to fatalities, developing a composite estimate of lightning-related injuries is more difficult given greater discrepancies in the reporting periods, considerable interannual variation, and, in the case of emergency visits, limited geographic coverage. 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. However, comparison with the CIHI hospital admission and ER data (69.5 injuries per year) reveals a gross underreporting in the media database—almost 600% for 2002-03.

In order to prepare an aggregate estimate, the ER data for Ontario were extrapolated to other regions in Canada based on the relative share of historic injuries reported in the media database and added to lightning-related hospital admission counts and injuries from lightning-ignited fires. 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 a rate of 3.3-5.2 injuries per million population.

Table 3. Composite estimates of lightning-related injuries in Canada, 1994-2003 (Mills et al. 2008a)

	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**

3.0 Property Damage, Disruption, and Associated Economic Impacts

The second phase of research assessed the extent of property damage, service interruptions and economic implications associated with lightning in Canada. Mills et al. (2008b) provide details of both the literature review and the methods used to extrapolate Canadian impacts. Only the essential elements are summarized here.

The literature review was conducted to provide a list of sectors and activities that regularly experience impacts; general understanding of damage mechanisms; quantified estimates of economic and social costs, or other measures of physical impact; and an evaluation of data sources and analysis methods. Three general types of impact were revealed: human casualties, property damage, and losses associated with the interruption of electricity and other critical services. Affected sectors include health; property and casualty insurance; forestry; electricity generation, transmission, and distribution; agriculture; telecommunications; transportation; and tourism and recreation—the first four sectors are the most important in terms of contributing to overall impacts and costs. Impacts were usually reported in terms of physical indicators (i.e., number of people injured, damage report counts, electricity outage frequency and duration, number of insurance claims, etc.) with a smaller set of studies also estimating economic costs. Based on the available though often limited descriptions of analyses, virtually all of the research that was examined reported direct lightning-related damage costs or cost savings associated with preventive measures. No formal economic analyses of indirect costs or non-market costs attributable to lightning damage were uncovered. Much of the work that has been completed is focused on the U.S., with only a few Canadian studies. The case study described in section 3 attempted to address the apparent need for additional Canadian research by developing an aggregate picture of lightning impacts and costs across multiple sectors.

3.1 Analysis of Canadian media reports

Media reports were a primary source of data used in the lightning-related injury study conducted by the authors (Mills *et al.*, 2008a). Since many instances of property damage were uncovered in the search for injury events, it was decided to also utilize media accounts to evaluate impacts. Given the dearth of stories prior to 1994, coincident with general availability of internet services, and to keep the period consistent with that used in the injury analysis (Mills *et al.*, 2008a), it was decided to limit the media report study from 1994-2006. The subsequent analysis is therefore based on 371 reports of damage over 13 years.

Data extracted from the archived media reports varied in detail, accuracy, and extent, however, each story and applicable derived information were added to a lightning incident database. When discernible, entries included information on the location (city and province) of the incident, damage or disruption mechanism (e.g., house or forest fire, power interruption), types of property damaged or disruption (e.g., building/home, evacuation), various indicators of impact magnitude (e.g., number of homes damaged, number of people/households evacuated) and estimated losses or costs. Where possible, the source of information contained in the article (i.e., witness/victim account, police/fire/emergency official, etc.) was also recorded.

The survey of media reports revealed examples that define a broad range of damage and disruption types, however, it was less helpful in characterizing the extent or magnitude of impacts and costs. Three categories of impact were evident from the reports:

1. Physical damage from direct or indirect strikes and fires to homes and sheds, churches, schools, hospitals/extended care facilities, commercial buildings, recreational buildings, sailboats, lighthouses, water treatment plants, agricultural buildings and contents, livestock, hay/straw bales, forests, pastures, oil and natural gas pipelines, oil storage facilities/tanks, traffic signals, vehicles, communication towers and systems, electrical transformers/stations, and hydroelectric plants;
2. Electricity and to a lesser extent communication service interruptions affecting a variety of customers and forcing, among other things, a nuclear power plant shutdown, traffic signal failures, and alarm system failures; and
3. Evacuations or evacuation alerts related to forest fires.

Table 4 summarizes data obtained or inferred from the media reports for several indicators of impact that could be quantified. Over the 1994-2006 period cumulative costs exceeded $17.5 million; about 900 buildings and 700 power transformers were damaged or destroyed by lightning; and in excess of 3.3 million people are estimated to have been affected by power outages.

The results are strongly influenced by a few extreme values and incomplete reporting. For instance, 700 buildings were reported damaged or destroyed in only two events. Removing these extremes reduces the annual average from 69 to 15. Similarly, over half of the total cost is attributable to a single report of $10 million in forest fire suppression costs. In terms of reporting, information concerning damage costs and the number of people affected by power outages was discernible for only about 10 and 50 percent of reports, respectively. As well, the total number of damage or disruption reports (371) was only 2.5 times greater than those for human casualties (148) as analyzed in Mills *et al.* (2008a). These observations support findings from U.S. studies that damage incidents are severely underreported by media (Holle *et al.*, 1996; Curran *et al.*, 2000). At best, media reports obtained in the current study provide a qualitative and complementary source of information to the sector-specific empirical estimates developed in subsequent sections of this paper.

Table 4. Summary of media-based damage reports, 1994-2006

Impact	Total number or cost (1994-2006)[1]	Annual average[1]
Physical Damage		
Buildings	899	69
Transformers	672	52
Livestock mortality	105	8
Interruptions		
People affected by electricity outages[2]	3,358,214	258,324
Reports of communication failures	11	1
People evacuated or on alert due to forest fires	67,156	5,166
Costs		
Electricity-related	$2,995,000	$230,385
Buildings	$4,633,000	$356,385
Fire suppression	$10,000,000	$769,231
Other	$70,000	$5,385
Sum of reported costs	**$17,698,000**	**$1,361,385**

[1] all figures rounded to whole numbers
[2] figures estimated where not explicitly defined by using Statistics Canada population data for affected communities/regions or by applying population factor (2.6) where only the affected number of households was identified

3.2 Compilation of sector-specific impact estimates

While limited or incomplete in terms of quantifying costs and impacts, the media reports did verify the general importance of lightning to particular sectors as revealed through the literature review. These sectors and major impact areas include: health (injury burden), insured and uninsured personal and commercial property damage and disruption, forestry (wildfire management), and electricity transmission and distribution. A variety of empirical data and methods were used to derive impact and ultimately cost estimates for each sector. These are explained in detail in subsequent sections. While not fully comprehensive, the authors believe that the final summary estimate accounts for a majority of the costs incurred as a result of lightning strikes in Canada. Unless otherwise noted, all costs are inflated to 2007 and reported in Canadian currency.

Health (injury burden)

As described previously, an average of 9-10 deaths and 92-164 injuries are attributable to lightning each year in Canada (Mills et al. 2008a). While casualty statistics stand on their own in terms of motivating policy or action to reduce impacts, the economic burden associated with casualties is often significant and should not be overlooked when aggregating or comparing costs across sectors.

Lightning-related casualty cost estimates were derived from two Canadian studies that dealt with both injuries and fatalities but using different methodologies (Angus *et al.*, 1998; Vodden *et al.*, 1994). Angus *et al.* (1998) evaluated the economic impact of unintentional injury in Canada using a cost-of-illness approach that valued both direct (i.e., treatment-related) and indirect (i.e., lost productivity) costs. In principle, indirect costs include those related to impaired quality of life, pain, suffering, etc., however, for the purposes of their study, only lost productivity estimates developed using a human capital approach were incorporated (Angus *et al.*, 1998). Direct and indirect costs derived from Angus *et al.* (1998) for *fire*, *other* and *all* classes of injury were used to estimate to determine lightning-related costs. Low and high estimates were generated using the low and high average annual injury counts (and hospitalization/ER breakdown) provided by Mills *et al.* (2008a). Total annual average costs range from $3.6 million to $5.9 million.

Vodden *et al.* (1994) assessed the social costs of motor vehicle collisions in Ontario. Costs associated with human consequences were determined using a willingness-to-pay approach that measures the value an individual places on reducing the risk of being killed or injured. Time and material costs attributable to emergency response and healthcare were added to determine the total social cost of collisions (Vodden *et al.*, 1994). Total costs per injury and severity were then multiplied by corresponding lightning-related injury counts developed by Mills *et al.* (2008a). Total annual average costs ranged from $70.3 million to $79.3 million, the greater magnitude reflecting the large WTP-based social values adopted by Vodden *et al.* (1994).

Property damage

Commercial, industrial and residential fire costs

Information from annual reports of provincial fire authorities and the Council of Canadian Fire Marshals and Fire Commissioners (CCFMFC) were obtained to estimate the extent of lightning-related fire damage to commercial, industrial, institutional and residential property. Losses are estimated by the reporting fire agency and encompass only physical damage to structures and contents therein (i.e., not loss of business). Standardized reporting protocols and coding for all variables are documented in CCFMFC (2002).

Over the 1990-2002 period, CCFMFC member fire agencies responded to an average of 818 lightning-ignited fires each year causing $16.4 million in annual losses. If only the most recent 1998-2002 period is considered, then about 390 fires produce $14.9 million of losses each year. Lightning generally accounts for around 1 percent of all fires and slightly less than 1 percent of all fire losses, though these figures vary by year and province. The average reported loss for a lighting-ignited fire was about $20,114.

Insurance claims

Insurance claim data is likely one of the best sources of information for evaluating the impacts of lightning. While claim information is much more comprehensive than media sources and offers the benefit of consistent reporting, it can also be very difficult to obtain, especially for large regions, provinces or entire countries given the multitude of firms providing insurance services. Insurance data were not available within the timeframe of the current study, however, attempts were made to extrapolate a Canadian estimate from 3 U.S. studies (Holle *et al.*, 1996; Stallins, 2002; Insurance Information Institute, 2007).

Prior to developing a cost estimate, it was necessary to establish baseline lightning-related insurance claim rates for Canada. Extreme low and high estimates were calculated from the 3 U.S. studies (4.5-23.9 claims/10,000 population; 47-102 CG flashes/claim) and then corrected for population and CG lightning densities experienced in Canadian provinces. The final national Canadian estimate is 3,900-5,250 lightning-related claims per year. Baseline costs per claim obtained from Holle *et al.* (1996), Stallins (2002), and Insurance Information Institute (2007) were applied to the adjusted Canadian claim figures. Estimated annual lighting-related insurance claim losses amount to $6-21 million dollars. Application of an average home insurance deductible of $500 would add from $1.95 million to $2.63 million to the low and high scenarios, respectively. The larger figures are based on the Insurance Information Institute (2007) study, which was completed using the most current data (2003-2006), and are likely more reflective of actual losses. They account for considerable recent growth in losses per claim that is attributable to increased household investment in a greater number of higher-valued consumer electronics.

Forestry (fire suppression)

The social costs of forest fires include those related to protection and suppression, property damage to buildings and other infrastructure, lost productive timber, amenity and recreation, and existence values of forests. Only the first two in this list were treated by Mills et al. (2008b). Annual provincial and national summary statistics on fire frequency, cause, hectares burned, response category, and property losses for both the intensive and limited protection zones were obtained from the Canadian Interagency Forest Fire Centre (CIFFC, 2007) and the National Forestry Database Program (NFDP, 2007) and used to establish the number of fires and area burned that could be attributed to lightning. The data also formed the basis for apportioning three primary types of costs: 1) pre-suppression costs incurred through fire management activities prior to the occurrence of a fire, 2) suppression costs from all activities related to controlling and extinguishing a fire once it has been detected, and 3) Property damage. Relatively complete provincial level data were available for the years 2002 and 2004-2006 while data for National Parks were available for 2002, 2003, and 2005.

Lighting accounted for 47 percent of all actioned fires in Canada over the 2002-2005 period and the same portion (47 percent) of actioned fires within the important intensive protection zone (Mills et al. 2008b). In terms of the area burned, 65 percent of the area that received full or modified response was related to lightning-ignited fires. About 67 percent of the intensive protection area burned that received action was associated with lightning. Given that the level of preparedness and effort expended to fight fires is likely a function of both fire frequency and fire size (i.e., area burned), the minimum and maximum proportions (i.e., factors of 0.47 and 0.67) were used to assign and bound national costs to lightning incidents. Property damage was apportioned in an identical way for the same years. Results are summarized in Table 5. The total Canadian average annual expenditure of about $620 million fits squarely within the estimated range of $400-800 million cited in the literature review (NRCan, 2004) with lightning estimated to account for between $290-415 million of the total.

Table 5. Lightning-related forest fire expenditures and property damage (2002, 2004-2006) derived from CIFFC (2007) and NFDP (2007)

Cost Category	Total Canadian Expenditure	Lightning-related Expenditure	
		Low Estimate (0.47)	High Estimate (0.67)
Pre-suppression	$276,097,758	$129,765,946	$184,985,498
Suppression	$339,553,723	$159,590,250	$227,500,994
Property damage	$2,691,683	$1,265,091	$1,803,428
TOTAL	$618,343,164	$290,621,287	$414,289,920
INFLATED TOTAL	$656,051,246	$308,344,086	$439,554,335

Electricity transmission and distribution

The literature review revealed that lightning is an important variable in the management and operation of electricity infrastructure, in particular the transmission and distribution systems that provide power to residential, commercial, institutional and industrial customers. Forced outages and impacts to power quality affect these customers as well as the income of electric utilities. In order to derive an estimate of the costs of lightning-related outages and quality events in Canada, information concerning the duration of outages in Canada was combined with cost data originally developed for the U.S. Given the limited scope of this study and availability of data, it was not possible to develop a similarly robust power quality impact estimate.

Much of the outage cost analysis was based on work by Lawton *et al.* (2003) as interpreted and applied in an analysis of the cost of power interruptions to U.S. electricity consumers by LaCommare and Eto (2004). Customer damage functions were developed by Lawton *et al.* (2003) based on data from 24 studies and over 60,000 customer survey responses covering residential, commercial and industrial sectors in the U.S. Direct costing survey methods, whereby respondents are asked to identify net costs across multiple outage scenarios, were adopted in the commercial and industrial studies. Willingness-to-pay or willingness-to-accept approaches, in which customers are asked how much they are prepared to pay to avoid an outage scenario (or receive a credit remuneration for the costs/inconvenience), were used in the residential studies. The damage function models, developed using Tobit regression procedures for each customer class, estimate the average customer loss per event based on several predictors that account for the influence of outage duration, time-of-day, day-of-week, season, region, household income, and number of employees (size factor). The general form of the models, as defined in LaCommare and Eto (2004), is specified as follows:

$$Y = Exp[\beta_o + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_n X_n + \varepsilon] + e$$

Where,
Y is the outage cost for a particular customer class (residential, commercial, industrial);
β_o is the y-axis intercept;
X_n is the independent variable;
β_n is the regression coefficient for each parameter; and
ε and e are model error terms.

The specific regression coefficients for each parameter along with assumptions used to develop Canadian inputs were too detailed for consideration in the current paper but are defined in Mills et al. (2008b). Final results for the Canadian electricity sector application are presented Tables 6-7. Lightning-caused sustained outages are estimated to cost Canadian customers about $83 million each year while momentary outages cost an additional $273 million. The commercial sector accounts for about 73 percent of total costs with the industrial and residential sectors contributing 24 percent and 3 percent, respectively. These proportions are very similar (within 1-2 percent) to baseline costs assessed for the United States (LaCommare and Eto, 2004) and reflect the combined influence of average costs per outage per customer and the total number of customers in each class.

Table 6. Estimated annual lightning-caused sustained outage costs in Canada

Customer Type	Average cost per sustained outage per customer	Total estimated customers	Customers affected by sustained outages (5% total)[1]	Total Costs[1]
Residential	$3.12	13,560,223	678,011	$2,112,599
Commercial	$684.70	1,772,152	88,608	$60,669,254
Industrial	$2,147.21	187,723	9,386	$20,153,999
TOTAL		**15,520,098**	**776,005**	**$82,935,852**

[1] conservative estimate based on reported 5.9% lightning proportion of total customer interruptions in 2000 (Gelineau, 2002) (essentially assumes an overall SAIFI of 1.0 and lightning-SAIFI of 0.05)

Table 7. Estimated annual lightning-caused momentary outage costs per customer in Canada

Customer Type	Average cost per momentary outage	Total estimated momentary customer outages[1]	Total Costs[1]
Residential	$2.98	2,429,540	$7,242,897
Commercial	$634.14	317,510	$201,345,671
Industrial	$1,914.62	33,634	$64,395,829
TOTAL		**2,780,684**	**$272,984,397**

[1] based on ratio of U.S. MAIFI:SAIFI values used by LaCommare and Eto (2004) and applied to Canadian lightning-related SAIFI

Lost revenue is another product of power outages. Using the average outage duration applied in the customer cost analysis (0.2 hours), average demand data (McCracken and Rylska, 2005), and electricity pricing information (NRCan, 2006), revenue losses are estimated to total about $16,000. Even if the figures are in error by a few orders of magnitude, they are dwarfed by the customer losses associated with sustained and momentary outages.

An initial aggregate estimate

By combining the range of low and high estimates from each of the four sector analyses, one produces an overall annual lightning-related damage and disruption figure between $600 million and $1 billion (Table 8). While this figure is incomplete, based on the literature review the authors believe that it includes the major contributions to lightning-related costs.

Table 8. Combined annual estimates of lightning-related damage and disruption costs for Canada

Sector	Key impact/cost	Estimated Annual Costs/Losses[1]	
		Low	High
Health	Lightning-related injuries and fatalities	$3,648,793	$79,291,126
Property	Lightning-ignited municipal fires	$14,858,541	$16,414,436
	Insured losses and deductibles	$7,906,521	$23,540,272
Forestry	Forest fire suppression and pre-suppression	$306,981,081	$437,611,328
Electricity	Sustained and momentary outage costs to customers	$266,940,187	$444,900,311
	Lost revenue	$16,187	$16,187
TOTAL		**$600,351,310**	**$1,001,773,660**

[1] low and high estimates taken from report tables; electricity low and high values determined by subtracting and adding 25% to baseline estimates (Mills et al., 2008b)

4.0 Discussion

Care should be taken when interpreting the casualty and damage estimates noted in this paper. They were derived from multiple sources using different protocols and definitions. In the case of casualties, the estimates are based on a relatively small number of deaths and injuries with large variation between years and among jurisdictions. Even with the inclusion of indirect casualty information from fire loss data, the absolute and relative risks remain very small when compared to other causes of mortality or major trauma. Influenza, HIV/AIDS, falls, and motor vehicle collision mortality rates are 1-3 orders of magnitude greater than lightning-related fatality rates estimated in this study (Statistics Canada, 2005). 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 or other forms of injury, exposure to lightning and thus the potential risk of injury are 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 facilitates the targeting of public risk-reduction strategies, information and programs (Mills et al., 2008a). As well, the downward trend in lightning casualties appears to have flattened if not slightly increased over the past decade in Canada. Population growth and increasing exposure through greater participation in outdoor activities are most likely the root cause of this pattern which should continue to be monitored. Finally, when compared to other natural hazard events in Canada the average annual number of deaths and injuries related to lightning is significant. This relative comparison should be encouraged through additional monitoring and analysis of impacts and be considered in investment decisions related to the planning of public weather-related hazard programs.

The damage and disruption estimates must also be interpreted with caution because of uncertainties that arise from the degree of incompleteness, potential double-counting, transferability of U.S.-based relationships, variable treatments of costs (direct, indirect, social costs, etc.), assumptions concerning the Canada-wide applicability of results, and the general use of multiple data sources over variable timeframes. Overall, the authors believe that the estimates are conservative. In part this is because impacts and costs for several sectors including transportation (e.g., aviation) and tourism and recreation (e.g., golfing) are not included in the analysis. In the case of aviation, where convective disturbances are estimated to cost the U.S. industry up to $2 billion annually (Weber *et al.*, 1998), cause-of-delay and frequency of ground operation interruptions information for Canada were not readily available but would no doubt add to the total. Despite these and other caveats noted by Mills et al. (2008b), the estimated impact of lightning in terms of damage and disruption to Canadians is very large and certainly much greater than that attributed to other forms of hazardous weather (i.e., tornadoes, hail, hurricanes). With this very basic impact information in hand it is possible to begin evaluating where the introduction of new preventive measures and technologies may influence decisions and yield potential cost savings. This includes further development of the CLDN and related information products, services, and forecasts (e.g., Burrows et al., 2002). While evidence of substantial innovation and investment in lightning protection and detection was apparent for the electricity sector and wildfire management agencies, Mills et al. (2008b) suggest that, at the macro scale, residual costs or impacts may still warrant further investment. The authors believe that more value can be leveraged from the current lightning detection systems and that the full potential of lightning forecast applications remains largely unrealized. In addition to more precise information about lightning-related risks, impacts, and costs, capitalizing on the potential of lightning products and services will require a long-term commitment to understanding the problems and decision-making context of individuals, enterprises, and institutions. Much remains to be done.

5.0 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 continuing investment in the Canadian Lightning Detection Network (CLDN) which forms part of the larger North American and global detection systems. Despite this recognition, little research has been conducted to assess the extent of injuries, property damage and disruption caused by lightning in Canada. Such information provides a baseline against which the benefits of lightning detection, monitoring, forecasting, and other sector-specific actions and investments can be measured. Addressing this gap, Environment Canada initiated a review of available literature and conducted an initial multi-sector assessment of lightning-related impacts and costs for Canada. Based on an analysis of media reports, fire loss data, vital statistics, hospital admission and emergency room visitation records, an average of 9-10 lightning-related deaths and 92-164 injuries occur each year. Secondary data and extrapolations from U.S. studies were used to develop gross cost estimates for the health, property, forestry, and electricity sectors. When aggregated, annual lightning-related damage and disruption costs in Canada were estimated to range from $600 million to $1 billion. Additional research is required to more precisely or completely define lightning-related risks, impacts and costs. Such analysis should be conducted in a broader framework constructed to evaluate the efficacy and cost-effectiveness of risk or damage prevention measures—including those concerning an expanded or enriched use of the CLDN and lightning forecast data by public agencies and private sector clients.

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