Institute for Catastrophic Loss Reduction

Toward a National Assessment of the Travel Risks Associated with Inclement Weather

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Executive Summary

Recent studies confirm the common perception that inclement weather is associated with increased driving risk. However, risk estimates vary according to the research methods used and also by geography. In order to comment on the overall magnitude of the problem in Canada, a national study using a standardized method is needed. This report represents a major milestone in such a national assessment, providing detailed risk data for 27 major urban areas in Canada over a 17-year period. The report also provides information on driver adjustments during inclement weather based on both literature reviews and a case study of driving in the rain on the Gardiner Expressway in Toronto.

The main finding from the motor-vehicle collision analysis is that the risk of injury in Canadian cities increases by approximately 70 percent during precipitation relative to normal seasonal conditions. Minimal and minor injuries tend to increase more than do major and fatal injuries, as expected because drivers tend to slow down during inclement weather and injury severity is reduced at lower speeds. However, the injury profile is different for different types of precipitation:

- For rainfall, the increase is approximately 90, 60, 40 and 40 percent for minimal, minor, major and fatal injuries, respectively. These estimates are based on more than 25,000 event-control pairs and 135,000 casualty reports.
- For snowfall, the increase is approximately 110, 80, 40 and 10 percent for minimal, minor, major and fatal injuries, respectively. These estimates are based on nearly 8,000 event-control pairs and 28,000 casualty reports.
- For freezing rain and rain mixed with snow, the increase is approximately 100, 70, 60 and 120 percent for minimal, minor, major and fatal injuries, respectively. These estimates are based on approximately 3,500 event-control pairs and 13,000 casualty reports.

Another key finding is that weather-related driving risks are not the same in all cities. There is a tendency for driving risks during inclement weather to increase more in the larger cities, where driving is already challenging and traffic volumes are high.

In terms of driving adjustments, both theoretical and empirical studies confirm that drivers take extra precaution during adverse conditions, mainly by reducing speed. However, the magnitude of the adjustments tends to be insufficient for the conditions. A case study of driving speeds and following distances on the Gardiner Expressway in Toronto showed that, during light rains, average driving speeds were reduced by only 5 kilometres per hour, although these speed reductions were accompanied by more uniform speeds and increased distance between vehicles—all of which improve safety. Ongoing research in several nations is exploring how driver education and weather warnings could improve driver adjustments.

PART 1

PRECIPITATION-RELATED DRIVING RISKS IN CANADIAN CITIES

1. 1 Introduction

Traffic collisions result from a complex interplay of human, vehicular and environmental factors. Understanding the role of any specific risk factor, such as weather, requires careful attention to both the circumstances of collision events as well as the amount of exposure to those circumstances.

In 1982, Risk and Shaoul of the Transport Operations Research Group at University of Newcastle upon Tyne, England published a thought piece entitled, “Exposure to Risk and the Risk of Exposure” in the journal, *Accident Analysis and Prevention*. In this article, and in various subsequent discussions by other authors (Stewart, 1983), a distinction is made between the extent of opportunity for accidents, often measured as the amount of travel under certain conditions, and the probability of an accident during particular conditions. The latter is often expressed as the frequency of accidents during a particular condition relative to a control condition.

Total risk is a function of both the drivers’ exposure to a hazard and the probability of a negative outcome once exposed. These concepts are used in the current study to provide an organized framework for reporting (1) summary data on the weather conditions experienced by drivers in different parts of the country, i.e., exposure to weather hazards; and (2) estimates of the relative risk associated with driving during precipitation in these various locations, i.e., the risk of exposure.

1.2 Data and Methods

The analysis is based on weather data and collision records for 27 cities over a 17-year period, 1984-2000, as summarized in Table 1. Weather data were obtained from the climate archive of the Meteorological Service of Canada; information on injury and fatal collisions was obtained from Transport Canada’s national collision database.

There are two parts to the analysis. The first part addresses the question of exposure to weather hazards. For each of the 27 cities, the frequency of different weather events is summarized based on hourly meteorological observations over multiple years. Second, the effect of weather on casualty rates is explored, using first graphs and then a quasi-experimental, matched pair analysis. The latter provides detailed information on the risk of exposure through a comparison of the injury risk during precipitation relative to normal seasonal conditions.

Table 1: Data Included in the Risk Analysis

City (by longitude from West to East)	Years with Complete Data
Victoria	1984-2000
Vancouver	1984-2000
Richmond	1984-2000
Kamloops	1984-2000
Calgary	1991-1998
Edmonton	1991-1998
Saskatoon	1984-2000
Regina	1984-1998
Winnipeg	1984-1988, 1990-1993
Thunder Bay	1984-2000
Windsor	1984-2000
London	1984-2000
Sudbury	1984-2000
Brampton	1984-2000
Toronto	1984-2000
Oshawa	1987-2000
Ottawa	1984-2000
Gatineau	1984-2000
Montreal	1984-2000
Sherbrooke	1984-1994
Chicoutimi-Jonquiere	1984-2000
Quebec City	1984-1995
Fredericton	1984-2000
Saint John	1984-2000
Moncton	1984-2000
Halifax	1984-2000
St. John’s	1984-1987, 1989-1999

1.3 Exposure to Weather-Related Risks

The probability of a collision is a function of both the amount of travel and the conditions of travel. However it is virtually impossible to know the exact amount of travel that occurs under most environmental conditions because such conditions vary over space and change quickly over time.

It is possible, however, to calculate the percentage of time that certain weather conditions were observed at weather stations, and this provides a useful proxy for exposure to weather-related driving hazards. Accordingly, hourly observations at Canada's primary weather stations were acquired for sites located within or in close proximity to Canada's largest cities.

These hourly weather observations are expressed as codes. There are more than 500 unique combinations of weather codes used to capture the specific environmental conditions that are observed, e.g., IP-FZFG indicates ice pellets with freezing fog. For summary purposes, we decided to group the hours into seven categories that correspond broadly with the information on collision report forms:

- no observed weather;
- raining;
- snowing;
- sleet, hail;
- fog, smog, mist;
- dust, smoke
- strong winds

For classification purpose, where more than one code was reported, it was necessary to subjectively identify a primary condition—in other words, what would the public or police perceive given a mix of weather. In general, precipitation was chosen as the primary condition when it occurred with strong winds, fog, smog or mist. Frozen precipitation was given priority when mixed with liquid precipitation, and ice pellets or hail was chosen when observed with any other condition. A detailed list of criteria is provided in Appendix A. The likely effect of these assumptions is overestimation of the exposure to snowfall and underestimation of the exposure to both rainfall and reduced visibility caused by fog or blowing snow. The magnitude of these possible errors will be a function of how often mixed conditions occur—generally increasing from west to east.

Hourly results were then aggregated and expressed as percentages of the total number of hours in the study period for each city. Table 2 summarizes the results, which are generally consistent with expectations based on climatology. Conditions were clear (i.e., no precipitation, reduced visibility or strong winds) for a majority of the time in all cities, 75 percent or greater in cities outside of Atlantic Canada and eastern Quebec, and somewhat lower in eastern maritime regions where fog and precipitation are more common.

Precipitation (rain, snow or other frozen precipitation) was the primary weather condition during 10 to 20 percent of hours in most of the cities examined. Prairie cities were only marginally drier than those in coastal B.C., Ontario and the Maritimes. Precipitation was more prevalent in St. John's (22%), Chicoutimi-Jonquière (24%), Quebec City (19%) and Sherbrooke (20%), which is explained in part by the position of regional storm tracks. The incidence of precipitation was lowest for Kamloops (7%), pointing to the precipitation-shadow effect of mountainous terrain.

Overall, rainfall occurred most often along the southwest coast of B.C. (13-16%) and least often in the B.C. Interior and Prairie cities. Conditions were increasingly wetter as one moved east with a secondary rainfall peak in St. John’s (11%).

Snowfall was the primary weather condition during 10 percent or more hours in Saskatoon, Regina, Sudbury, Sherbrooke, Quebec City, Chicoutimi-Jonquière and St. John’s. Snowfall accounted for less than one percent of hours in Victoria and Vancouver, about 3 percent in Kamloops, and from 6 to 10 percent in the other cities. The proportion of snowfall hours relative to rainfall was much higher (difference greater than 3 percent) for Chicoutimi-Jonquière and cities in the Prairies and northern Ontario. These regions experience a long, cold winter season with few intrusions of warm air that would be conducive to rainfall. The more moderate climate experienced in Kamloops, southern Ontario, southern Quebec and Atlantic Canada explains in part why cities in these regions had similar (within 3 percent) proportions of hours with rainfall and snowfall. With mean winter temperatures well above 0°C, the proportion of hours with rainfall was appreciably greater than snowfall in Victoria and Vancouver.

Notable differences, again usually consistent with regional climatologies, were also observed for the other weather conditions. Fog, smog or mist was reported for a greater proportion of hours for cities in Atlantic Canada (7-16 percent) and southern Ontario (8-16 percent) relative to cities in Quebec (3-6 percent) and western Canada (5 percent or less). Onshore winds off of the cold Atlantic Ocean in spring and summer account for the fogginess in the Atlantic cities, while air pollution (haze) likely contributes to the anomaly observed in southern Ontario.

Thus, it is clear that exposure to weather hazards varies geographically. The next part of the report explores the heightened risk of casualty that is associated with inclement weather.

Table 2: Weather Conditions Observed (% time) at Canada’s Largest Cities

City	No weather	Rain	Snow	Other Frozen Precip.	Fog, Smog, Mist	Dust, Smoke	Strong Winds	All conditions
Victoria	80.98	12.89	0.86	0.02	5.09	0.15	0.00	100.00
Vancouver	78.95	15.69	0.95	0.02	4.32	0.07	0.00	100.00
Richmond	78.95	15.69	0.95	0.02	4.32	0.07	0.00	100.00
Kamloops	91.07	4.55	2.61	0.01	1.70	0.06	0.00	100.00
Calgary	83.87	4.37	8.18	0.02	3.36	0.18	0.01	100.00
Edmonton	84.88	4.63	7.63	0.01	2.66	0.19	0.00	100.00
Saskatoon	82.2	3.45	11.16	0.04	2.79	0.31	0.06	100.00
Regina	79.55	3.81	12.18	0.06	3.70	0.41	0.29	100.00
Winnipeg	82.83	4.68	8.70	0.06	2.98	0.36	0.39	100.00
Thunder Bay	80.41	5.10	8.75	0.09	5.47	0.12	0.05	100.00
Windsor	72.53	7.22	6.34	0.08	13.77	0.04	0.02	100.00
London	66.14	8.03	9.82	0.13	15.79	0.02	0.06	100.00
Sudbury	75.85	6.33	10.56	0.15	7.03	0.04	0.05	100.00
Brampton	75.81	7.31	5.83	0.17	10.83	0.01	0.03	100.00
Toronto	75.81	7.31	5.83	0.17	10.83	0.01	0.03	100.00
Oshawa	75.18	6.89	6.74	0.11	11.06	0.01	0.01	100.00
Ottawa	76.37	7.47	7.37	0.27	8.47	0.01	0.03	100.00
Gatineau	76.37	7.47	7.37	0.27	8.47	0.01	0.03	100.00
Montreal	79.13	8.05	7.15	0.26	5.39	0.01	0.02	100.00
Sherbrooke	74.80	8.79	11.28	0.09	5.02	0.00	0.03	100.00
Quebec City	75.54	8.32	10.23	0.31	5.52	0.04	0.04	100.00
Chicoutimi-Jonquiere	73.27	8.93	14.59	0.22	2.70	0.04	0.25	100.00
Fredericton	78.75	8.24	5.91	0.33	6.71	0.04	0.02	100.00
Saint John	70.29	8.56	6.32	0.27	14.51	0.03	0.02	100.00
Moncton	75.24	8.50	8.29	0.36	7.55	0.03	0.04	100.00
Halifax	70.61	9.45	5.62	0.40	13.86	0.01	0.05	100.00
St. John’s	61.74	10.81	11.03	0.40	15.77	0.00	0.25	100.00
Minimum	61.74	3.45	0.85	0.01	1.70	0.00	0.00	100.00
Maximum	91.07	15.69	14.59	0.40	15.79	0.41	0.39	100.00
Average	76.93	7.87	7.49	0.16	7.40	0.08	0.07	100.00

1.4 Risk of Exposure to Weather

Inclement weather reduces both driver visibility and road-tire friction. Rain, for example, impairs the driver's ability to see through the car windshield and makes the pavement appear darker. Also, wet or icy roads significantly reduce the effective coefficient of friction between the tires and the road, thus increasing stopping distances. Previous studies have demonstrated that these driving hazards increase collision and casualty risk, but the question is by how much.

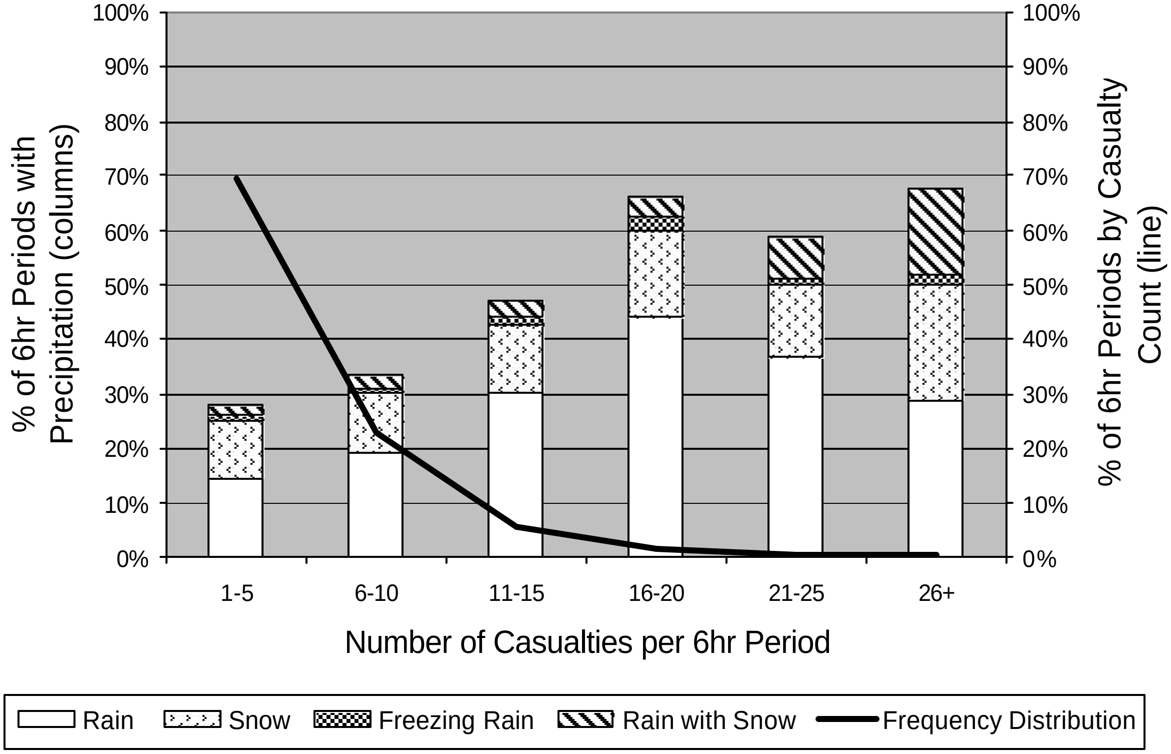
In order to explore the risk of exposure to inclement weather, for each of the 27 cities, we created a data base that links casualty information with weather information. Hourly, six-hourly and daily weather data were incorporated in the data base, but the basic unit of analysis was the six-hour period, since this is the smallest unit of analysis for snowfall amount—one of the key variables for characterizing winter weather in Canada.

<u>The Over-Representation of Precipitation During High-Casualty Periods</u>

As a starting point, we explored the association between number of casualties and weather condition graphically. For each of the 27 cities, we created a frequency distribution of the number of six-hour periods in which a specified number of casualties occurred. For example, in Ottawa over the 17 years of record, nearly 30 percent of the six-hour periods resulted in five or fewer casualties and an additional one-third of the time periods resulted in 6 to 10 casualties. These frequencies are indicated by the solid line in Figure 1. Then for each frequency class, we calculated how often different types of precipitation occurred: rain, snow, freezing rain, and rain with snow. These percentages are given in the stacked column graphs of Figure 1. As evident here, time periods with low casualty counts were usually characterized by good weather; whereas precipitation was observed in most of the time periods with high casualty counts.

Graphs for all 27 cities are provided in Appendix B. Evident in these graphs are the regional climatologies across Canada. For example, rain is the dominant form of precipitation in cities located in coastal B.C., while the Prairie cities experience more snowfall. Also, some cities are drier overall (e.g., Kamloops), while others experience precipitation more often (e.g., St. John's). Of greater importance, however, is the fact that periods with high casualty counts are more likely to be associated with precipitation than those with low casualty counts, as indicated by the tendency for the columns to increase in height from left to right.

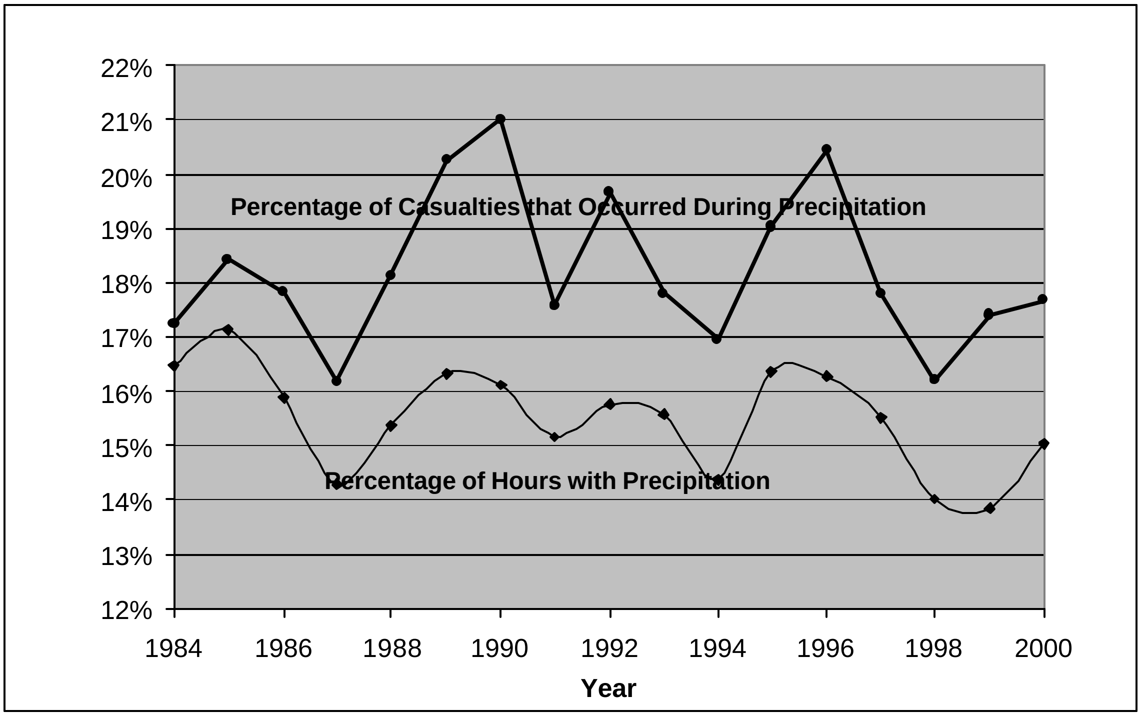
Figure 1: Casualties and Precipitation in Ottawa



The Relative Risk of Casualty During Different Forms of Precipitation

Two approaches were taken for exploring the risk of exposure to inclement weather. At an aggregate level, we compared the percentage of casualties that occurred during precipitation with the percentage of the time when precipitation was observed at weather stations. One would expect the first percentage to be higher than the second if injury risk increases during precipitation. As illustrated in Figure 2, this is the case. However, this type of comparison cannot account for variations in the nature of the weather conditions or the fact that traffic is not spread uniformly over time. Thus the percent frequencies should not be used directly with the collision records to estimate the risk of exposure. In order to calculate accurate and comparable risk estimates, some regard for the weather type and/or intensity and some control over time of day and season are required.

Figure 2: Graphical Representation of the Increased Risk of Driving During Precipitation for 27 Canadian Cities Combined



Further analysis was conducted in order to address the question: When precipitation does occur, what is the risk of driving relative to normal seasonal conditions. A matched- pair analysis was conducted toward this end, whereby injury counts were compared between events (periods of precipitation) and matched controls (periods where neither precipitation nor other significant weather occurred). In all cases, an event and its matched control were identical in terms of time of day and day of week; and events and controls were separated by no more than two calendar weeks. Once event-control pairs were identified, based primarily on the weather observed at the nearest weather station but also considering weather information provided on collision reports, the number of people who were injured or killed during these time periods was recorded.

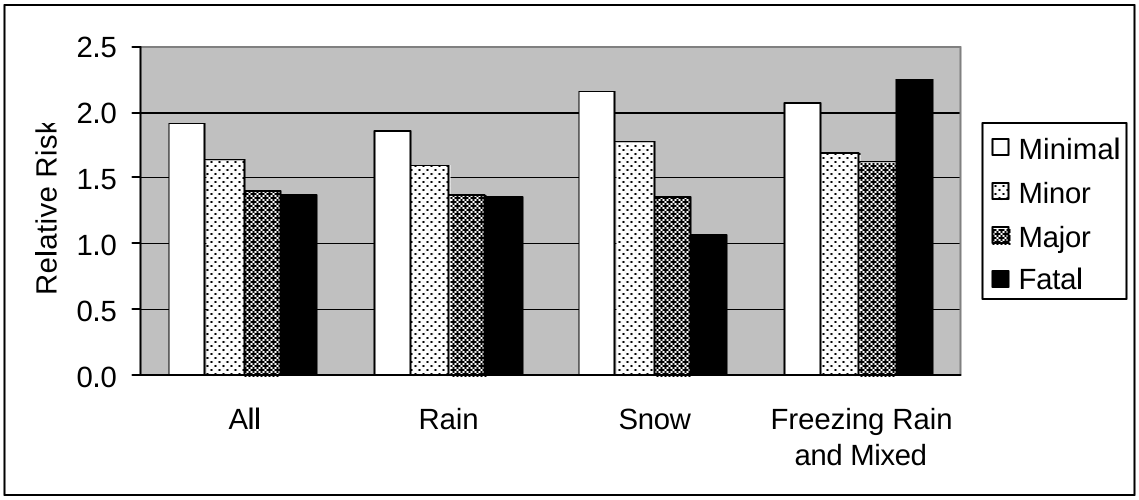
The relative risk of injury during precipitation was then determined by dividing the number of injuries during events by the number of injuries during controls. When the risk of injury is greater during precipitation than at other times, the resulting relative risk is greater than 1.0; for example, a relative risk of 1.4 indicates that 40 percent more injuries occurred during precipitation than during normal seasonal conditions. While many combinations of precipitation type and intensity could be explored, this report provides only aggregate results, focusing first on the relative risk for four different forms of precipitation events and then on relative risk during rainfalls of different intensities.

The relative risk ratios for different forms of precipitation (as defined in Table 3) are summarized in Figure 3. These results, which are based on more than 36,000 six-hour event-control pairs for the 27 cities combined, show that casualty risk increases during all forms of precipitation—rain, snow, and freezing rain and/or mixed rain and snow. Minimal and minor injuries tend to increase more than do major and fatal injuries. This is expected given the reduced speeds and other driver adjustments that occur during inclement weather.

Table 3: Criteria Used to Define Event-Control Pairs for the Analysis of Precipitation-Related Risk

	Criterion Used to Define Events	Criteria Used to Define Matching Controls
Precipitation Amount	≥ 0.4 mm	= 0.0 mm
# Hours When Precipitation was Observed	≥ 3 (out of 6)	≤ 1 (out of 6)
# Hours With Visibility < .5 km		≤ 1 (out of 6)
% Collision Reports Indicating Precipitation at Time of Crash	≥ 50	= 0
Other		No collision reports indicating icy pavement, and no measurable precipitation for at least 6 hours before start of control period.

Figure 3: Relative Risk of Casualties of Different Severity for Different Types of Precipitation



For all forms of precipitation combined, the risk ratios for minimal injury, minor injury, major injury and fatal injury are 1.9, 1.6, 1.4 and 1.4, respectively, as shown by the first cluster of columns in Figure 1. Indeed, if one combines the information for the different levels of injury severity, resulting in a relative risk ratio of 1.7, one arrives at the first national assessment of the relative risk of casualty during precipitation in Canadian cities. The latter number suggests that, across the nation, urban casualties are increased by approximately 70 percent during precipitation.

However, the injury profile varies by type of precipitation:

- For rainfall, the increase is approximately 90, 60, 40 and 40 percent for minimal, minor, major and fatal injuries, respectively. These estimates are based on more than 25,000 event-control pairs and 135,000 casualty reports.
- For snowfall, the increase is approximately 110, 80, 40 and 10 percent for minimal, minor, major and fatal injuries, respectively. These estimates are based on nearly 8,000 event-control pairs and 28,000 casualty reports.
- For freezing rain and rain mixed with snow, the increase is approximately 100, 70, 60 and 120 percent for minimal, minor, major and fatal injuries, respectively. These estimates are based on approximately 3,500 event-control pairs and 13,000 casualty reports.

Based on sample sizes, confidence in all of the estimates for rainfall are very high. For snowfall, confidence is high for estimates of minimal, minor and major injuries, but only moderate for fatalities. For mixed precipitation, confidence is high for estimates of minimal and minor injuries, but only moderate for major injuries and low for fatalities.

Another key finding is that weather-related driving risks are not the same in all cities. There is a tendency for driving risks to increase more during inclement weather in the larger cities, where driving is already challenging and traffic volumes are high. More information on the risk profile of individual cities is provided in Table 4. Where there were fewer than 100 event-control pairs, the risk ratio is not displayed for that city, pending further investigation of the level of confidence that can be associated with smaller samples. Small sample size is also the rationale for not showing the risk ratios for freezing rain and rain mixed with snow for individual cities.

It should also be noted that the driving conditions, including the network and traffic, would have changed over the study period. However, the advantage of the matched-pair design is that these effects are essentially controlled in order to isolate the effects of weather.

Table 4 : Precipitation-Related Injury Risks for Individual Cities

City	**Years with Complete Data**	**Relative Risk of Injury During Rain**	**Relative Risk of Injury During Snow**
Victoria	1984-2000	1.3	
Vancouver	1984-2000	1.9	
Richmond	1984-2000	1.6	
Kamloops	1984-2000	1.3	3.1
Calgary	1991-1998	1.3	1.8
Edmonton	1991-1998	1.6	1.8
Saskatoon	1984-2000	1.6	2.6
Regina	1984-1998	1.3	2.5
Winnipeg	1984-1988 1990-1993	2.4	3.4
Thunder Bay	1984-2000	1.4	2.1
Windsor	1984-2000	2.0	2.1
London	1984-2000	2.1	1.9
Sudbury	1984-2000	1.7	2.1
Brampton	1984-2000	1.6	1.9
Toronto	1984-2000	1.8	2.1
Oshawa	1987-2000	1.8	1.7
Ottawa	1984-2000	1.9	2.0
Gatineau	1984-2000	1.6	1.8
Montreal	1984-2000	1.7	1.7
Sherbrooke	1984-1994	1.1	1.4
Quebec City	1984-1995	1.2	1.6
Chicoutimi-Jonquiere	1984-2000	1.1	1.4
Fredericton	1984-2000	1.0	1.7
Saint John	1984-2000	1.1	1.5
Moncton	1984-2000	1.1	1.2
Halifax	1984-2000	1.2	1.1
St. John’s	1984-1987, 1989-1999	1.4	1.5

Rainfall Intensity and Driving Risks

The final theme explored in this part of the report is the effect of rainfall intensity on casualty risk. In order to document the effect of rainfall intensity on casualties, the risk analyses were re-run using different rainfall amounts to define the events. The cutoff amount used (six-hour totals) were: more than a trace, more than 2 mm, more than 5 mm and more than 1 cm. Across Canada, the proportion of the six-hour periods with more than a trace of precipitation varies from one-quarter to one-half, while for greater than 1 cm the percentage is between one and eight percent, depending on the region. Most drivers would be exposed to driving in the rain many times each year, but might only drive in heavy rain, as indicated by the last two categories, a few times a year. The results (Table 5) illustrate how risk increases with storm intensity, at least for more serious injuries.

Table 5 : Rainfall Intensity and Injury Risk

	Relative Risk			
	Minimal Injury	Minor Injury	Major Injury	Fatality
All Events with more than a trace of rain	1.9	1.6	1.4	1.4
Events with more than 2 mm rain	2.0	1.7	1.4	1.4
Events with more than 5 mm rain	2.0	1.7	1.5	1.6
Events with more than 1 cm rain	1.9	1.6	1.9	2.2

1.5 Conclusion

This report represents a major milestone toward the development of a national assessment of the injury risks associated with inclement weather, providing detailed data for 27 major urban areas in Canada over a 17-year period. The main finding from the collision analysis is that the risk of driving-related injury in Canadian cities increases by approximately 70 percent during precipitation relative to normal seasonal conditions. Minimal and minor injuries tend to increase more than do major and fatal injuries, as expected because drivers tend to slow down during inclement weather. However, the injury profile is different for different types of precipitation and weather-related driving risks are not the same in all cities. There is a tendency for driving risks during inclement weather to increase more in the larger cities, where driving is already challenging. Further investigation of geographical differences and differences across storm types should illuminate how weather interacts with other variables in altering the temporal and patterns of driving risk.

PART 2

DRIVING ADJUSTMENTS DURING INCLEMENT WEATHER

2.1 Introduction

Knowing how drivers respond to changing environmental conditions is important for understanding both road safety patterns and traffic operations. Two key aspects of the driving environment are the weather and traffic levels. However, little research has been undertaken to estimate how driving changes with weather, and how these changes are affected by roadway congestion.

The current report[1] contributes to our understanding of these issues. Specifically, the study provides empirical estimates of differences in traffic volumes, driving speeds and vehicle headways during rainfall conditions versus normal seasonal weather conditions. This is done for both uncongested conditions and periods of congestion, using data for the Gardiner Expressway in Toronto.

2.2 Research Context

There is general agreement in the road safety community that socio-psychological characteristics play an important role in explaining driver behaviour and safety outcomes (Evans, 1991). However, there is no single psychological theory that can be used to explain the complex actions of drivers. Rather, several theories provide partial explanations for a range of driver behaviours from intentional risk taking to unintentional driver errors.

These theories include, for example, the related ideas of reasoned action and planned behaviour (e.g., Aberg et al., 1997; Parker et al., 1992; Elliott et al., 2003), which articulate how attitude, perceived control, and subjective norms affect behaviours such as speed compliance. Also of relevance are theories that deal with risk compensation, whereby drivers adapt to driving situations in order to bring their perceived levels of risk into line with their acceptable levels of risk. Examples of risk-compensation theories include Summala's zero risk theory, first put forward in the 1970s (Summala, 1996), and Wilde's (1982) risk homeostasis theory.

However, despite the fact that traffic psychology is an active area of theoretical research, current theories, such as those listed above, are insufficient to allow accurate predictions of the magnitude, and even sometimes the direction, of driver responses to various external stimuli, such as weather. The alternative approach is to conduct empirical analyses of traffic conditions during varied conditions that permit the estimation of behavioural responses and to try to infer decision-making processes from the resultant patterns. The latter approach has been adopted for the current study.

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[1] This report is based on a Master's thesis completed in 2004 by Dan Unrau in the Department of Geography, University of Waterloo, Waterloo, Ontario, N2L 3G1. The title of the thesis is *Driver Response to Rainfall on the Gardiner Expressway*.

Most empirical studies into the relationship between weather and road safety do not deal directly with driver behaviour. Rather, the focus is on risk levels, as indicated by collision rates. Overwhelmingly, results from safety studies indicate that adverse weather is associated with an increase in the total number of collisions. However, studies also show that the weather-related increases in risk are not uniform; rather they are higher for property damage collisions than for more serious crashes (Andrey et al., 2001, 2003). The first result provides evidence that drivers' adjustments to inclement weather are insufficient to completely offset the hazards associated with reduced roadway friction and poorer visibility, while the second finding suggests that some degree of driver compensation does occur, probably in the form of speed reduction.

More detailed information on driving adjustments during weather can be derived from two kinds of studies—those that document aggregate changes in traffic characteristics and those that provide insight into individual drivers' perceptions and behaviours. The former has the advantage of being based on large datasets, but has the disadvantages of being highway- or intersection-specific and based upon data derived from automated surveillance systems that provide no information on drivers' characteristics or motivations. The second type of study, which typically involves surveying or interviewing drivers, has the advantage of providing insight into drivers' thinking, but estimates of change are often imprecise because of small datasets or problems associated with estimation and recall. Thus neither type of study is sufficient on its own, but together the two types provide complementary insights into driver adjustments to weather as a natural hazard. The following paragraphs summarize our state of knowledge on three of these driver adjustments that are known to affect safety—decisions on whether/when to drive, changes in driving speed, and adjustments that indicate more/less caution while driving.

One potential response to inclement weather is to cancel or defer a trip, which reduces the population's exposure to risk and affects traffic density, both of which can affect safety (Golob et al., 2004). In studies using aggregate data, vehicle counts recorded in fixed periods (from 20-second to one-day intervals) have been used to monitor changes over time (e.g., Hanbali and Huemmel, 1993; Hassan and Barker, 1999; Ibrahim and Hall, 1994; Knapp, 2001; Minaker, 2003). Results indicate that traffic levels are typically reduced during inclement conditions, with only minor changes during light precipitation but with reductions of 20 percent or more during heavy rainfalls and winter storms. It is generally assumed, however, that such reductions are as much related to reduced travel speeds (which reduces the rate of throughput) as to trip rescheduling, and indeed driver surveys confirm that trip cancellation is rare except in extreme weather, such as freezing rain (Andrey and Knapper, 2003).

A second type of response is to adjust travel speed, which affects both collision rate and severity. Interestingly, most studies to date suggest that speed reductions are a common response but that speed adjustments are typically small, again except during extreme weather. For example, Ibrahim and Hall (1994) found that, during free-flow conditions, mean expressway speeds were reduced by 2 kph during light rain and 5 to 10 kph during heavy rain. Similar speed adjustments were observed by Brilon and Ponzlet (1996) and Edwards (1999) for wet and/or foggy conditions and can be inferred from travel-time estimates reported in Stern et al. (2003). Studies of snowfall suggest much greater speed reductions—in the order of 20 kph (Knapp, 2001; Liang et al. 1998). As a complement to studies using traffic data from automated stations, Doherty and Andrey (1993) and Andrey and Knapper (2003) provide self-reported data of what drivers do in response to various weather scenarios. They also found that speed adjustments during wet weather were minimal, but that the level of change increased as weather severity increased.

Also related to mean speed, and possibly of more importance to safety, is the variation in travel speed across drivers. A high speed deviation is thought to increase the risk of being in a collision because the potential for vehicle conflicts is increased (Padget et al., 2001), although it is very difficult to infer individual risk from ecological studies (Navon, 2003). Still, there are examples where serious crash events have been associated with high speed deviation during inclement weather (e.g., the 87-vehicle collision on Highway 401 on September 3, 1999). Indeed, studies to date, while few in number, suggest that the standard deviation of speed actually increases during poor weather (Liang et al., 1999, Padget et al., 2001).

Also closely related to speed, vehicle headway provides insight into drivers' cautionary measures (Evans and Wasielewski, 1982). Like speed, headway distances are dependent on both drivers' experience levels and behavioural tendencies. Short following distances allow for less time to react if the lead vehicle brakes or if an obstacle is encountered. Even if a headway were to remain static, a corresponding increase in speed would result in reduced time for reaction before a collision. For this reason, short headways are associated with increased accident risk (Rajalin et al. 1997). However, in terms of the effects of weather on headways, little research has been published.

In summary, previous research suggests that most drivers compensate for inclement weather by reducing travel speeds and increasing vehicle headways, both of which are associated with reduced risk. However, some studies suggest that speed deviation may be higher during inclement weather than under normal conditions, which could have the effect of reducing safety. Finally, weather appears to have little effect on the frequency of driving trips, except in extreme weather when a minority of trips are cancelled or rescheduled.

2.3 Traffic Data

The current study is based on data for the Gardiner Expressway, a six-lane, limited-access highway that provides access to the core of Canada's largest city, Toronto. The highway has a speed limit of 90 kph and an annual average daily vehicle count of 90,000 vehicles (Dadson et al., 1999).

Traffic conditions are continually recorded using a double-loop monitoring system. When a vehicle passes over a sensor, a circuit is completed and several pieces of information are recorded. From this recorded information, summary data in 20-second intervals are available for four variables: traffic volume (vehicle count); average speed (kph); occupancy (the percent time that the sensor is occupied, which is an indication of traffic density); and average vehicle length (metres).

Of these variables, the first two, volume and average speed, were used in the current study. Occupancy was not used; rather, headway[2] was used as a measure of traffic density. Average vehicle length was also not used because preliminary analysis indicated that it is fairly constant through time. These three variables—volume, average speed, and average headway—were then aggregated to 5-minute intervals in reduce the degree of scatter in the data. Finally, a new variable, the standard deviation of speed was calculated using the 20-second average speed readings for each 5-minute time interval. This last variable does not capture the total variability in driving speeds across vehicles, but does provide a measure of the relative variability in speed from one time period to another.

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[2] Headway was calculated using the formula from the Highway Capacity Manual:
Headway=3600/Hourly Flow. The constant, 3600, is the equivalent number of seconds in an hour.

Then a decision was made as to which site along the Gardiner Expressway would be used in the analysis. There are 21 matched pairs of stations, one in each direction of travel. In order to reduce complexity, the decision was made to choose one site that would minimize the effects of external factors such as road curvature, grade, and merging maneuvers. For this reason, sites were removed from consideration if they were located near an on- or off- ramp. Additionally, sites were removed from consideration if the data quality at the site was poor (i.e., had a large number of missing data points). The study site thus selected was dw060, located on the western portion of the Gardiner, near the cross street, Strachan Avenue (Figure 1).

FIGURE 1: STUDY SITE

Map Source: MapQuest.com

Other operational decisions made for the study were with regards to lanes of traffic and days of the week. For the purposes of analysis, only the median lane, or the lane closest to the center median, was included for each direction of traffic. Due to the dynamics of the highway, and prevailing traffic laws, this is the lane with the least amount of truck traffic, and therefore, has the highest concentration of passenger automobiles. Also, the analysis includes weekdays only (Monday through Friday) when there are predictable congestion peaks in both the morning and afternoon.

2.4 Weather Data and Event Selection

Data were acquired from three weather stations in the City of Toronto: City Centre Airport, Bloor St. Station and Pearson International Airport, located 1.1, 3.1 and 16.1 km from the study site, respectively. However, the City Centre site does not provide hourly precipitation amounts, and the Bloor St. location provides such information for the summer months only. Therefore, Pearson Airport was used as the principal site for weather data; these records were supplemented with data from Bloor St. where Pearson data were missing. To test the appropriateness of Pearson data for the current study, the hourly precipitation observations taken at the City Centre Airport were compared with hourly accumulation data for Pearson. In total, only 482 of the 8769 hourly observations differed. However, it was evident that the timing of heavy rainfall did not necessarily correspond between the two sites, and this was considered in the definition of the sample set, as explained in the following paragraph.

Using hourly rainfall totals for 1998, rainfall events were defined based on the starting and ending times of measurable rainfall. After removing events that lasted only a single hour or for which traffic data were not available, only 32 rainfall events remained. Additional events were removed from the sample set if a traffic accident occurred near the study site during precipitation (3 events removed) or if a time-matched control period (with no notable weather) one week before or after the event was not available (5 events removed).

Of the 24 remaining events, there were a total of 230 hours of observations – 115 hours of rainfall and 115 matched control hours. Of these 115 hours of rainfall, 105 were classified as light (0.1 – 2.4 millimetres total accumulation), using Environment Canada's typology. The remaining hours were classified as moderate or heavy, and they were removed from the data set largely due to their small sample size, but also because these rainfall events occurred mainly in the hours between midnight and morning rush hour, when traffic volumes were especially light.

2.5 Analysis

The direction and extent of drivers' adjustments to periods of light rainfall was estimated by comparing rainfall conditions and paired "normal" conditions. More specifically, each 5-minute time interval with rainfall was matched with the same clock time either one week before or after the period of rainfall, and a series of paired t-tests were performed to test for differences in mean traffic volume, travel speed, speed deviation and vehicle headway.

2.6 Results

The results of the t-tests indicate that drivers compensate for light rainfall, as summarized in Tables 1 to 4. Generally speaking, rainfall resulted in lower volumes, lower average speeds, lower speed deviations, as well as increased headways, although some differences in magnitude, based on travel direction and prevailing traffic conditions (i.e., uncongested versus conditions), were observed.

As shown in Table 1, volumes were reduced during periods of light precipitation in both uncongested and congested periods. Although not statistically significant at the .05 level, the difference in means for eastbound uncongested periods resulted in an average drop in volume of 2.6 percent. The westbound direction experienced a larger drop in volumes of 5.9 percent. For congested periods, the reductions in volumes were reversed, with the eastbound direction experiencing a larger drop (4.3%) than the westbound direction (1.8%).

TABLE 1: T-TEST RESULTS FOR TRAFFIC VOLUME

Volume (vehicles/5 min)			Eastbound		Westbound	
			Control	Light Rainfall	Control	Light Rainfall
Uncongested	Mean		30.2	29.4	33.7	31.7
	% Diff.		-2.6		-5.9	
	n		451		426	
	p	t	.083	-1.7	.000	-4.5
Congested	Mean		117.0	112.0	111.8	109.8
	% Diff.		-4.3		-1.8	
	n		671		819	
	p	t	.000	-5.6	.012	-2.5

The reductions in volume during periods of light rain are most likely the result of a combination of reduced speeds and increased headways, but it is also possible that some trip rescheduling could have occurred.

The results for average speed are summarized in Table 2. For uncongested conditions, speeds drop 5.2 percent in eastbound traffic, and 3.3 percent in westbound traffic. In periods of congestion, speeds drop to a larger degree with an 8.6 percent drop in eastbound traffic and a 7.5 percent drop in westbound traffic.

TABLE 2: T-TEST RESULTS FOR AVERAGE SPEED

Average Speed (kph)			Eastbound		Westbound	
			Control	Light Rainfall	Control	Light Rainfall
Uncongested	Mean		87.2	82.7	98.0	94.7
	% Diff.		-5.2		-3.3	
	n		451		426	
	p	t	.000	-14.9	.000	-10.9
Congested	Mean		76.5	69.9	76.0	70.3
	% Diff.		-8.6		-7.5	
	n		669		819	
	p	t	.000	-15.3	.000	-9.7

The higher speed reductions in congested conditions seem to indicate that drivers are more sensitive to precipitation and wet roads when volumes are high. These speed reductions in congested conditions would affect more vehicles due to the interactions that occur between vehicles. These interactions would be fewer in uncongested conditions due to larger following distances.

In addition to reductions in mean speed, rainfall is also associated with reduced speed variability. These differences are larger in congested conditions than in uncongested conditions (Table 3). These reductions in speed deviation may not play a large role in volume reductions. However, they do suggest that, in periods of rainfall, drivers not only reduce their speed, but they also travel at more uniform speeds, thus potentially decreasing the opportunity for conflicts.

TABLE 3: T-TEST RESULTS FOR SPEED DEVIATION

Speed Deviation (kph)			Eastbound		Westbound	
			Control	Light Rainfall	Control	Light Rainfall
Uncongested	Mean		8.5	8.1	8.9	8.9
	% Diff.		-4.7		0.0	
	n		449		426	
	p	t	.039	-2.1	.880	-0.2
Congested	Mean		5.5	4.9	6.9	6.4
	% Diff.		-10.9		-7.2	
	n		669		819	
	p	t	.000	-5.8	.000	-4.8

Headways increase in rainfall conditions in both uncongested and congested periods (Table 4). Although the largest percent differences generally occur in congested conditions, it is during uncongested periods that headways increase the most in absolute terms.

TABLE 4: T-TEST RESULTS FOR HEADWAY VARIABLE

Headway (seconds)			Eastbound		Westbound	
			Control	Light Rainfall	Control	Light Rainfall
Uncongested	Mean		10.2	10.7	9.4	9.9
	% Diff.		+4.9		+5.3	
	n		451		426	
	p	t	.000	4.6	.000	4.3
Congested	Mean		2.6	2.8	2.8	2.9
	% Diff.		+7.7		+3.6	
	n		671		819	
	p	t	.000	5.1	.000	6.3

2.7 Conclusions

In summary, results indicate that volumes drop, average speed and speed variation are reduced, and vehicle headways are increased during light rainfall as compared to normal seasonal weather conditions. These changes were observed for both directions of travel and for both uncongested and congested conditions. These findings suggest that drivers compensate for the travel risks associated with wet weather, although it should be noted that changes in volume cannot necessarily be attributed to trip rescheduling—but rather may be associated with the slower travel speeds and increased gaps between vehicles. Also of note is the modest extent to which average speeds are reduced—by less than 5 kph. Finally, it is worth highlighting that the reduced speed deviations observed here are inconsistent with the findings from two previous studies, suggesting that further research needs to be conducted on speed variability.

2.8 Discussion

Ongoing research around the world is exploring how driver education and weather warnings could improve driver adjustments to environmental risk factors, such as weather. It is clear, however, that this field of study is still in its infancy (e.g., Boyle and Mannering, 2004; Chatterjee and McDonald, 2004; Rama and Kulmala, 2000)

Of potential relevance to the road safety community is the understanding of human responses to hazards and warnings that has accrued in the natural hazards community over the past half century. In a recent review of public hazards education, Mileti et al. (2004) suggest that seven issues need to be considered:

1. There is a difference between public education and warnings;
2. The lessons learned about the social psychology of hazard education are largely transferable from one hazard type to another;
3. Effective education must be ongoing;

4. Good hazards education recognizes that there is no one public;
5. Perceiving risk is no guarantee that action will be taken;
6. Probability estimates aren’t that important; and
7. People are more likely to take appropriate action if they think that it is their idea to do so.

For the most part, it would seem that the transportation community is embarking on the challenge of educating and warning motorists without fully benefiting from what has been learned in other hazards research. The issues developed in the context of natural hazards research generally raise questions, for example about how risk should be conveyed, how to engage the media and make available information that would be useful to motorists at the various decision points, and how to use messaging that will evoke appropriate and consistent action. Despite the proliferation of devices and technologies that can provide real or near-real time information, little attention is being given to message content and the effectiveness of information in reducing risk. Other alternatives, such as intelligent speed control technologies, are also being explored for their potential safety benefit during adverse weather conditions (Carsten and Tate, 2005).

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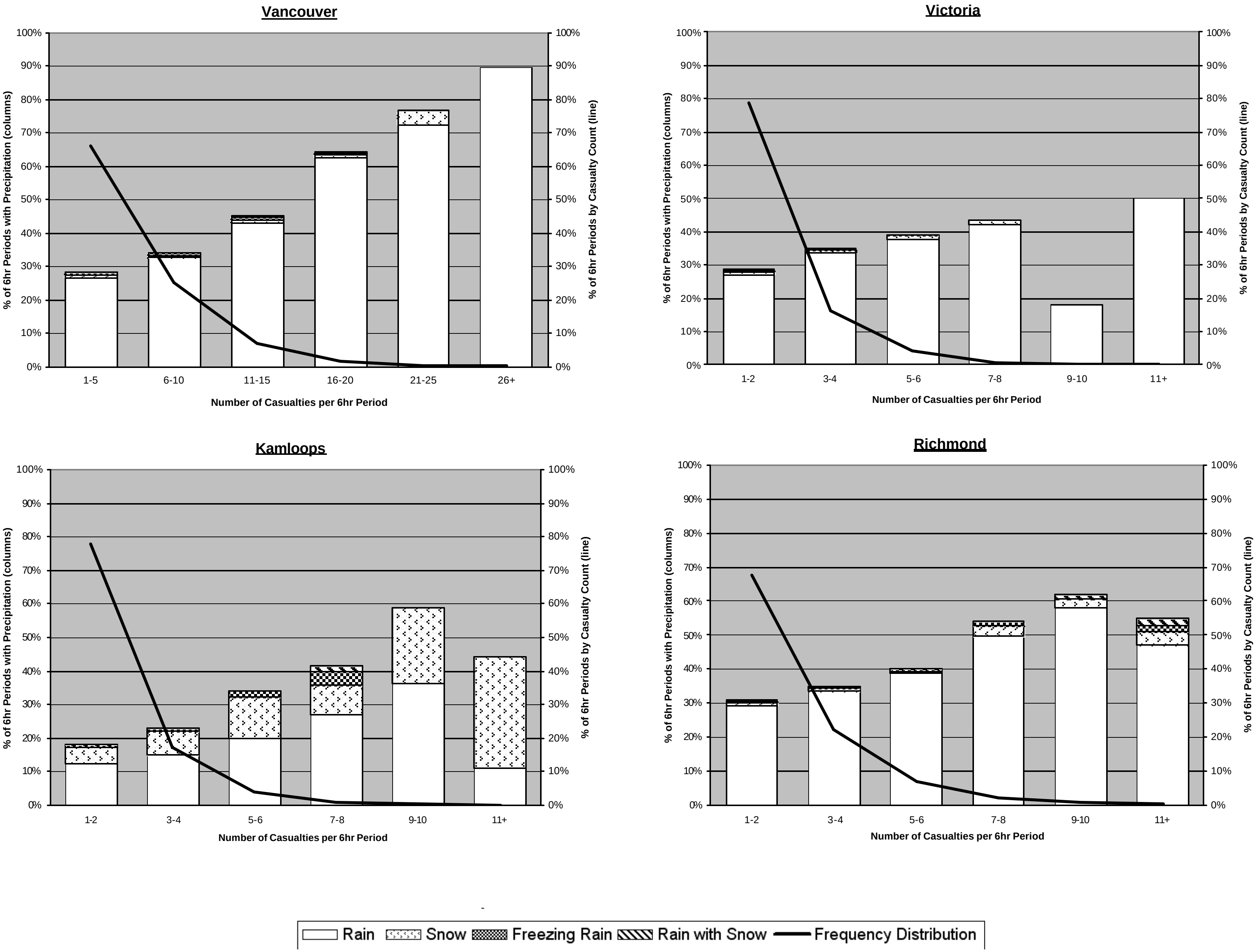
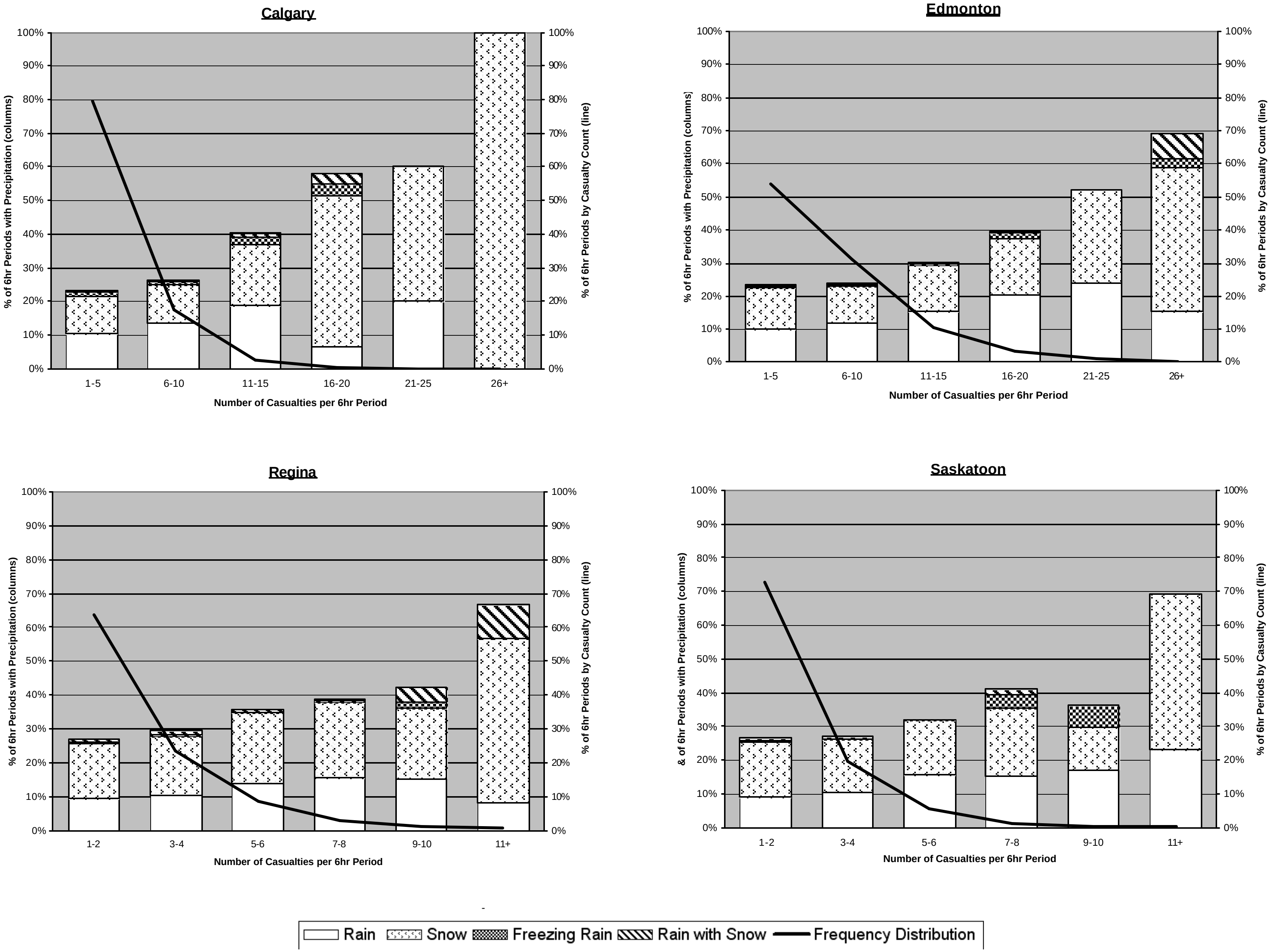
APPENDIX A

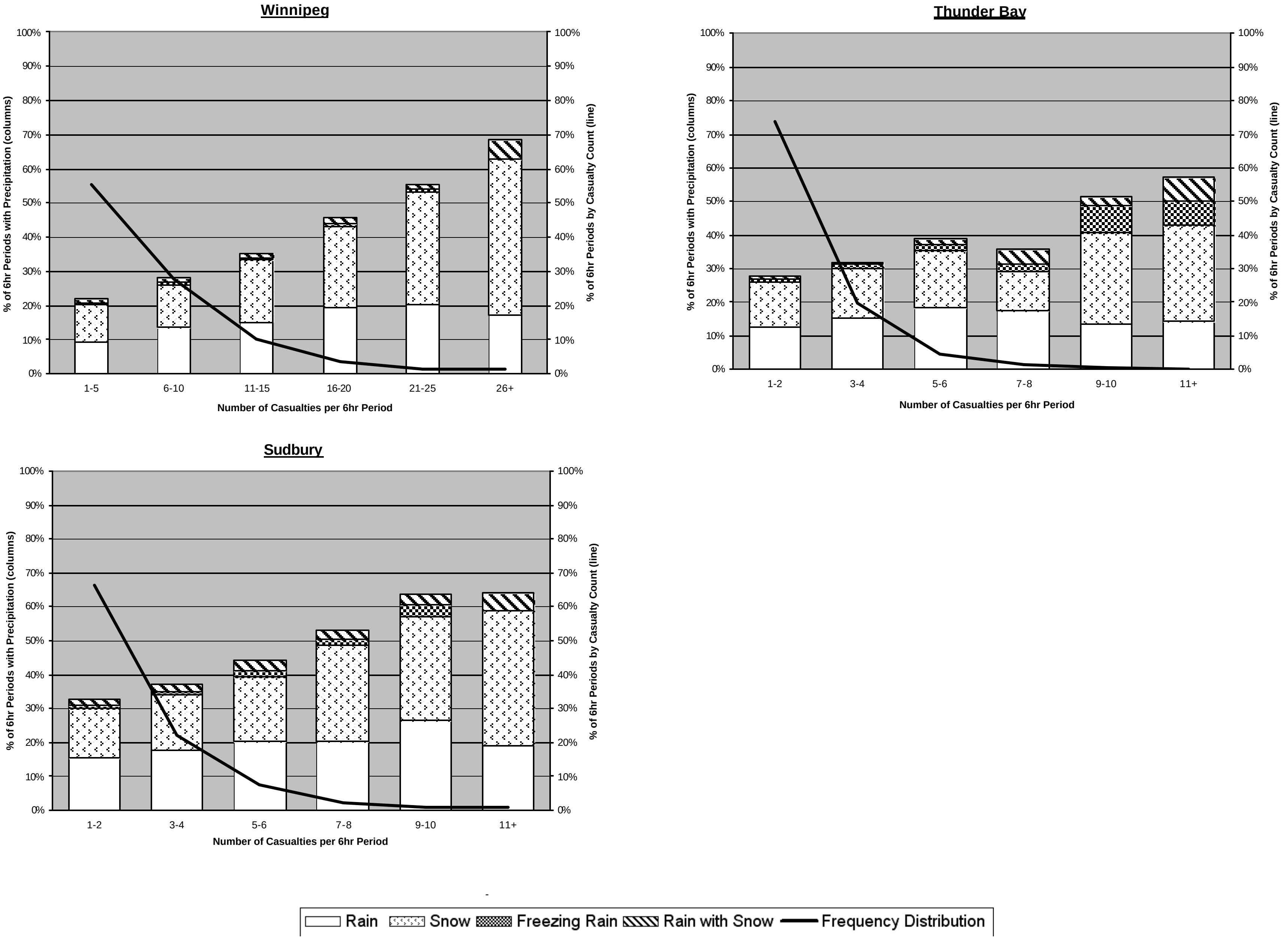
Description	GRP Codes Included
No weather	-
Rainfall	Funnel Cloud TRW, L+, L+F, LF, R, R-, R+, R+F, R+H, R+L-F, R-BD, RF, R-F, RFH, R-FH, RFK, R-FK, F-FZFG, RH, R-H, R-K, R-KH, RL-, R-L-, R-LF, RL-F, R-L-F, R-L-FH, F-L-FK, F-L-H, R-L-SG-, R-L-SG-F, R-L-SP-F, R-SG-, R-SG-F, RW, RW-, RW+, RW+F, RW+FH, RW+FK, RW+H, RW+L-F, RW-BD, RW-D, RWF, RW-F, RWFH, RW-FJ, RW-FK, RW-FKH, RWH, RW-H, RW-L-, RW-LF, RWL-F, RW-L-F, RW-L-FH, RW-L-H, RW-SG-, RW-SG-F, RWSP-, RW-SP-, RW-SP-F, R-ZL-F, R-AL-S-, R-ZR-, R-ZR-F, T, T+, T+H, T+RW, T+RW-, T+RW+, T+RW+F, T+RWF, T+RW-F, T+RW-H, TBD, TF, TFH, TH, TK, TKH, TL-F, TOR, TR, TR-, TR+F, TRF, TR-F, TRH, TR-H, TR-L-F, TRW, TRW-, TRW+, TRW+F. TRW+FH, TRW+H, TRWBD, TRW-BD, TRWF, TRW-F, TRWFH, TRW-FH, TRW-FK, TRWH, TRW-H, TRWK, TRW-K, TRW-KBD, TRW-L-F, TRWSP-, SRW-SP-, TZL-F, ZL, ZL-, ZL+, ZL-BS, ZLF, ZL-F, ZL-FH, ZL-FK, ZL-FZFG, ZL-H, ZL-ICF, ZR, ZR-, ZR+, ZR+F, ZR-BS, ZRF, ZR-F, ZR-FH, ZR-FK, ZR-FZFG, ZRH, ZR-H, ZR-SG-, ZR-SG-F, ZR-SP-, ZR-SP-F, ZR-ZL-, ZR-ZL-F, ZR-ZL-FZFG, ZR-ZL-SG-, ZR-ZL-SG-F
Snowfall	IC, ICBS, ICSW-, ICSW-BS, L-F-, F-S-F, L-SG-, L-SG-F, L-SG-FH, L-S-H, L-SP-, L-SP-F, L-S-SG-F, L-SW-, L-SW-F, L-SW-SP-F, L-ZR-F, R-S, RS-, R-S-, R-S-BS, RS-F, R-S-F, R-S-H, R-SP-, R-SP-F, R-S-SG-, R-S-SG-F, R-S-SP-, R-SW-, RSW-F, R-SW-F, RW+S-F, RW+SW-, RW-S-, RW-S-F, RW-SW, RWSW-, RW-SW-, RWSW-F, RW-SW-F, RW-SW-H, RW-SW-SP-, RW-SW-SP-F, S, S-, S+, S+BS, S+F, S+FBS, S+SG-, S+SG+BS, S+SP-, SBS, S-BS, SBSFZFG, S-BSFZFG, SF, S-F, SFBS, S-FBS, S-FH, S-FK, SFZFG, S-FZFG, SG, SG-, SG+, SG-BS, SB-F, SG-FH, SG-FH, SG-FK, SG-FZFG, SG-H, SG-IF, SG-KH, SG-SP-, SG-SP-F, SG-SW-, SH, S-H, S-IF, S-IFK, S-K, S-KH, SP, SP-, SP+, SPBS, SP-BS, SP-F, SP-FBS, SP-H, SSG, S-SG, SSG-, S-SG-, SSGBS, SSG-BS, S-SG-BS, SSG-F, S-SG-F, S-SG-H, S-SP-, SSP-BS, S-SP-BS, S-SP-F, SW, SW-, SW+, SW+BS, SW+SP-, SW-BD, SW-BN, SWBS, SW-BS, SWF, SW-F, SW-FH, SW-FK, SWFZFG, SW-FZFG, SW-H, SW-IF, SW-K, SW-KH, SWSP, SW-SP, SWSP-, SW-SP-BS, SW-SP-F, SW-SP-H, TRW-SW-, TS, TS-, TS+BS, TSBS, TS-BS, TS-F, TSP-, TSP-F, TSW, TSW-, TSWBS, TSW-SP-F, TZR-S-, TZR-S-F, ZL-S, ZL-S-, ZL-S+, ZL-SBS, ZL-S-BS, ZL-S-BSFZFG, ZL-S-F, ZL-S-FZFG, ZL-SG-, ZL-SG-BS, ZL-SG-F, ZL-SG-FZFG, ZL-SG-H, ZL-SG-SP-, ZL-S-H, ZL-SP-, ZL-SP-F, ZL-S-SG-, ZL-S-SG-F, ZL-S-SP-, ZL-SW-, ZL-SW-BS, ZL-SW-SP-F, ZR-S, ZRS-, ZR-S-, ZR-S+, ZR-S+BS, ZR-S-BS, ZRS-F, ZR-S-F, ZR-S-FZFG, ZR-S-H, ZR-S-SG-, ZR-S-SP-, ZR-SW-, ZR-SW-BS, ZR-SW-F, ZR-ZL-S-, ZR-ZL-S-F
Other frozen precipitation	A, A-, IP, IP-, IP+, IPBS, IP-BS, IPF, IP-F, IPFZFG, IP-FZFG, IP-H, IP-K, IP-SP-, IP-SP-K, IP-SW, IP-SW-, IP-SWBS, IP-SW-F, IPW, IPW-, IPWF, IPW-F, IPW-H, IPW-SP-, IPW-SW, IPW-SW-, IPW-SW-F, IPW-SW-SP-, L-IP-, L-IP-F, L-IPW-, L-EPW-F, L-S-IP-F, L-ZR-IP-F, R+IP-F, RAF, R-IP, RIP-, R-IP-, RIPF, R-IPF, RIP-F, R-IP-F, R-IP-H, R-IPW-, R-IPW-F, R-IPW-SW-F, R-L-IP-, RL-IP-F, R-L-IP-F, R-L-IPW-F, R-S-IP, R-SIP-, RS-IP-, R-S-IP-, R-S-IP-F, R-S-IPW-, R-S-IPW-F, RW+A, RW+A-, RW-A, RWA-, RW-A-, RWIP, RW-IP-, RW-IP-F, RW-IP-SW-, RW-IP-SW-F, RW-IPW, RWIPW-, RWIPW-F, RW-IPW-F, RW-IPW-SW-, RW-IPW-SW-F, RW-K, RW-KH, RW-SW-A, S+IP, S+IP-, S+IP+, S+IPBS, S+IP-BS, S-A-, SG-IP-, SG-IP-F, SIP, S-IP, SIP-, S-IP-, S-IPBS, SIP-BS, S-IP-BS, SIPF, S-IPF, S-IP-F, S-IP-FBS, S-IP-FZFG, S-IP-H, S-IPW, SIPW-, S-IPW-F, S-SG-IP-, S-SG-IP-BS, S-SG-IP-F, S-SG-IPW-, T+RW+A, T+RW+A-, T+RW+A-F, TIPW-, TRW+A, TRW+A-, TRW+A+, TRW+A-F, TRWA, TRW-A, TRWA-, TRW-A-, TRW-A-F, TRWA-H, TRWIPW-, TSGIP-F, TS-IP-, TSW-A-F, TZL-IPW-, TZL-IPW-F, TZRIP-, TZR-IP-F, TZR-IP-SP-F, TZR-S-IP-, ZL-IP, ZL-IP-, ZL-IP-BS, ZL-IP-F, ZL-IP-SW, ZL-IP-SW-F, ZL-IPW-F, ZL-SG-IP-, ZL-SG-IP-F, ZL-SIP-, ZL-S-IP-, ZL-S-IP-BS, ZL-S-IP-F, ZR-IP, ZRIP-, ZR-IP-, ZR-IP-BS, ZRIPF, ZR-IPF, ZRIP-F, ZR-IP-F, ZR-IP-H, ZR-IP-SP-, ZR-IPW, ZR-IPW-, ZRIPW-F, ZR-IPW-F, ZR-IPW-SW-, ZR-IPW-SW-F, ZR-S+IP-, ZR-SG-IP-, ZR-SIP-, ZR-S-IP-, ZR-S-IPBS, ZR-S-IP-BS, ZR-S-IPF, ZR-S-IP-F, ZR-S-IP-FZFG, ZR-S-IP-H, ZR-S-IPW-, ZR-S-IPW-F, ZR-ZL-IP-, ZR-ZL-IP-F, ZR-ZL-S-IP-
Fog, mist or smog	F, FBS, FH, FK, FKH, FZFG, H, HBD, HBN, ICF, ICFK, ICFZFG, ICH, ICIF, ICKH, ICKH, IF, IFH, IFK, L, L-, L-F, L-FH, L-FK, L-FZFG, L-H, L-K, L-FH
Dust or smoke	BD, BN, BSBD, D, ICK, K, KBD, KH
Strong winds	BS

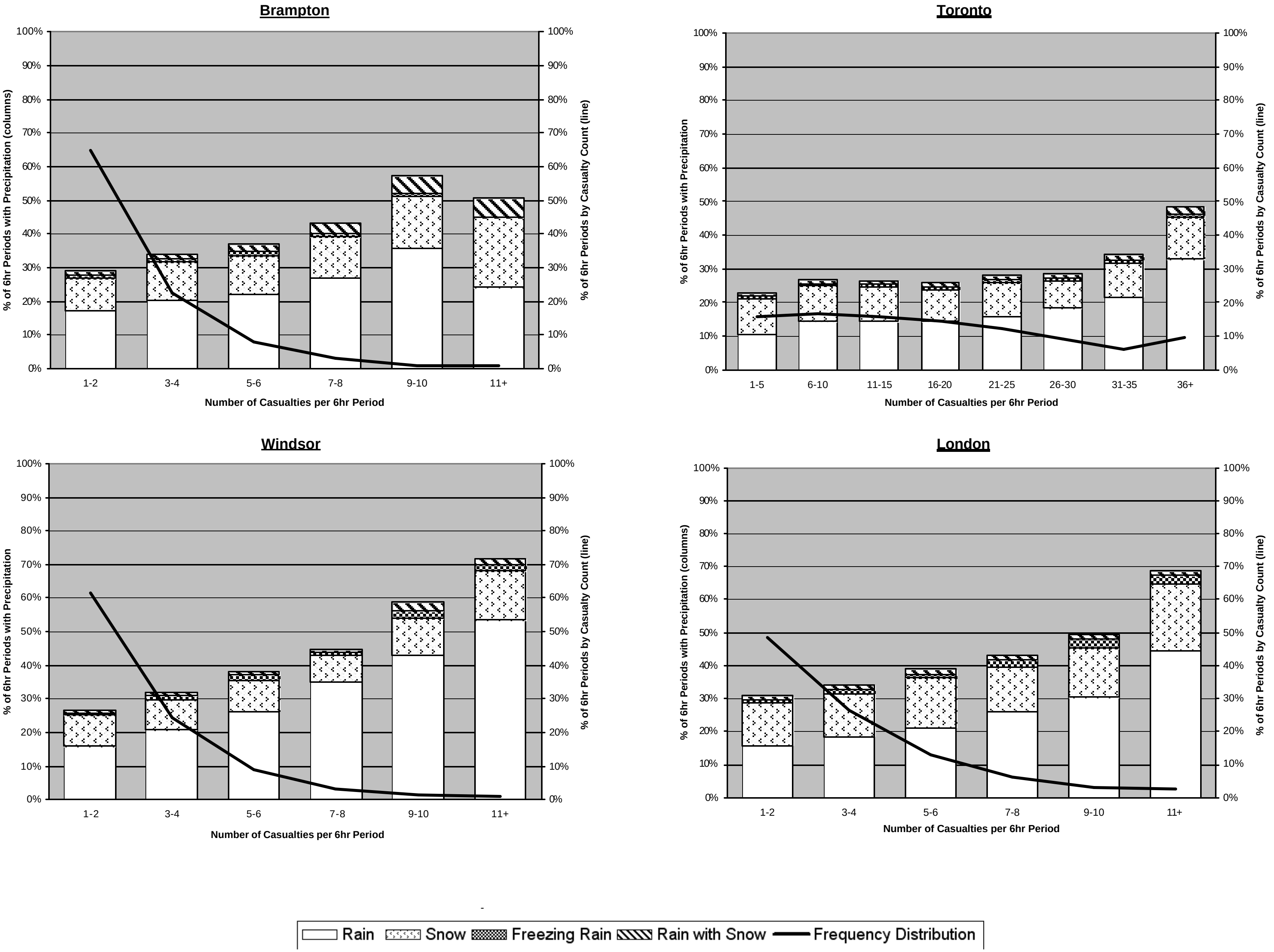
APPENDIX B

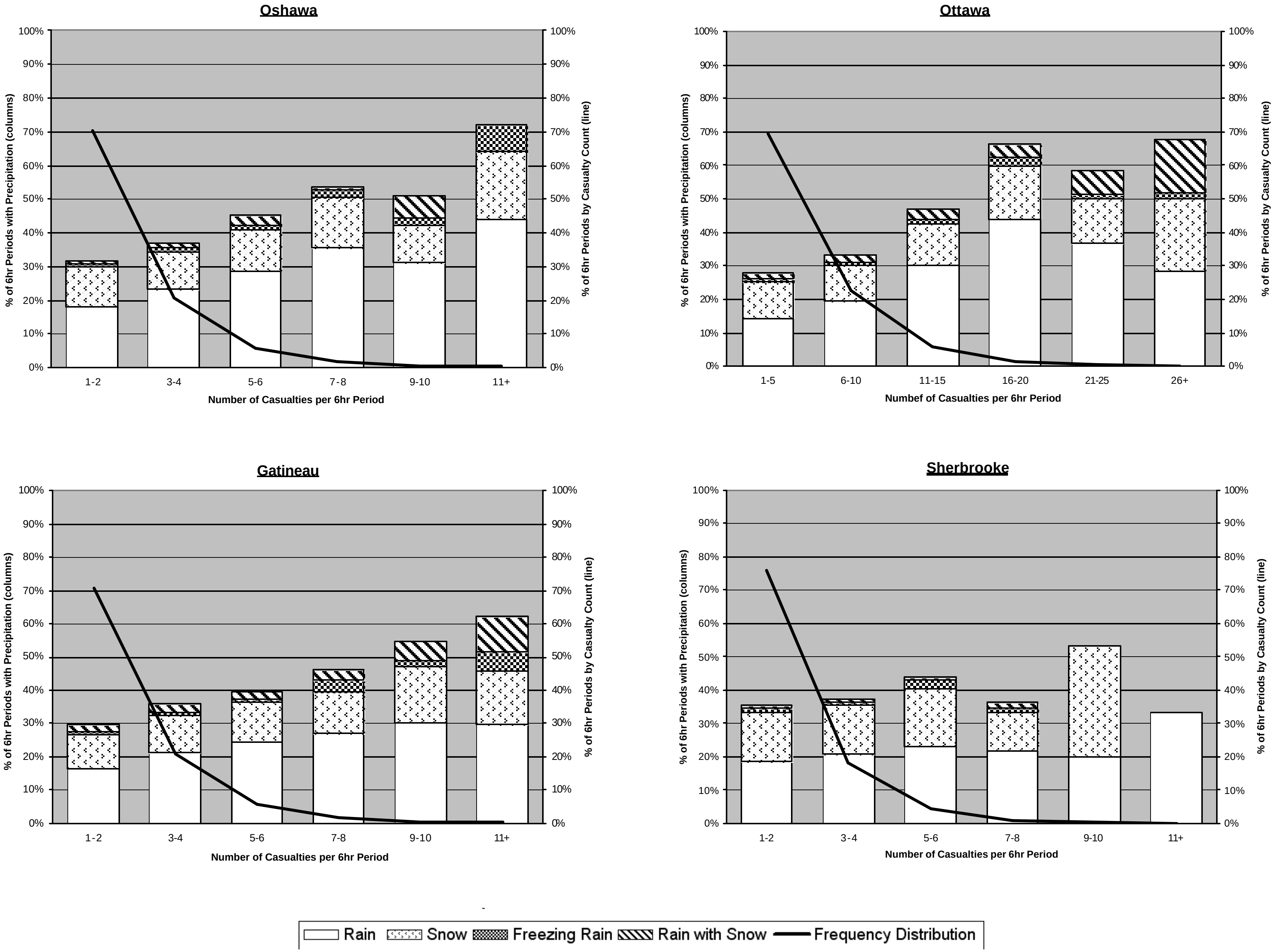

Vancouver
Victoria
Kamloops
Richmond
% of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
Number of Casualties per 6hr Period
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
1-5
6-10
11-15
16-20
21-25
26+
1-2
3-4
5-6
7-8
9-10
11+
Rain
Snow
Freezing Rain
Rain with Snow
Frequency Distribution

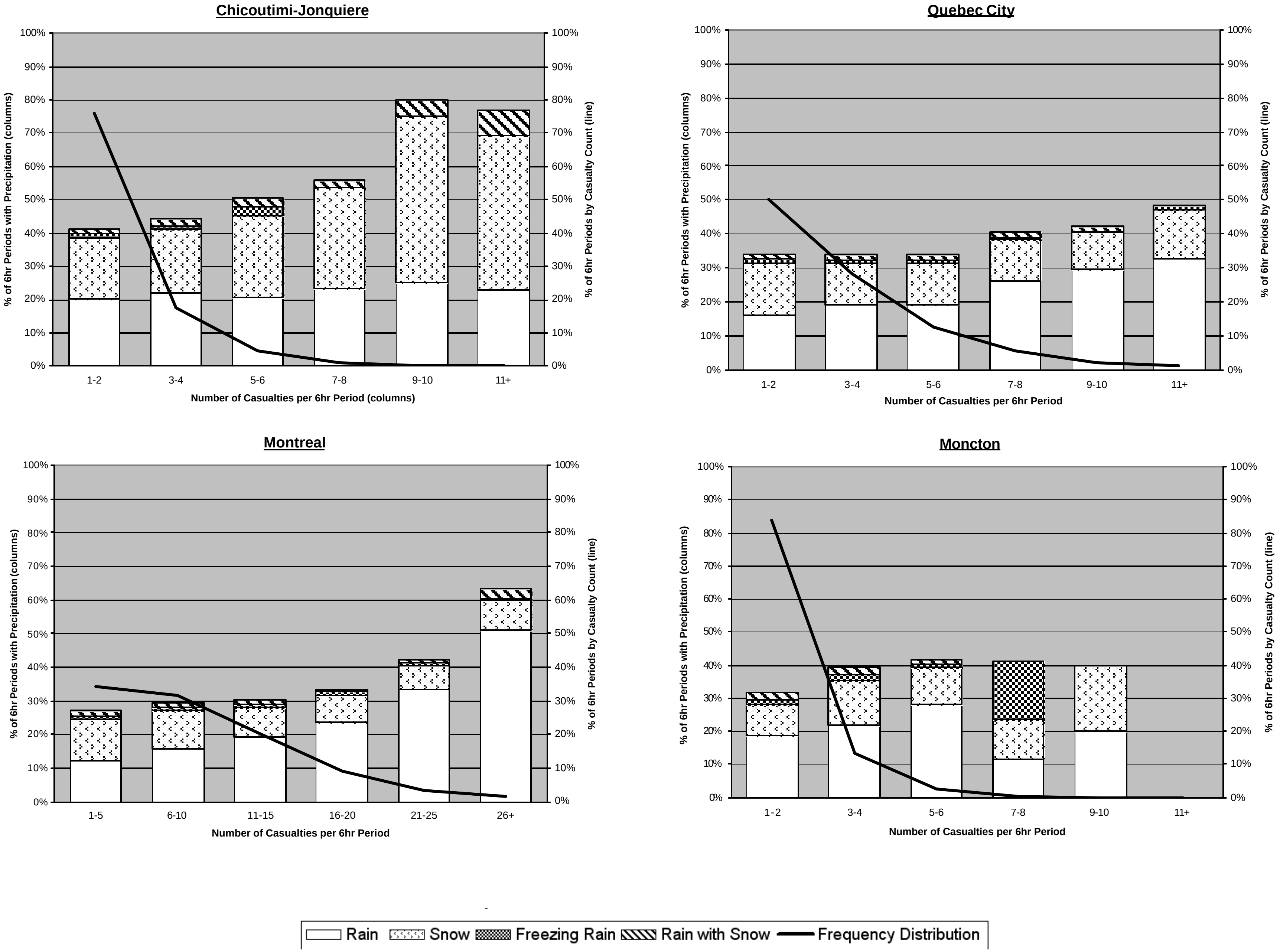


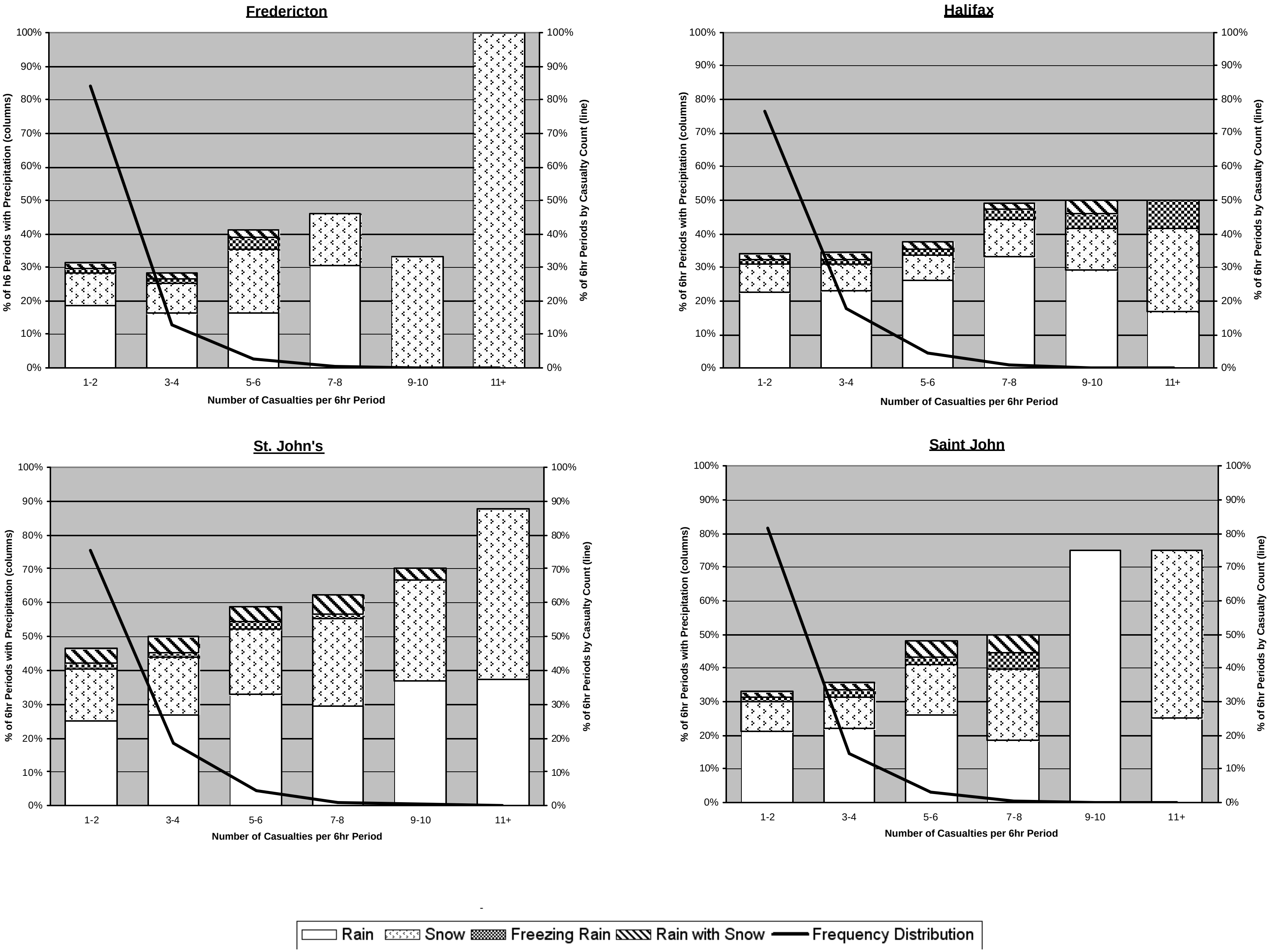
Calgary
Edmonton
Regina
Saskatoon
% of 6hr Periods with Precipitation (columns)
& of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
Number of Casualties per 6hr Period
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
1-5
6-10
11-15
16-20
21-25
26+
1-2
3-4
5-6
7-8
9-10
11+
Rain
Snow
Freezing Rain
Rain with Snow
Frequency Distribution

Winnipeg
Thunder Bay
Sudbury
% of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
1-5
6-10
11-15
16-20
21-25
26+
1-2
3-4
5-6
7-8
9-10
11+
Number of Casualties per 6hr Period
Rain
Snow
Freezing Rain
Rain with Snow
Frequency Distribution

Brampton
% of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
1-2
3-4
5-6
7-8
9-10
11+
Number of Casualties per 6hr Period
Toronto
% of 6hr Periods with Precipitation
% of 6hr Periods by Casualty Count (line)
1-5
6-10
11-15
16-20
21-25
26-30
31-35
36+
Number of Casualties per 6hr Period
Windsor
% of 6hr Periods with Precipitation
% of 6hr Periods by Casualty Count (line)
1-2
3-4
5-6
7-8
9-10
11+
Number of Casualties per 6hr Period
London
% of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
1-2
3-4
5-6
7-8
9-10
11+
Number of Casualties per 6hr Period
Rain
Snow
Freezing Rain
Rain with Snow
Frequency Distribution


Oshawa
Ottawa
Gatineau
Sherbrooke
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
1-2
3-4
5-6
7-8
9-10
11+
1-5
6-10
11-15
16-20
21-25
26+
Number of Casualties per 6hr Period
Numbef of Casualties per 6hr Period
Rain
Snow
Freezing Rain
Rain with Snow
Frequency Distribution


Chicoutimi-Jonquiere
% of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
Number of Casualties per 6hr Period (columns)
1-2
3-4
5-6
7-8
9-10
11+
Quebec City
% of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
Number of Casualties per 6hr Period
Montreal
% of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
Number of Casualties per 6hr Period
1-5
6-10
11-15
16-20
21-25
26+
Moncton
% of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
Number of Casualties per 6hr Period
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Rain
Snow
Freezing Rain
Rain with Snow
Frequency Distribution


Fredericton
% of h6 Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
Number of Casualties per 6hr Period
Halifax
% of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
Number of Casualties per 6hr Period
St. John's
% of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
Number of Casualties per 6hr Period
Saint John
% of 6hr Periods with Precipitation (columns)
% of 6hr Periods by Casualty Count (line)
Number of Casualties per 6hr Period
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
1-2
3-4
5-6
7-8
9-10
11+
Rain
Snow
Freezing Rain
Rain with Snow
Frequency Distribution