Transportation Association of Canada

Climate Change and Road Safety: Projections within Urban Areas

May 2013

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Climate Change and Road Safety: Projections Within Urban Areas

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Abstract

Weather creates hazardous conditions of various types that increase the risk for road users. By examining the occurrence of weather-related hazards today and by projecting such occurrences into the future, the report documents the ways in which climate change may affect road safety.

Climate change will not affect all parts of Canada in identical ways. The study provides detailed analysis for selected urban areas, and considers how climate change affects them in varying ways and to varying extents.

The two objectives for the study were to:

1. identify projected weather change trends; and
2. identify the collision trends as a result of the weather change.

The magnitude of associated risks is based on statistical estimates of the extent to which road safety is compromised during weather. Some motor vehicle collision types also may be affected by climate change. To gain insight into this issue, collision attributes are compared during precipitation versus mostly dry, seasonal conditions. In this way, we identify the types of motor vehicle collisions that are over-represented during inclement weather. We then combine this information with projections of climate change in order to identify collision subsets that could be most affected by climate change.

The continued importance of inclement weather for road safety outcomes in Canadian cities is highlighted within the report. The report documents the ways in which climate change may affect road safety, estimates the magnitude of associated risks, and identifies which motor vehicle collision types could be most affected by climate change and where they will take place in the future.

Keywords

Environment
Accident Statistics

- accident
- analysis (math)
- collision
- forecast
- risk
- risk assessment
- safety
- statistics
- urban area
- variability
- weather

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Changements climatiques et sécurité routière : perspectives urbaines

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Résumé

Les mauvaises conditions météorologiques augmentent le risque pour les usagers de la route. En examinant les dangers découlant des conditions météorologiques actuelles et en effectuant des projections pour les années à venir, le rapport indique comment les changements climatiques peuvent influer sur la sécurité routière.

Les changements climatiques n'affecteront pas toutes les régions du Canada de la même façon. L'analyse détaillée de cette étude repose sur les données des centres urbains sélectionnés, et considère l'impact des changements climatiques de façons différentes et à des niveaux variés.

Les deux objectifs de l'étude comportaient :

1. l'identification des tendances liées aux changements des conditions météorologiques; et
2. l'identification des tendances liées aux collisions résultant des changements des conditions météorologiques.

L'importance des risques connexes repose sur des estimations statistiques dans la mesure où la sécurité routière est comprise lorsque certaines conditions météorologiques sont présentes. Certaines collisions routières peuvent également être affectées par les changements climatiques. Afin d'obtenir plus d'information, les éléments de collisions sont comparés durant les périodes de précipitations versus les conditions saisonnières sans précipitation. De cette façon, nous identifions les collisions routières qui sont surreprésentées en présence de mauvaises conditions météorologiques. Les projections de changements climatiques sont ensuite combinées à cette information afin d'identifier les sous-ensembles qui pourraient être affectés par les changements climatiques.

Le rapport souligne que les mauvaises conditions météorologiques ont un effet négatif continu sur les résultats en matière de sécurité routière dans les villes canadiennes. Il indique les façons dont les changements climatiques peuvent influer sur la sécurité routière, évalue l'importance des risques connexes et identifie les types de collisions routières qui sont le plus grandement affectées par les changements climatiques dans les années à venir.

Mots clés

Environnement
Statistiques d'accidents

- accident
- analyse (mathématique)
- collision
- risque
- risque évaluation
- sécurité
- statistiques
- urbaines
- variabilité

Information complémentaire

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Executive Summary

TAC's Road Safety Standing Committee and Climate Change Task Force initiated a project to develop a detailed report concerning weather-related safety conditions in Canada, now and in the future. The project documents the ways in which climate change may affect road safety in Canadian cities, estimates the magnitude of associated risks, and identifies which motor vehicle collision types could be most affected by climate change and where they will take place in the future. By examining the occurrence of weather-related hazards today and by projecting such occurrences into the future, the report documents the ways in which climate change may affect road safety.

Traffic collisions are the result of complex interactions between people, vehicles and roadways. Inclement weather is one of many risk factors that affect the frequency and severity of road crashes. Weather that reduces road friction, impairs visibility and/or makes vehicle handling more difficult contributes to a more hazardous operating environment. Precipitation is the most serious weather-related driving risk in Canada, in large part because it simultaneously affects both road friction and driver visibility, but also because precipitation, in all its various forms – rain, drizzle, hail, snow, freezing precipitation and ice pellets – occurs frequently. As a result, the report focuses mainly on precipitation events, although some attention also is given to other weather hazards including reduced visibility, blowing snow, high winds, extreme heat, and wet, snowy or icy roads when precipitation is not occurring.

The magnitude of associated risks is based on statistical estimates of the extent to which road safety is compromised during weather. Using police reports of road collisions that occurred from 2000-2009, the analysis provides quantitative estimates of collision risk during different weather conditions. These risk estimates are then combined with projections of climate change to provide insights into the magnitude and nature of the safety risks associated with climate change in the future period, 2041-2070.

The risk analysis component of this study is based on data for eight urban areas – Vancouver, Calgary, Toronto, Ottawa, Montreal, Quebec City, Moncton and Halifax. Overall, the risk of injury collision is 12% higher on days with rainfall as compared to dry days; the estimate for property-damage-only collisions is 14%. There is also a progression in risk as the daily accumulation of rainfall increases. On days where snowfall or other winter precipitation occurs, collision risk is considerably more elevated than what was found for rainfall – 44% for property-damage-only collisions and 22% for collisions involving at least one injury. Risks are significantly elevated even for small precipitation accumulations of winter precipitation, although there is no clear progression of risk as precipitation amount increases. Risks during winter precipitation events are also significantly elevated for major and fatal collisions.

The risk analysis for individual cities shows a more varied pattern. Vancouver has the greatest increase in injury collisions on precipitation days, with increases of 23% for rain days and 27% for winter precipitation days. Toronto and Ottawa are similar to one another: for rain days, the estimates are 12% and 10%, respectively, and for winter precipitation days the values are 26% and 24%. Montreal has lower risk estimates than either Toronto or Ottawa (7% and 12% for rain days and winter days, respectively). Both Calgary and Quebec City have elevated risk levels (22% and 11%, respectively) on winter precipitation days but no significant increases during rainfall. The cities of Moncton and Halifax show no

significant increase on either rain or winter precipitation days, which may be related to the smaller populations of these communities. There is also some evidence that other weather conditions including reduced visibility, blowing snow, high winds, extreme heat, and snowy or icy roads lead to higher collision rates, although these events occur less frequently.

Changes in precipitation are some of the main consequences of increased concentrations of greenhouse gases in the atmosphere. The impacts of climate change on road safety are expected to result more from changes in precipitation form (e.g., rain versus snow) and amount (i.e., heavy versus light rainfall), than from total seasonal precipitation or even precipitation frequency. In this study we use an ensemble of simulations of the Canadian Regional Climate Model driven by different global circulation models. The simulations provide daily precipitation totals, as well as minimum and maximum temperature; these data are then used, along with historical weather records, to estimate the frequency of rain days and winter precipitation days in the future.

Simulations of future climate are presented for six study areas: Vancouver, Calgary, Toronto, Montreal, Quebec City and Halifax. All of the simulations project warming, and most of the simulations indicate that total precipitation will increase in the study areas. Expected changes in annual precipitation days are more variable: for five of the six study areas (not Montreal), some models suggest an increase in precipitation days and others indicate a decrease in precipitation days. This is a reasonable outcome, given that changes in the frequency of precipitation are expected to be small. However, there are location-specific differences in the forms and daily amounts of precipitation that are projected for 2041-2070.

The implications of climate change for road safety are estimated based on local risk rates combined with changes in the frequency of precipitation events of different types and intensities. The net effect varies from a possible decrease of 29% in weather-attributable injury collisions in Calgary to an increase of 4% in Vancouver. Overall, the analysis shows that winter-weather hazards will be reduced, but rainfall hazards, especially heavier rains, will increase.

Some locales (Calgary, Toronto) are expected to have substantially fewer weather-attributable injury collisions overall by the 2050s because of shorter/milder winters. In other parts of the country (Montreal, Quebec City, Halifax), the safety benefits of less winter precipitation are offset almost exactly by the increased risk associated with more frequent and heavier rainfalls. In Vancouver, projected increases in rainfall are expected to translate into a net increase in weather-related collisions. The situation for other weather hazards is less certain, but it would appear that fog, blowing snow, and snowy or icy roads will occur less frequently in many parts of the country in the future.

The final part of the analysis identifies those subsets of collisions that are over-represented during inclement weather. This provides a way of identifying issues that are of current concern – given present-day climate – and potentially of concern in the future, given the changing nature of climate in Canada.

In terms of rain-related collision risk – something that is important today and will be of growing importance because of climate change – the data highlight how rainfall at night is particularly problematic, as is driving in the rain on curved sections of roadway or driving too fast for conditions. As well, collisions at traffic signals and crashes involving pedestrians are over-represented during rainfall.

Collision rates are significantly elevated during winter precipitation in comparison to both dry conditions and rain days, but the frequency of winter precipitation days is expected to decrease across southern Canada by mid-century. Hazards related to snow and ice will continue, however, despite the shorter season in most years and regions. Issues related to snowfall and other winter-weather conditions include more single-vehicle collisions (e.g., those involving run-off-road or hitting a roadside object), more collisions on curved sections of roadway and on gradients, and in some cases on bridges, ramps and other special features. Of particular note are the tendencies for higher-speed roads and non-daylight conditions to be over-represented in winter-weather collisions.

In summary, the report highlights the continued importance of inclement weather for road safety outcomes in Canadian cities. Indeed, increases in the frequency and intensity of rainfall events are expected to mostly offset the safety gains associated with shorter and milder winters across urban regions of Canada. With climate change, increased emphasis should be given to rainfall-related driving hazards, especially to the visibility and friction reductions that accompany heavier rainfalls.

Résumé

Le Comité permanent de la sécurité routière et le Groupe de travail sur les changements climatiques de l'ATC ont mis de l'avant un projet ayant pour objet la production d'un rapport détaillé sur les conditions météorologiques et la sécurité routière au Canada, et ce, tant pour le présent que pour l'avenir. Le rapport produit dans le cadre de ce projet indiquera les façons dont les changements climatiques peuvent influer sur la sécurité routière dans les villes canadiennes, évaluera l'importance des risques connexes et identifiera les types de collisions routières qui sont le plus grandement touchés par les changements climatiques, ainsi que les régions à risque d'être plus grandement affectées par les changements climatiques dans les années à venir. En examinant les dangers découlant des conditions climatiques actuelles et en effectuant des projections pour les années à venir, le rapport indiquera comment les changements climatiques peuvent influer sur la sécurité routière.

Les collisions routières résultent d'interactions complexes entre les gens, les véhicules et les routes. Les mauvaises conditions météorologiques ne constituent qu'un seul des nombreux facteurs qui influent sur la fréquence et la gravité des accidents de la route. Lorsque les conditions météorologiques réduisent l'indice de frottement de la chaussée, réduisent la visibilité ou font en sorte que le véhicule est plus difficile à contrôler, l'environnement de conduite devient plus dangereux. En ce qui concerne la conduite automobile au Canada, les précipitations représentent le plus grand facteur de risque associé aux conditions météorologiques, et ce, en grande partie parce que les précipitations réduisent à la fois l'adhérence de la chaussée et la visibilité du conducteur, mais aussi parce que les précipitations sous toutes leurs formes – pluie, bruine, grêle, neige, verglas et grésil – sont fréquentes. Par conséquent, ce rapport met principalement l'accent sur les précipitations, même si une certaine attention est accordée à d'autres facteurs de risque météorologiques tels que la visibilité réduite, la poudrerie, les forts vents, la chaleur extrême et les routes mouillées, enneigées ou glacées malgré l'absence de précipitations.

L'importance des risques connexes repose sur des estimations statistiques dans la mesure où la sécurité routière est compromise lorsque certaines conditions météorologiques sont présentes. À l'aide des rapports de police sur les collisions routières survenues de 2000 à 2009, l'analyse présente des estimations quantitatives des risques de collisions en fonction de différentes conditions météorologiques. Des estimations de risque sont ensuite combinées aux projections de changement climatique pour déterminer l'importance et la nature des risques de sécurité associés aux changements climatiques pour la période de 2041 à 2070.

Le volet d'analyse des risques de cette étude repose sur les données de huit centres urbains – Vancouver, Calgary, Toronto, Ottawa, Montréal, Québec, Moncton et Halifax. Dans l'ensemble, le risque de collision avec blessure pendant les jours de pluie est de 12 % plus élevé que pour les jours sans pluie, tandis que le risque de collision avec dommages matériels seulement est de 14 % plus élevé. On observe également une progression du risque lorsque les accumulations de pluie augmentent pendant la journée. Les jours où il y a des chutes de neige ou d'autres types de précipitations hivernales, le risque de collision est considérablement plus élevé que les jours où il pleut, soit 44 % de plus pour les collisions avec dommages matériels seulement et 22 % pour les collisions causant au moins une blessure. Les risques sont beaucoup plus grands même lorsque les accumulations de précipitations hivernales sont faibles, mais on n'observe

aucune progression définie du risque lorsque les précipitations augmentent. Les risques associés aux précipitations hivernales sont aussi beaucoup plus grands en ce qui concerne les collisions graves et mortelles.

L'analyse des risques associés à chaque ville démontre une tendance plus variée. Vancouver affiche la plus forte hausse des collisions avec blessure les jours de précipitations; cette hausse étant de 23 % pour les jours de pluie et de 27 % pour les jours de précipitations hivernales. Toronto et Ottawa affichent des résultats semblables, soit de 12 % et 10 % respectivement pour les jours de pluie et de 26 % et 24 % respectivement pour les jours de précipitations hivernales. Montréal affiche un risque plus faible que les villes de Toronto et d'Ottawa (7 % et 12 % pour les jours de pluie et de précipitations hivernales respectivement). Calgary et Québec affichent des niveaux de risque plus élevés (22 % et 11 % respectivement) pour les jours de précipitations hivernales, mais aucune hausse marquée pour les jours de pluie. Les villes de Moncton et d'Halifax n'affichent aucune hausse marquée tant pour les jours de pluie que pour les jours de précipitations hivernales, ce qui peut être attribuable aux populations moins grandes de ces collectivités. Certaines données démontrent également que d'autres conditions météorologiques, dont la visibilité réduite, la poudrerie, les forts vents, la chaleur extrême et les routes enneigées ou glacées, peuvent faire augmenter les taux de collision, même si de telles conditions météorologiques sont moins fréquentes.

Les précipitations changeantes sont les principales conséquences des concentrations accrues de gaz à effet de serre dans l'atmosphère. Les impacts des changements climatiques sur la sécurité routière sont habituellement davantage liés aux précipitations changeantes (p. ex., pluie et neige) et à la quantité de précipitations (p. ex., forte pluie et faible pluie) qu'au total des précipitations saisonnières ou même à la fréquence des précipitations. Dans la présente étude, nous utilisons un ensemble de simulations du *Modèle régional canadien du climat* fondé sur différents modèles de circulation dans le monde. Les simulations fournissent des totaux quotidiens de précipitations, ainsi que des températures minimale et maximale; ces données sont ensuite utilisées, de concert avec les données météorologiques historiques, pour estimer la fréquence des jours de pluie et des jours de précipitations hivernales pour les années à venir.

Des simulations du climat futur sont présentées pour six régions à l'étude : Vancouver, Calgary, Toronto, Montréal, Québec et Halifax. Toutes les simulations prévoient un réchauffement, et la plupart des simulations indiquent que les précipitations totales augmenteront dans les régions à l'étude. Les changements prévus en ce qui concerne les jours de précipitations par année sont plus variables : pour cinq des six régions à l'étude (toutes les régions sauf Montréal), certains modèles suggèrent une augmentation des jours de précipitations et d'autres indiquent une diminution des jours de précipitations. Ces résultats sont raisonnables étant donné qu'on ne prévoit que de faibles changements en ce qui concerne la fréquence des précipitations. Toutefois, on observe des différences propres à certains emplacements quant aux formes et aux quantités quotidiennes de précipitations qui sont prévues pour la période de 2041 à 2070.

Les incidences des changements climatiques pour la sécurité routière sont évaluées d'après les taux de risque locaux, qui sont combinés aux changements de la fréquence des précipitations de différents types et de différentes intensités. L’effet net varie, soit d’une baisse possible de 29 % des collisions avec blessures attribuables aux conditions météorologiques à Calgary à une hausse de 4 % à Vancouver. Dans l’ensemble, l’analyse démontre que les risques associés aux conditions météorologiques hivernales diminueront, mais que les risques associés à la pluie, en particulier aux fortes pluies, augmenteront.

Certaines localités (Calgary, Toronto) devraient afficher, en général, un taux de collisions avec blessures et attribuables aux conditions météorologiques beaucoup moins grand d’ici les années 2050 en raison des hivers plus courts et plus doux. Dans d’autres parties du pays (Montréal, Québec, Halifax), les avantages de sécurité découlant de la diminution des précipitations hivernales sont presque totalement éliminés par le risque accru associé à l’augmentation de la fréquence et de l’intensité des précipitations sous forme de pluie. À Vancouver, l’augmentation prévue des précipitations sous forme de pluie devrait se traduire par une hausse nette des collisions attribuables aux conditions météorologiques. En ce qui concerne les autres risques associés aux conditions météorologiques, la situation est moins certaine, mais il semble que le brouillard, la poudrerie et les routes enneigées et glacées seront moins fréquents dans de nombreuses parties du pays au cours des années à venir.

La partie finale de l’analyse indique les sous-ensembles de collisions qui sont surreprésentés en présence de mauvaises conditions météorologiques. On peut ainsi définir les enjeux d’intérêt commun – d’après le climat actuel – et qui pourraient être préoccupants pour l’avenir, étant donné la nature changeante du climat au Canada.

En ce qui concerne les risques de collision associés à la pluie – un risque déjà important aujourd’hui et qui aura une importance future accrue en raison des changements climatiques – les données indiquent comment la pluie est particulièrement problématique en période nocturne, tout comme l’est la conduite sous la pluie sur des sections de route en courbe ou la conduite à vitesse trop élevée pour les conditions qui prévalent. De plus, les collisions aux panneaux de signalisation et les accidents avec des piétons sont surreprésentés lorsqu’il pleut.

Les taux de collision augmentent beaucoup en présence de précipitations hivernales comparativement aux taux observés en l’absence de précipitations et en présence de pluie, mais la fréquence des jours de précipitations hivernales devrait diminuer dans tout le sud du Canada d’ici le milieu du siècle. Toutefois, les risques associés à la neige et à la glace demeureront présents même si la saison sera plus courte la plupart des ans et dans la plupart des régions. Les enjeux associés aux chutes de neige et à d’autres conditions hivernales sont davantage associés aux collisions impliquant un seul véhicule (c’est-à-dire les collisions attribuables à des sorties de route ou les collisions avec un objet en bordure de la route), aux collisions sur des sections de route en courbe ou en pente et, dans certains cas, aux collisions sur des ponts, dans des bretelles et en présence d’autres infrastructures spéciales. Il est important de souligner que les collisions sur les routes à grande vitesse et dans des conditions autres que celles de la lumière du jour ont tendance à être surreprésentées dans l’ensemble des collisions dans des conditions hivernales.

En bref, le rapport souligne que les mauvaises conditions météorologiques ont un effet négatif continu sur les résultats en matière de sécurité routière dans les villes canadiennes. En effet, la hausse prévue de la fréquence et de l’intensité des précipitations sous forme de pluie devrait éliminer presque totalement les gains qui auraient pu être réalisés en matière de sécurité grâce aux hivers plus courts et plus doux que connaîtront les régions urbaines du Canada. En ce qui concerne les changements climatiques, une attention accrue devrait être accordée aux risques de conduite associés aux précipitations sous forme de pluie, en particulier à la réduction de la visibilité et du frottement qui accompagne les fortes précipitations sous forme de pluie.

1 Introduction/problem statement

The Climate Change Task Force and Road Safety Standing Committee of the Transportation Association of Canada initiated a project to develop a detailed report concerning weather-related safety conditions in Canada, now and in the future. The project documents the ways in which climate change may affect road safety, estimates the magnitude of associated risks, and identifies which motor vehicle collision types could be most affected by climate change and where they will take place in the future.

Weather creates hazardous conditions of various types that increase the risk for road users. By examining the occurrence of weather-related hazards today and by projecting such occurrences into the future, the report documents the ways in which climate change may affect road safety.

The magnitude of associated risks is based on statistical estimates of the extent to which road safety is compromised during weather. Using police reports of road collisions that occurred from 2000-2009, the analysis provides quantitative estimates of the extent to which collision risk increases during precipitation and other types of potentially hazardous weather. These relative risk estimates are then combined with projections of climate change to provide insights into the magnitude of the safety risks associated with climate change in the 2041-2070 period, i.e., the mid-2050s.

Some motor vehicle collision types also may be affected by climate change. To gain insight into this issue, collision attributes are compared during precipitation versus mostly dry, seasonal conditions. In this way, we identify the types of motor vehicle collisions that are over-represented during inclement weather. We then combine this information with projections of climate change in order to identify collision subsets that could be most affected by climate change.

Climate change will not affect all parts of Canada in identical ways. The study provides detailed analysis for selected urban areas, and considers how climate change affects them in varying ways and to varying extents. The rationale for focusing on urban areas is threefold:

1. Increasingly, Canadians live in urban areas. As such, approximately 60% of collisions occur on city streets, arterial roads and urban expressways (Andrey, 2010).
2. Weather varies spatially, and detailed, quality-controlled, standardized weather data are available only at Environment Canada's principal weather stations – many of which are located in or near urban areas.
3. Available collision data provide only general information on collision location (e.g., city name or police jurisdiction code), precluding detailed analysis for individual highways.

The two objectives for the study are to:

1. identify projected weather change trends; and
2. identify the collision trends as a result of the weather change.

The tasks associated with the project are outlined in Table 1-1.

Table 1-1: Tasks associated with the project

Task	*Description*	*Report section(s)*
1	Examine and report on the availability and completeness of weather observation and collision data for large cities in Canada, in order to finalize the study areas to be used.	3.1
2	Prepare a 10-page literature review organized around four themes: the physical hazards of weather (e.g., road friction, driver visibility), driver adaptations to weather, weather-related safety outcomes, and the implications of winter road maintenance for road safety.	2.1, 2.2, 2.3, 2.4, 2.5
3	Using weather data for one study area and one year, estimate the risk of collision during rainfall and snowfall based on different temporal scales, i.e., 3-hour, 6-hour, day, storm.	3.3
4	Use past weather information from Environment Canada's observational network to summarize the type and frequency of weather-related driving hazards in the various study areas over the past 25 years.	2.1, 3.1, 4.3
5	Using data for one study area, test the ways in which the raw grid data from regional climate simulations can be interpreted for urban-scale analysis.	3.5
6	Based on the findings in Step 3, and taking into consideration regional climate simulations, recommend a temporal scale of analysis for the project. Based on the findings in Steps 5 and 6, recommend a set of weather conditions (types and intensities) for use in the risk analysis.	3.3, 3.4
7	Using a matched-pair design, calculate the relative risk of collision during inclement weather versus normal seasonal driving. Provide such estimates (with 95% confidence intervals) for each agreed to study area, for each of the agreed to weather condition, and for different collision severities (fatal or major injury, minor or minimal injury, property-damage-only).	3.2, 4.1
9	Using data for one or more of the study areas, explore special cases/types of weather-related driving risks that occur less frequently, e.g., icy roads or fog, with a view to developing a methodology for understanding the implications of climate change for these types of driving circumstances.	4.3
10	Prepare a 5-page literature review on the climate change analysis published previously for the weather conditions identified in Step 6. The literature review will be done for Canada only.	2.6, 2.7
11	Using data for one or more of the study areas, explore the extent to which particular collision attributes (e.g., number and type of vehicles involved, driver age or other characteristics, collision configuration prior to impact, speed limit, roadway geometrics) are over/under represented during weather events of different types. This can be accomplished by establishing risk ratios for particular subsets of collisions and/or through statistical modeling.	4.5
12	Build climate change scenarios based on an ensemble of regional climate projections for the weather conditions identified previously.	4.2
13	Combine the projections from Step 12 with the relative risks of collision as calculated previously to create projections of future weather-related collision frequencies of different severities for each of the study areas.	4.2
14	Translate the findings on relative risk into absolute risk, e.g., number of casualties per year, both for the historical period and for future climate projections, based on the results from work described above.	4.1, 4.2
15	Changing traffic trends will not be predicted, but mention of and consideration will be made in the report.	4.4
16	Provide a frequency analysis and maps (as needed) for analysis of the impact of climate change on road safety.	4.2, 4.4
8, 20	Overall supervision and quality control.	--

2 Literature review

This section presents a review of the literature on weather and road safety (Task 2) as well as a summary of the type and frequency of weather-related driving hazards in Canadian cities over the past 25 years (Task 4). It also describes observed 20th century and projected future climate trends (Task 10).

2.1 The physical hazards of weather

Traffic collisions are the result of complex interactions between people, vehicles and roadways. Inclement weather is one of many risk factors that affect the frequency and severity of road crashes. Weather that reduces road friction, impairs visibility and/or makes vehicle handling more difficult contributes to a more hazardous operating environment. Table 2-1 lists the three main types of weather-related driving hazards, and the weather conditions that are associated with these hazards.

Table 2-1: Weather-related driving hazards

Nature of hazard	*Relevant weather conditions*
Reduced friction/controllability	• Wet roads associated with rainfall, melting snow • Snowy or icy roads associated with snowfall, snow compaction, melting snow/ice, freezing rain and other forms of solid precipitation
Impaired visibility	• Falling precipitation • Splash and spray • Blowing snow • Fog and ice fog • Dust storms • Haze, smog • Glare
Decreased stability	• High-velocity cross winds • Buffeting (gusts with passing trucks)

While each specific condition is the subject of considerable research, a comprehensive assessment of the implications of climate and climate change for road safety requires consideration of the broad range of weather hazards that are experienced in any given place. Table 2-2 provides a typology of weather hazards, as well as information on the physical conditions necessary for their occurrence and some details on when and where these conditions occur in Canada.

Table 2-2: Hazard typology

Meteorological condition	***Occurrence***
Liquid Precipitation, i.e., rain (larger droplets) **and drizzle** (smaller droplets), are formed when atmospheric water vapour condenses and falls under the force of gravity. Rain is **a compound hazard, as it both reduces friction and impairs visibility.** A rainfall of at least 0.2 millimetres per hour is sufficient to **wet the roads** (Harwood et al., 1988). Road drying time depends on humidity, wind and drainage; it can be as short as one hour but is often much longer (Andrey and Yagar, 1993). Road surface friction values are lower on wet roads than on bare and dry roads, such that stopping distance is increased on wet roads. Stopping distances also vary by travel velocity, tire tread and pavement surface. Rainfall **impairs driver visibility** through its effects on atmospheric transparency, headlights, windshield and pavement – especially at night. Seeing distances decline as rainfall intensity increases (Hautière et al., 2009).	Rainfall requires atmospheric temperatures to be above 0 °C near and above the surface. In Canada, rainfall occurrence varies by location, e.g., Saskatoon reports rainfall on only 3.5% of all hours, while for Vancouver the value is 15.7%.
Hail (ice pellets with a diameter of at least 5 mm), which sometime occurs during summer thunderstorms, is **primarily a visibility hazard**.	Hail occurs most frequently in Alberta.
Solid Precipitation occurs in the cold season as **snowflakes** (crystalline structure), **snow pellets and snow grains** (balls due to melting and re-freezing). Snowfall is a **compound hazard, as it both reduces road friction and impairs visibility.** **Road surface friction values decrease as conditions change** from bare and dry → bare and wet → slushy → partly snow covered → snow covered → snow packed → icy (Transportation Association of Canada, 2008, as cited in Usman, 2011). There is a **strong inverse relationship between snowfall rate** (measured as liquid-equivalent precipitation per hour) **and visibility distance**. Visibility distance is also affected by snow crystal type and lighting (Rasmussen et al., 1999).	Snow forms when the atmospheric temperature is at or below freezing and there is moisture in the air. Snow also can reach the ground when the surface temperature is between 0 °C and 5 °C. Most heavy snowfalls occur when temperatures near the ground are not too cold, typically greater than -9 °C. Globally, snowfall accounts for only 5% of precipitation. In Canada, snowfall occurrence varies by location, e.g., Vancouver and Victoria report snowfall on <1% of all hours, whereas in Chicoutimi snow occurs ~15% of the time.
Freezing rain, freezing drizzle, and freezing fog involve supercooled water droplets turning to ice when in contact with cold surfaces. They are compound hazards, affecting both friction and visibility, but **the dominant effect is very low friction** because of roads being fully or partially covered by ice.	In Canada, freezing rain is common from October to May, when there is a temperature inversion and near-surface temperatures below 0 °C. Freezing fog is common in mountainous areas that are exposed to low clouds, e.g., Calgary.
Some precipitation events include **both rain and snow**, or other forms of solid precipitation. **Ice pellets** (sleet) are formed when drops of rain or partly melted snowflakes freeze into ice before they hit the ground; ice pellets often fall with rain and snow. These occurrences affect both **friction and visibility**.	In Canada, it is common for precipitation events that occur in early or later winter to involve both rain and snow. For example, in both Vancouver and Toronto, approximately 3% of precipitation events (defined as 6-hour periods with measurable precipitation) have both rain and snow.

Table 2-2: Hazard typology

Meteorological condition	*Occurrence*
Wet, snowy or icy roads represent a **friction/controllability hazard**, even if precipitation is not falling. Ice is most slippery at temperatures near 0 °C. **Wet roads** can also **reduce driver visibility** because of splash and spray, especially by trucks.	Wet, snowy or icy conditions occur in the hours between and after precipitation, especially on roads that are a low priority for snow and ice control and also on bridges where ice may form on cold rainy days, on very cold days due to condensation of vehicle exhaust and when ambient temperatures rise above freezing after a prolonged cold spell. Other times, slippery conditions occur in the absence of precipitation (e.g., the formation of frost when the road surface temperature is lower than the dew point temperature of the air, and both are below freezing); the latter issue is of particular concern in maritime regions of Europe (Norrman et al., 2000; Ericksson, 2001; Andersson, 2011). In most Canadian cities, at least one-third of the collisions that occur on wet/snowy/icy roads occur when precipitation is not falling. System-wide road-condition data typically are not available in Canada, but human observations and road-weather-information systems provide site or segment data for some roads.
Various other conditions result in reduced driver visibility: • **Fog** (suspended water droplets) and **ice fog** (fog made up of ice crystals) **compromise driver visibility.** • Blowing snow, which is wind-driven snow near the ground, can be concurrent with snowfall, or it may occur after snow has accumulated if it is picked up and blown by strong winds. **Blowing snow affects both friction and visibility.** • **Other visibility hazards** include dust storms (winds blowing soil particles), smoke, and sunlight glare. • Meteorological data are also available for haze (suspension of extremely small, dry particles) and smog (mixture of noxious gases and particles that appear as haze), but these typically do not translate into serious visibility hazards in Canada.	Fog is common in Canada (Natural Resources Canada, 2003), especially along coastal Newfoundland where fog or mist is observed ~15% of the time. Ice fog typically occurs only at temperatures below -30 °C, and often in association with fuel combustion. In Canada, blowing snow occurs most frequently in the Arctic and Prairie provinces; in these regions 15-40% of blowing-snow events occur when precipitation is not falling (Baggaley and Hanesiak, 2005). Meteorological observations suggest, however, that blowing snow occurs infrequently in most urban regions of Canada. Other visibility hazards tend to be localized (e.g., dust storms in Saskatchewan, smoke in the vicinity of forest fires) or associated with particular times of day (e.g., glare).
Strong and/or gusty winds affect vehicle handling, especially for trucks and vans. **High wind speeds frequently occur during precipitation events**, producing a triple hazard – reduced friction, impaired visibility and challenging vehicle handling.	High winds can contribute to overturning, sideslip and rotation collisions, although effects vary by site and vehicle (Baker and Reynolds, 1992; Edwards, 1994 and 1998; Guo and Xu, 2006; Young and Liesman, 2007). In a UK study by Edwards (1994, 1998) the threshold wind speed used to identify times when driving was potentially affected by high winds was 40 km per hour (22 knots).

Table 2-2: Hazard typology

Meteorological condition	*Occurrence*
High temperatures potentially affect driver comfort and thus concentration/judgment.	Since most vehicles have air conditioning, heat is not likely a driving hazard in Canada. However, heat may be an issue for subsets of travellers (e.g., reduced use of protective clothing by motorcyclists, de Rome et al., 2011).

Precipitation is the most serious weather-related driving risk in Canada, in large part because it simultaneously affects both road friction and driver visibility, but also because precipitation, in all its various forms – rain, drizzle, hail, snow, freezing precipitation and ice pellets – occurs frequently. Across Canada's urban regions, Kamloops, British Columbia, is the city that receives precipitation least often, but even here precipitation is observed 7% of the time. By contrast, in St. John's, Newfoundland and Chicoutimi, Quebec, precipitation is observed more than 20% of the time (Andrey et al., 2005).

Other weather hazards are also important. Wet, snowy or icy roads represent a friction/controllability hazard, even when precipitation is not falling. These conditions also occur frequently, especially in the winter, when considerable time is required for a road to return to the state of being bare and dry. Fog and blowing snow are also hazardous because of the ways in which they compromise driver visibility.

A number of other hazards, as listed near the bottom of Table 2-2, affect particular circumstances. However, these hazards are less pervasive in their occurrence or less serious in their effects.

2.2 Weather-related safety outcomes

Over the past decade, numerous studies have quantified the impacts of weather, especially precipitation, on roadway collisions. Four different kinds of studies can be identified. The first includes macroscopic studies that use collision data at the state/regional level, combined with aggregate weather variables such as monthly precipitation, to model collision frequency as a function of both environmental and other factors (e.g., Eisenberg, 2004; Evans, 2004). A second group, meso-scale studies, are based on collision data at the city-level and detailed hourly and daily atmospheric information from nearby weather stations; these studies provide large-sample estimates of the extent and ways in which collision frequency and attributes change during weather of different types – typically in comparison to control periods that represent normal seasonal driving conditions (e.g., various studies by Andrey and colleagues, Keay and Simmonds, 2006; Brijs et al., 2008). A third group, micro-scale studies, consider the safety record of road segments vis-à-vis detailed weather and road condition data provided by road weather information systems, traffic loop systems, cameras and/or winter maintenance equipment logs (e.g., Khattak and Knapp, 2000; Sun et al., 2011). A fourth group includes those studies that dissect a particular weather system or event – in terms of its meteorology and/or safety impacts. These studies tend to focus on extreme/outlier events (e.g., Pike, 1992; Armstrong and Hibbert, 2001).

Each type of study has advantages and disadvantages. Macro-scale studies are based on readily available data and provide broad spatial coverage; however, weather is treated in a very general way such that it is impossible to link outcomes to particular events or specific conditions. Meso-scale studies provide robust risk estimates for particular locations, but they are spatially less comprehensive than macro studies and they provide only limited insights into how adaptations (either by individual drivers or by road authorities) affect the risk outcomes. In micro-studies, both atmospheric and roadway conditions can be described in detail, and collision rates can be calculated taking into account traffic volumes and the timing of snow-and-ice control operations. However, generalization of results can be problematic – both because of smaller sample sizes and because of the uniqueness of individual road segments. Finally, case studies of individual storms are useful for understanding vulnerability thresholds but are not intended to provide an overall assessment of the extent and magnitude of the problem. Given the need to have rigorous empirical estimates with some generalizability to other locations, the decision was made to conduct a meso-scale study for various urban regions of Canada.

Several reviews provide a basis for quantitatively estimating the extent to which collision rates change during inclement weather (Andrey et al., 2003; Eisenberg, 2004; Hermans et al., 2006: Strong et al., 2010). These reviews convincingly show that collision and injury rates are significantly elevated during precipitation events. Qiu and Nixon's (2008) recent meta-analysis, which is based on 34 published studies from different parts of the world, shows that, on average, collision rates increase by 71% during rain and 84% during snow. Andrey's (2010) multi-year analysis for injury collisions in 10 Canadian cities provides nearly identical overall results – 72% for rain, and 87% for snow. Other insights that emerge from the literature cited above are summarized in Table 2-3.

Table 2-3: Details on weather-related collision risk

Form of precipitation	Overall, collision risk is higher during snowfall than during rainfall. Risk estimates for other forms of precipitation are less conclusive, but some studies identify freezing rain as being particularly problematic. Based on past research, it appears that precipitation (or at least heavy snowfalls), leads to fewer fatalities because of behavioural adjustments, although some studies indicate that fatalities are increased under winter conditions (Lane et al., 1995). Many studies indicate that property-damage-only collisions increase the most during inclement weather, and serious crashes increase the least – again suggesting driver adjustment.
Precipitation intensity	There is strong evidence that collision risk increases as precipitation intensity increases. This is true for both liquid and solid forms of precipitation.
Temporal trends	Collision risk during rainfall has declined over the past two decades – in both absolute and relative terms (Andrey, 2010). While absolute risk has decreased for snowfall, no significant trend in relative risk has been observed.
Other timing	Collision rates are especially elevated after dry spells and on the first snowfalls of the winter season. Collision rates following rain storms quickly return to normal, even if roads remain wet (Andrey and Yagar, 1993).
Interactions between weather and non-weather variables	Some studies consider the interaction between weather and other risk factors related to roadway, vehicular and driver characteristics. These suggest that there are significant interactions, e.g., with roadway geometrics, speed limits, traffic volumes, vehicle types.

In summary, our understanding of weather-related collision risks is sufficient to extend this type of safety analysis to scenarios of future climates. That said, such research will need to acknowledge that global climate models provide only approximations of future precipitation regimes (temperature projections are comparatively more robust) (Rishey and O'Kane, 2011). Also, it is important to acknowledge that the transportation system will change in the coming decades – and changes in mobility will be the primary driver of risk exposure and thus risk outcomes. While it is beyond the scope of this project to model future mobility patterns, it will be important to consider how projected changes in weather-related risk might be affected by some of the expected changes in transportation planning and technology over the next half century.

2.3 Driver adaptations to weather

Past research has established that inclement weather increases collision rates, suggesting that drivers' adjustments to weather are insufficient to completely offset the physical hazards associated with reduced road friction, impaired driver visibility and/or decreased vehicle stability/controllability. However, weather-related increases in collisions are not consistent for all crash types; rather, the increase is higher for property-damage-only collisions than for more serious crashes, suggesting that drivers do adjust their driving in order to ameliorate the risk.

Some drivers cancel or defer trips or change travel modes, thereby affecting risk exposure. Related studies suggest very low levels of auto trip cancellation/deferral during rainfall and light snow, but sometimes larger reductions during very poor driving conditions, such as winter storms (Knapp, 2001; Kilpeläinen and Summala, 2007). Recent research provides insight into the magnitude of traffic volume reduction during Canadian winters. The first such study focuses on Alberta highways during snowfall and extreme cold (Datla and Sharma, 2008 and 2010); results indicate a reduction of 1% to 2% in traffic volume for each centimeter of snowfall when temperature is above freezing (e.g., autumn), but lower reductions during adverse weather from mid-November to mid-March. The second study, using data for urban and rural regions of southern Ontario, suggests average reductions between 1.9% and 4.7% on days with precipitation (Andrey et al., 2012).

Other driver adjustments are more pervasive, including greater driver attention, increased time gaps between vehicles, reduced traffic intensity, and lower and less variable travel speeds (Edwards, 2002; Andrey and Knapper, 2003; Unrau and Andrey, 2006; Cools et al., 2010). All of these adjustments are in the direction of safety. However, both observational studies and driving performance experiments in simulated weather conditions indicate that current levels of driver adaptation are not sufficient, given the physical nature of the hazards that drivers encounter during wet, snowy, icy and foggy conditions (Unrau and Andrey, 2006; Brooks et al., 2011).

2.4 Implications of winter road maintenance for road safety

Road authorities also respond to winter weather in efforts to maintain both mobility and safety. Winter maintenance programs involve operations that include systematic applications of materials (anti-icing, de-icing and abrasives) to prevent ice formation on road surfaces or improve traction, and plowing, grading and removal of snow accumulations. The nature and magnitude of snow-and-ice control programs vary according to differences in environmental, roadway and traffic characteristics. As well, winter maintenance programs are quickly evolving with the introduction of road weather information systems, improved vehicle technologies, alternative materials, innovative practices and expert decision-support systems.

Norrman et al. (2000) were among the first to quantify the relationship between road safety and road surface condition, based on data from Sweden. While the analysis was based on aggregate data, it demonstrates that collision risk increases under particular slipperiness conditions, thus justifying maintenance decisions that quicken the return to bare and dry conditions. More recent research in the US by Qiu and Nixon (2009) confirmed the risk associated with snow-covered roads, estimating that the probability of collision nearly doubled during these situations. In Canada, research by Fu and colleagues (Fu et al., 2006; Usman et al., 2010) explored the relationship between road safety on Ontario highways and various weather and maintenance factors. They concluded that anti-icing, pre-wet salting with plowing and sanding all reduce accident occurrence; and they demonstrated the influence of specific friction conditions on collision outcomes.

Despite the myriad of adjustments by individual drivers, and the commitment of governments and private road authorities to provide safe roads, the physical hazards associated with active weather continue to be a major risk factor in countries such as Canada, where weather conditions are highly variable and sometimes harsh and where road transportation is the dominant mode of passenger and freight movements.

2.5 Climate change and road safety

There is widespread agreement within the international scientific community that climate change during the course of the 21st Century is now unequivocal. Potentially all natural and human systems will be affected, including transportation. The relevance of climate change for the transportation sector generally, and road safety more specifically, is multi-faceted (Jaroszweski et al., 2010). First, since transportation accounts for approximately one-quarter of the global and national carbon emissions (Chapman, 2007; Government of Canada, 2011), it is likely that climate-change mitigation strategies will have implications for passenger and freight travel, which will in turn affect mobility patterns and road safety. Second, a number of regional transport systems have been identified as being particularly vulnerable to climate change; in Canada, these include coastal infrastructure in Atlantic Canada, ice roads and roads on permafrost in the North, and shipping in the Great Lakes-St. Lawrence Seaway (Warren et al., 2004). In terms of road safety, the net effect of these regional vulnerabilities is likely modest, but road discontinuities or modal shift in freight transport could affect road safety. Third, climate variability and change will require adaptive planning by provinces and municipalities, for example in terms of roadway design and maintenance as well as snow-and-ice control (Mills et al., 2007; Macleod, 2011). These changes also will indirectly affect road safety. Finally, given the importance of weather in traffic collision patterns today, climate change is likely to have direct effects on the frequency and type of collisions in the future.

Research related to the effects of climate change on road safety is in its infancy. Rowland et al. (2007) provide a qualitative assessment of road safety sensitivities to climate change in Australia. Andersson's (2011) doctoral thesis provides insights into the implications of climate change for a subset of collisions that occur on slippery roads (when particular temperature conditions are observed) in Sweden and

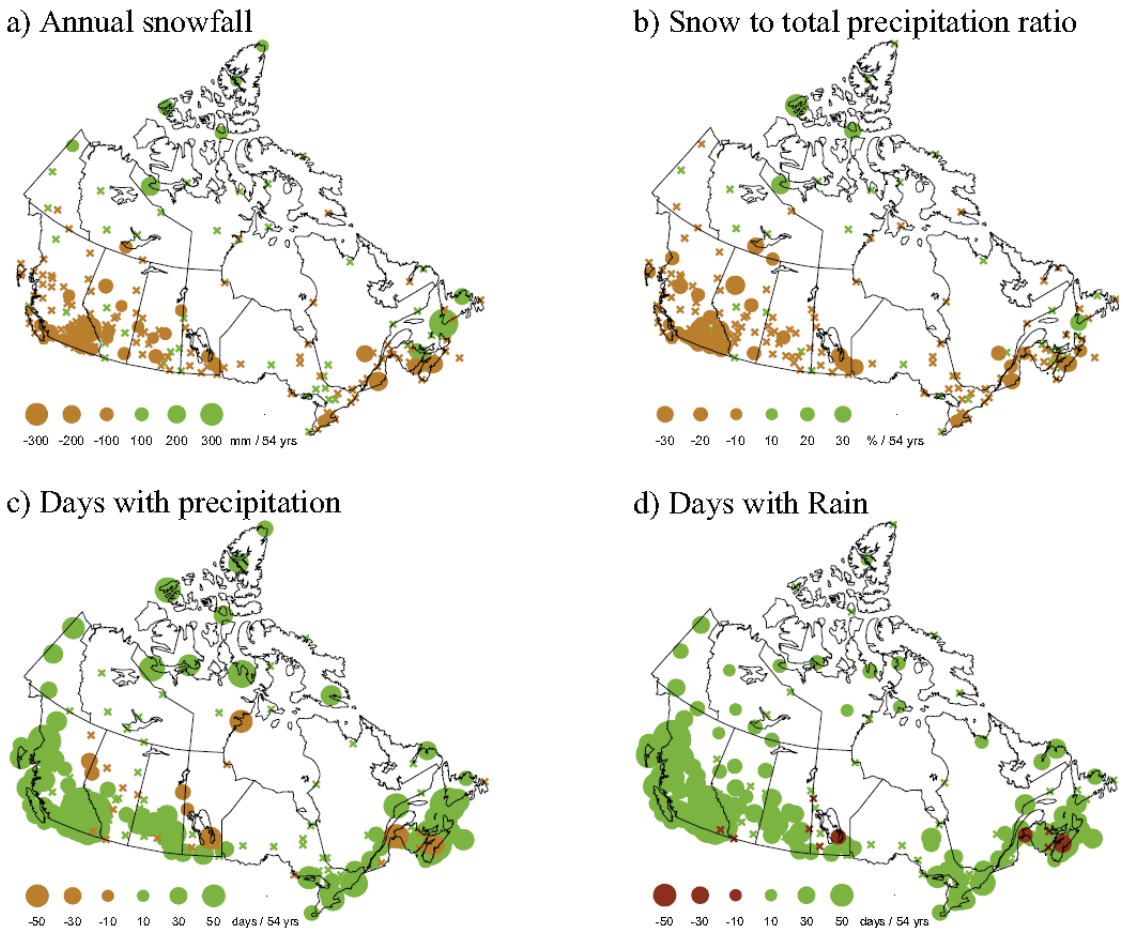
England. In the Canadian context, the recent Master's thesis by Hambly (2011) and the related publication in *Climatic Change* (Hambly et al., 2012) consider the implications of climate change for rainfall-related crashes in Vancouver and Toronto. However, no study, to date, has attempted to provide a comprehensive assessment of the implications of climate change for the frequency and type of collisions that can be expected under projected future climate conditions. The current project is directed toward addressing this knowledge gap with a particular focus on six urban regions of Canada.

2.6 20th century observed precipitation trends

Changes in the precipitation regime are one of the main consequences of increased concentrations of greenhouse gases in the atmosphere. As Trenberth (2011) finds, there is a direct influence of global warming on precipitation. Temperature increase leads to the increase in water holding capacity of air by about 7% per 1 °C warming, leading to increased water vapour content in the atmosphere. Hence, weather systems supplied with increased moisture produce more intense precipitation events. Such events are already observed during the 20th century. Because, with warming, more precipitation occurs as rain instead of snow and snow melts earlier, there is increased runoff and risk of flooding in early spring.

The analyses performed over Canada for the period 1950-2003 by Vincent and Mekis (2006) revealed an increase in the number of days with precipitation. This increase was particularly evident in the number of days with rainfall, as the ratio of snow to total precipitation diminished over most of southern Canada (Figure 2-1). Vincent and Mekis also reported a decrease in the maximum number of consecutive dry days and an increase in days with heavy precipitation. Zhang et al. (2000) also found an increase in annual precipitation ranging from 5% to 35% in southern Canada (south of 60°N latitude) over the period 1900-1998.

Figure 2-1: Observed changes in precipitation over Canada, 1950-2003



Brown and green dots indicate trends significant at the 5% level; the size of dots is proportional to the magnitude of the trend. Crosses denote non-significant trends. *Source*: Vincent and Mekis (2006)

The impacts of climate change are expected to result more from changes in the frequency and severity of extreme events than from changes in annual means. Through analysis of historical rainfall in the United States, Kunkel et al. (1999) measured the changes in annual maximum precipitation accumulated over seven days. During the period from 1931 to 1996, the maximum weekly precipitation increased by 26% in the Great Lakes area. In a similar study of the cumulative rainfall over five days, Min et al. (2011) came to essentially the same conclusion.

A particularly important category of precipitation, especially for northern countries such as Canada, is snow. Brown and Robinson (2011) studied spring snow cover variability and change in the Northern Hemisphere over the 1922–2010 period. Trend analysis provides evidence that Northern Hemisphere spring snow cover extent has undergone significant reductions over the past 90 years and that the rate of decrease has accelerated over the past 40 years. They also found that the rate of decrease in snow cover extent over North America is greatest in April.

2.7 Climate change projections

2.7.1 Changes in mean precipitation

Plummer at al. (2006) studied changes in average precipitation over North America for the period 2041-2060 compared to 1961-1990, and found that changes in seasonal average precipitation are projected to be in the range of +10% to -10% of present-day amounts for most seasons and most climatic regions of North America. However, for some regions such as the central Canadian Prairies during the spring season, the change signal is more robust; the projected increase in precipitation is around 20%. The largest relative changes in winter precipitation are projected to occur over the Canadian arctic where an increase in total annual precipitation is projected.

Sushama et al. (2006) found that, in spite of the model errors, the simulated climate change signals of water balance components such as precipitation were consistent in sign. An overall increase in annual average precipitation is expected for the 2041-2070 period compared to the 1961-1990 climatological mean over much of central and western Canada (i.e., the Nelson, Churchill, Mackenzie, Fraser and Yukon drainage basins). This increase, however, is not very large – between 2% and 14% for all basins – with the greatest increase, 14%, over the northernmost Yukon basin.

The simulated warming suggests a shortened snow season over all of North America. However, quantity of snowfall is generally expected to increase in the coldest areas. Elsewhere, less snowfall is anticipated throughout the winter (Räisänen, 2008). Sushama et al. (2006) also found that a significant decrease in snow cover will occur for all basins in their study, with maximum decrease in the Fraser basin.

2.7.2 Changes in precipitation extremes

As the Intergovernmental Panel on Climate Change (IPCC 2001; 2007) suggests, the frequency and severity of extreme events will change significantly in the future and those events will have major impacts on society. Moreover, it is expected that an increase in magnitude of short duration (1-day) and longer (7-day) precipitation extremes will have severe implications for various water resources-related development and management activities such as combined sewer systems, flood control in fast responding areas and water storage systems (Mladjic et al., 2011). The increase in magnitude of 1-day precipitation extremes at a 20-year return period is between 3-10 millimetres, and that of 7-day extremes for the same return period between 9-20 mm for different regions of Canada.

Major flooding events are related to heavy precipitation accumulated over several days. Thus, the increase in the quantity of precipitation in these events will have important consequences in the future. Min et al. (2011) have connected changes in 5-day precipitation extremes to human influence. According to the authors, climate models also project increases in heavy precipitation, but less extensive than indicated by observations. This underestimation is due to the tendency of the models to generate light rainfall too frequently, thereby reducing the amount of moisture available to produce heavy rains.

Räisänen (2005) found that simulated changes in extremes on longer time scales (i.e., monthly to annual) are well correlated with the changes in long-term mean precipitation: wet extremes will become more severe especially where mean precipitation increases, and dry extremes where mean precipitation decreases – generally over the globe. Räisänen also reported that changes in the frequency of extremes (fraction of cases with precipitation above a high or below a low predefined threshold) are much larger than the changes in their magnitude. Additionally, time scale can play a role whereby increases in the frequency of seasonal mean rainfall extremes can be greater than the increases in the frequency of daily extremes (IPCC, 2007).

Mailhot et al. (2012) used a multi-model ensemble to study changes in annual maxima of precipitation over Canada for the period 2041-2070 versus 1971-2000. Those changes were studied for different return periods (2, 5, 10 and 20 years) and for different event durations (6, 12, 24, 72 and 120 hours). The results showed a general increase in annual maxima of precipitation for different durations and return periods with median increase between 12% and 18%. For a given return period, the changes are more important for the events of shorter duration.

2.7.3 Impacts of changes in precipitation regime across sectors

Climate change will exacerbate many current climate risks, and present new risks and opportunities, with significant implications for communities, infrastructure and ecosystems (Lemmen and Warren, 2004). An increase in mean precipitation over much of Canada and an increase in precipitation extremes, with a greater proportion of precipitation falling as rain rather than snow in southern regions is expected to have important impacts on transportation infrastructure. In the past, there have been many examples of damage to transportation infrastructure due to rainfall-induced landslides, mudslides and floods (Warren et al., 2004; Macleod, 2011).

Warming in Canada will be accompanied by a longer frost-free season and an augmentation in growing-degree days (Bonsal et al., 2001) which can be beneficial for agriculture; still, the substantial decrease in annual snowfall, leading to less snow accumulation, can be crucial for the beginning of the growing season. As well, a reduction in snowpack could reduce the amount of meltwater that contributes to streams and lakes and recharges groundwater, potentially reducing water availability.

A warming climate in Canada will have impacts on water quantity and quality across the country. For example, in the Great Lakes Basin, climate models predict changes in annual stream flow and lake levels, with the possibility of more frequent flooding. In such cases, current sewage treatment facilities will be unable to cope with increased volumes of stormwater and sewage runoff. In the Prairies, water levels in ponds, lakes and dugouts are projected to decline, largely due to increased evaporation, leading to changes in water chemistry, which could mean less available drinking water in some rural regions. Climate variability has a pronounced impact on the capacity of groundwater systems to maintain water supplies, in-stream conditions and aquatic habitat; impacts such as these may increase as a result of climate change (Environment Canada, 2011).

One of the many potential effects of a changing precipitation regime is that river catchment runoff may be altered. This could have implications for the design, operation and viability of hydroelectric power stations. Finally, activities such as tourism and recreation are expected to be largely affected by a changing climate. For example, with less snowfall expected, winter outdoor activities may be reduced, especially in the south where ski resorts already rely on artificial snowmaking.

3 Methods

This section of the report begins with an assessment of data availability and completeness, and an explanation for the choice of study areas (Task 1). This is followed by the rationale for two key decisions: the choice of a temporal scale of analysis (Tasks 3, 6) and selection of weather types for the risk analysis (Tasks 4, 6). The section ends with a summary of climate simulations and their interpretation for urban-scale analysis (Task 5).

3.1 Data sources and choice of study areas

Transport Canada maintains a National Collision Database, which contains information on all reported collisions in Canada. Appendix A provides details on the variables that are included in the database, as well as information on those variables that were provided to the researchers for the period 2000-2009; the year 2009 was the last year with complete data when the project was initiated.

An assessment of these collision data was undertaken to identify possible study locations. Of particular importance to the study is information on the general location of the collision, since this is necessary in order to identify a nearby weather station. The assessment shows that, based on the National Collision Database, it is possible to identify collisions that occurred in specific urban areas for all provinces except three: Quebec, Manitoba and Newfoundland and Labrador (Table 3-1). Quebec collisions are reported by administrative region, and each administrative region covers a large geographic area – making it impossible to identify specific urban areas from this dataset. For this reason, collision data from Transports Québec was incorporated directly; this task required variable translation and reconciliation but allowed for the inclusion of Quebec urban areas in the study. Supplementary data were not pursued for Manitoba or Newfoundland and Labrador – largely because data were available for other cities in the same climatic regions.

Based on this assessment, 12 large cities located in a range of climatic zones nationwide were identified as possible study candidates: Victoria, Vancouver, Calgary, Edmonton, Saskatoon, Regina, London, Toronto, Ottawa, Montreal, Quebec City and Halifax. Climate data were obtained for the nearest principal airport weather station to each candidate city and these were checked for completeness at hourly, six-hourly and daily intervals; all were found to have suitable records throughout the ten-year study period, 2000-2009.

A focus was placed on six large cities. The cities chosen are Vancouver, Calgary, Toronto, Montreal, Quebec City and Halifax. These include the four most populous urban areas in the country, Quebec City, and the largest city in Atlantic Canada. All have relatively complete collision and climate data; they have large urban populations and are thus important from a mobility and safety perspective, with a substantial amount of driving and high number of crashes annually in each city; and they represent different climatic regions of the country. Since both the City of Ottawa and the City of Moncton contributed as funding partners, the present-day safety analysis was completed for these cities as well. However, the climate change analysis does not extend to Ottawa or Moncton due to budget and time constraints. Information on all eight urban areas is provided in Table 3-2 to Table 3-5.

Table 3-1: Availability and completeness of data from the National Collision Database

Province	*Years with data*	*Collision location information*	*Comments for selected data attributes*
Alberta	2001-2009	2003-2009 (police service codes)	• Road surface condition (e.g., wet, icy) ~ 60% complete • Incomplete data for roadway attributes • No information on posted speed limits • Limited data on vehicle manoeuvres and crash events (less than 15% complete) • No data on driver years licensed
British Columbia	2000-2009	2000-2009 (police detachment codes)	• No data on driver years licensed
Manitoba	2000-2009	Not available	• Incomplete data on driver years licensed (~ 55%)
New Brunswick	2000-2009	2000-2009 (municipality codes)	• Limited data on person sex (< 25%), driver years licensed (~ 65%)
Newfoundland and Labrador	2000-2009	Not available	• One of three provinces with estimated vehicle speed • No data on driver years licensed
Nova Scotia	2000-2009	2000-2009 (police detachment codes)	• Data on posted speed limits ~ 65% complete • Limited data on driver years licensed (~ 30%)
Ontario	2000-2009	2000-2009 (county and municipality codes)	• One of three provinces with estimated vehicle speed • Posted speed limits ~ 75% complete • No data on driver years licensed • Only province to provide blood alcohol concentration
Prince Edward Island	2000-2009	2003-2009 (police detachment codes)	• One of three provinces with vehicle speed
Quebec	2000-2009	2003-2009 (administrative regions)	• Quebec administrative regions each cover a large geographic area, so we do not have the location information to identify specific urban areas from this dataset • Limited roadway/situational information • No vehicle speed information; posted speed limits ~ 25% complete • Person injury severity ~ 25% complete
Saskatchewan	2001-2009	2003-2009 (police detachment codes)	• Weather at the time of the collision ~ 55% complete provincially (> 80% in Regina, Saskatoon) • Posted speed limit completeness varies by jurisdiction (province 46% complete, Regina 83%, Saskatoon 56%) • Incomplete driver/person attributes (age/sex < 50% complete, missing driver years licensed) • Person injury severity ~ 50% complete
General notes on data completeness for all jurisdictions: 1. Records for property-damage-only (PDO) collisions were not provided for 2000. 2. Vehicle and person attributes were not provided for 2000-2002; vehicle type is unavailable for all years.			

Table 3-2: Study locations

City	*Province*	*Geographic description (Statistics Canada definition)*	*Population, 2006*	*Land area, 2006 (km^2)*	*Density (people/ km^2)*
Vancouver	BC	Vancouver, White Rock and Walnut Grove urban areas	2,051,941	1,196.5	1,715
Calgary	AB	City of Calgary	988,193	726.5	1,360
Toronto	ON	Toronto urban area	4,753,120	1,748.6	2,718
Ottawa	ON	Ottawa and Kanata urban areas	733,592	421.6	1,740
Montreal	QC	Island of Montreal (Montreal census division)	1,854,442	499.0	3,716
Quebec City	QC	City of Quebec (urban area pre-2000 amalgamation/fusion)	491,142	454.3	1,081
Moncton	NB	Moncton urban area	97,065	146.3	663
Halifax	NS	Halifax urban area	282,924	262.7	1,077

Population and land area are estimates for approximate areas covered by collision location codes; details are provided in Appendix B.
Source: Statistics Canada (2007)

Table 3-3: Road network information for the study locations

	Vancouver	*Calgary*	*Toronto*	*Ottawa*	*Montreal*	*Quebec City*	*Moncton*	*Halifax*
Total road network (centre-line km unless otherwise stated)	1,416	4,924	5,389	11,908 lane-km	5,821	2,740	620	3,784 [a]
Freeway/expressway		325	127	101	490	363	99	40
Arterial	215	641	1,163	1,992	935	286	76	279
Collector	143	936	768	5,301	762	379	89	465
Local	923	3,022	3,331	4,514	3,547	1,712	356	2,727
Other	135				87			
Speed limits	Complete data not available							
Winter maintenance	Various service/priority classes							
Journey to work: % trips by transit, walking or cycling	24.5	23.8	28.0	32.0	43.0	23.8	11.4	22.9

[a] Does not equal ∑ by road type; data presented as provided.
Source: Journey to work data obtained from Statistics Canada (2007). All other data provided by municipalities. Boundaries do not necessarily coincide with those used to define the study areas based on collision data.

Table 3-4: Average annual incident counts by jurisdiction, 2000-2009

	Vancouver	*Calgary* [b]	*Toronto*	*Ottawa*	*Montreal*	*Quebec City*	*Moncton*	*Halifax*
Collisions								
Total collisions	15,657	40,768	92,391	13,154	43,834	17,432	1,621	4,219
Fatal	93	36	126	22	50	14	3	6
Non-fatal injury	7,482	3,323	20,473	2,741	7,844	2,044	478	985
Property-damage-only [a]	8,082	37,410	71,792	10,391	35,939	15,373	1,140	3,227
Victims								
Total injuries	10,747	4,248	29,755	3,780	10,267	2,737	632	1,292
Fatalities	101	40	137	23	52	15	4	7
Injuries	10,647	4,208	29,618	3,757	10,215	2,723	629	1,285

[a] PDO data are for 2001-2009 only outside Quebec. Montreal and Quebec City PDO data include 2000.
[b] Calgary data are for 2003-2009 only.

Table 3-5: Climate summary for the study locations, 1971-2000

	Vancouver	*Calgary*	*Toronto*	*Ottawa*	*Montreal*	*Quebec City*	*Moncton*	*Halifax*
Climate station ID	1108447	3031093	6158733	6106000	7025250	7016294	8103200	8202250
Climate region	Pacific Coast	Prairies	Great Lakes-St. Lawrence				Atlantic Canada	
Latitude (N)	49°11'42"	51°06'50"	43°40'38"	45°19'21"	45°28'00"	46°48'00"	46°06'14"	44°53'00"
Longitude (W)	123°10'55"	114°01'13"	79°37'50"	75°40'09"	73°45'00"	71°23'00"	64°41'16"	63°31'00"
Elevation (m)	4.3	1,084.1	173.4	114.0	36.0	74.4	70.7	145.4
Annual # rain days [a]	161.3	67.5	111.8	114.7	119.4	121.1	131.1	131.9
Annual # snow days [a]	10.9	56.8	46.5	65.6	60.3	76.4	63.9	60.2
Annual # precipitation days [a]	166.1	113.6	145.5	162.6	163.3	181.9	174.5	171.2
Annual rainfall (mm)	1154.7	320.6	684.6	732.0	763.8	923.8	865.4	1238.9
Annual snowfall (cm)	48.2	126.7	115.4	235.7	217.5	315.9	349.9	230.5
Annual precipitation (mm)	1199.0	412.6	792.7	943.5	978.9	1230.3	1223.2	1452.2
Daily avg. temp., Jan (°C)	3.3	-8.9	-6.3	-10.8	-10.2	-12.8	-8.9	-6.0
Daily avg. temp., July (°C)	17.5	16.2	20.8	20.9	20.9	19.2	18.6	18.6
Annual days with max. temp ≤ 0 °C	4.5	63.4	57.2	81.3	77.4	98.8	74.2	57.1
Annual days with max. temp >30 °C	0.2	4.5	12.6	11.3	7.6	4.6	4.1	2.2

[a] Rain, snow, and precipitation days are defined as having measurable precipitation (i.e., ≥ 0.2 mm liquid equivalent)
Source: Environment Canada (2012)

Section 2 identified a number of weather hazards as having adverse safety outcomes; these conditions are highly variable across the country. Table 3-6 summarizes the occurrence of the various weather hazards at the study cities during the ten-year study period, 2000-2009, based on hourly data from Environment Canada. Detailed data over a longer time period for Canada's 27 largest cities are provided in Appendix C.

Table 3-6: Weather conditions observed (% time) at the study locations, 2000-2009

City	*Clear/no active weather*	*Rainfall*	*Snowfall*	*Other frozen precipitation*	*Fog, smog, or mist*	*Dust or smoke*	*Strong winds*	*All conditions*
Vancouver	81.43	14.66	0.87	0.00	3.03	0.01	0.00	100.00
Calgary	84.75	4.36	8.57	0.03	2.21	0.07	0.01	100.00
Toronto	81.12	6.87	5.35	0.21	6.43	0.00	0.01	100.00
Ottawa	79.70	7.83	7.25	0.23	4.97	0.00	0.02	100.00
Montreal	79.56	8.31	7.37	0.16	4.55	0.03	0.02	100.00
Quebec City	75.14	8.92	10.07	0.28	5.54	0.01	0.04	100.00
Moncton	78.08	8.51	7.82	0.28	5.27	0.01	0.03	100.00
Halifax	68.85	8.57	8.53	0.28	13.72	0.02	0.04	100.00
Minimum	68.85	4.36	0.87	0.00	2.21	0.00	0.00	100.00
Maximum	84.75	14.66	10.07	0.28	13.72	0.07	0.04	100.00
Average	78.50	8.54	6.77	0.17	5.98	0.02	0.02	100.00

From a traffic safety perspective, the study cities are broadly comparable in terms of injury collision rates (i.e., those involving injury or fatality), although large differences are evident in reported property-damage-only (PDO) collisions (Figure 3-1)[1]. The primary focus of this study was injury collisions. A downward trend in injury collisions is evident in each location – except Ottawa, which has no apparent trend – during the ten-year study period (Figure 3-2). This suggests that, despite growing populations and greater mobility, automobile travel overall is becoming safer in Canadian cities – part of a long-term trend observed nationwide over the past 60 years (Figure 3-3).

[1] According to 2001-2009 collision records, property-damage-only (PDO) crashes comprise a smaller share of reported collisions in Vancouver (52%) and a greater share in Calgary (92%) and Quebec City (88%) than in the other study cities; the national average is 78%. Similarly, Vancouver's per capita PDO involvement rate for 2006 (412 per 100,000 population) was lower and Calgary's (3,747) and Quebec City's (3,135) higher than the other locations, which range from 1,102 to 1,823; the national rate is1,623. These discrepancies suggest that PDOs are under-reported in Vancouver, and are either reported more frequently or have a high occurrence rate in Calgary and Quebec City. Personal communication with a representative from the City of Calgary indicated that there are regional differences in reporting rates.

Figure 3-1: Collision rates per 100,000 population, 2006

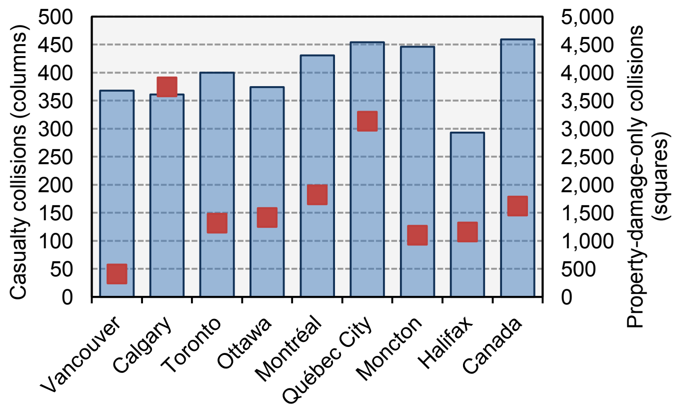


Figure 3-2: Annual number of injury collisions, 2000-2009

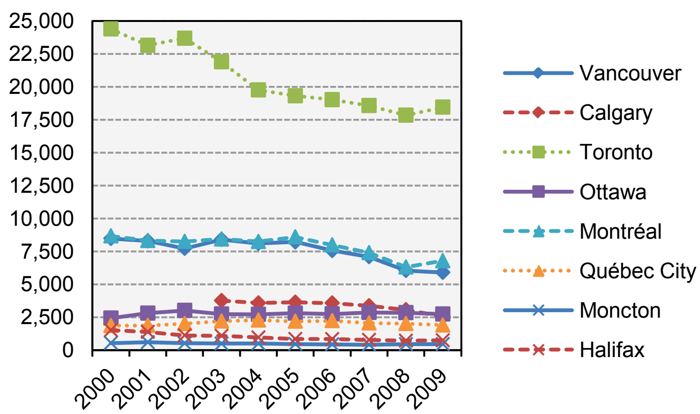
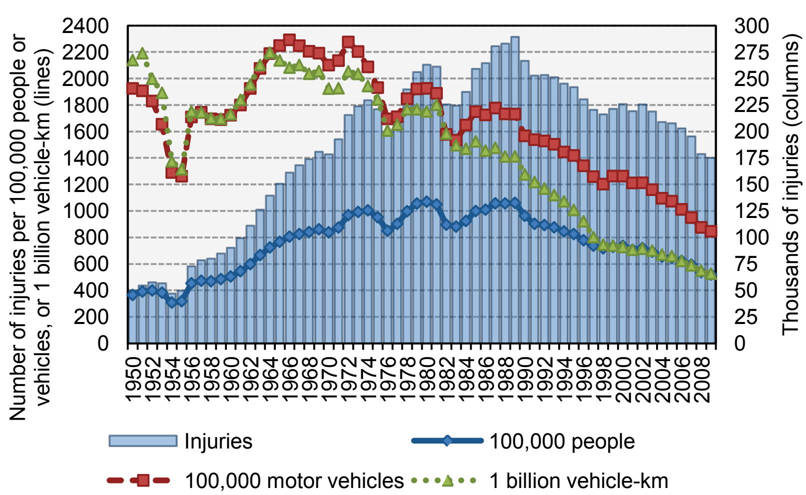


Figure 3-3: Long-term trend in motor vehicle injuries and fatalities, Canada, 1950-2009



Counts and rates include injuries of all severities (minimal, minor, major and fatal).

3.2 Analytical approach

The risk analysis component of this study utilizes a matched-pair design to estimate present-day differences in crash risk during adverse weather relative to 'dry', seasonal conditions (Codling, 1974; Andrey et al., 2003). A matching exercise is carried out whereby an 'event' period (e.g., a rainy Tuesday in July) is matched with a 'control' period, either one or two weeks immediately prior or following, where no active weather was observed and roads were mostly dry (i.e., clear, seasonal conditions). In the absence of city-scale travel exposure data, this approach reasonably controls for the influence of time-dependent variables (e.g., traffic volume, driver and vehicle mix) by assuming that travel patterns are similar for a given day of week, from one week to the next. It does not, however, account for the (usually small) travel reductions that typically occur during adverse weather: previous research has shown that traffic volumes decreased by 2% during rainfall and 10% to 29% during light and heavy snowfall, respectively (Qiu and Nixon, 2008), with postponement of some discretionary trips (Kilpeläinen and Summala, 2007). Relative risk estimates are therefore likely to slightly underestimate weather-related risks.

A relative risk greater than (less than) 1 indicates an increase (decrease) in risk during the event condition; a ratio of exactly 1 suggests no difference between the two. For example, a relative risk of 1.3 indicates that collision frequency is 30% higher during adverse weather than what occurs on the same day of the week when roads are mostly dry – that is, 30% of the collisions that occur while rainfall or other inclement weather is present are directly attributable to the weather, i.e., these crashes would not have otherwise occurred. The steps involved in calculating relative risk are explained in Appendix D.

The matched-pair approach is highly adaptable in that it can be used to estimate relative changes in crash risk for any location with sufficient weather and collision data, at various temporal scales, and can be applied to a wide range of weather conditions. It has been used extensively in the literature to estimate weather-related travel risks (Zhang et al., 2005; Keay and Simmonds, 2006; Mills et al., 2011). In addition, estimates of relative risk can easily be compared between different study areas.

In the current study, care was taken to ensure that the matched events provide a representative set of days on which to base the risk estimates. In the first pass through the data, it was noted that the monthly distribution of matched events did not coincide with the monthly distribution of all event days. Closer investigation indicated that this was because there were few control days during snowy winter seasons, especially in areas where roads remain icy, snowy or wet for an extended period of time, e.g., Ottawa and Quebec City. To ensure that this did not result in seasonal bias in the risk estimates, the analysis was re-run using a less restrictive criterion for road conditions. The initial criterion, as explained in Table 3-18, ensured that at least 85% of the collisions that occurred during control periods occurred on dry roads. When the analysis was re-run, the cutoff value was reduced to 50%, which resulted in a seasonal distribution of matched events that more closely aligned with the seasonal distribution of all events. Of importance to the current study is the fact that the relative risk estimates were largely unaffected by the dry-road criterion. As such, the analysis proceeded using the 85% cutoff value – as this represents the purest contrast between inclement weather conditions and good, seasonal conditions. The results of this sensitivity analysis are included in Appendix E.

3.3 Temporal scale of analysis

The choice of temporal scale is a key decision in estimating weather-related travel risks. Different temporal scales have been used in previous studies of weather-related collision risk:

- variable-length storms (Andrey, 1989);
- 6-hour periods (various works by Andrey and colleagues; Sherretz and Farhar, 1978);
- days (Codling, 1974; Eisenberg, 2004; Hambly et al., 2012); and
- months (Eisenberg, 2004).

Toronto was selected as a study area to inform this choice, as it experiences a high number of annual crashes and has an excellent historical weather record. Data were assembled for Toronto Pearson International Airport for two years during the study period; the first, 2006, was an exceptionally warm year with above normal precipitation but minimal snowfall, while 2007 was one of the driest years on record. Data for these two years were combined. Three temporal scales were examined: the storm level (using hourly data), 6-hour periods (defined in a standardized way by the World Meteorological Organization) and 24-hour days.

Events included those times when measurable precipitation (≥ 0.2 mm) was recorded and where precipitation was observed on at least two top-of-hour observations. Variable-length events comprised either consecutive hours with precipitation, or intermittent periods where the hours with precipitation were separated by no more than one hour with no measurable precipitation. Controls, i.e., non-weather periods, were time periods where there was no measurable precipitation.

Risk estimates were calculated for events with either observed rainfall or snowfall at the three temporal scales (Table 3-7). The highest risk estimates (and lowest crash counts per event/control) are associated with variable-length storms, and the lowest estimates for days with precipitation. This is as expected because the effect of weather on collision rates becomes diluted when more non-weather hours are included in each event period. Table 3-8 illustrates this tendency.

Table 3-7: Comparison of risk estimates at different temporal scales, Toronto, 2006-2007

	Rain			*Snow*		
Temporal scale	***Event collisions***	***Control collisions***	***Risk estimate***	***Event collisions***	***Control collisions***	***Risk estimate***
Variable [a]	1,470	953	1.54	--	--	--
6-hour	3,410	2,541	1.34	840	638	1.32
Day	6,776	6,205	1.09	1,405	1,195	1.18

[a] Not applicable for snow because snowfall accumulations are not recorded at the hourly level.

A variable-length event period begins and ends at the same time as a given weather occurrence, such that all of the event's hours coincide with the presence of inclement weather. Analysis of storms based on hourly data is therefore best able to isolate the effects of weather on collision rates; however, it is not possible to define snowfall events in this way by using standard meteorological records, as the finest resolution at which snowfall accumulation is available is six hours. Moreover, although measured rainfall is recorded at hourly intervals, the records are incomplete in many locations, particularly in the winter months. Accordingly, variable-length events were determined to be unsuitable for the present study.

Risk estimates based on precipitation accumulation records for 6-hour periods produced results that are generally consistent with previously reported estimates (e.g., Andrey, 2010). As shown in Table 3-8, rainfall events defined in this way typically include four hours of rainfall and two hours where rain was not occurring; for winter precipitation events, 4.5 hours (out of the six) are characterized by falling precipitation. Six-hour data are appropriate for estimating weather-related travel risks; however, projections of future precipitation are somewhat unreliable at this temporal scale – especially for extreme precipitation – due to numerical noise in the climate models.

Table 3-8: Average number of hours with observed precipitation during events, Toronto, 2006-2007

Temporal scale	*Rain*	*Snow*
Variable [a]	5.1 (100%)	--
6-hour	3.9 (65%)	4.6 (77%)
Day	6.5 (27%)	8.2 (34%)
[a] Not applicable for snow because snowfall accumulations are not recorded at the hourly level.		

On days with precipitation, a mix of conditions is observed. On average, precipitation is observed one-quarter to one-third of the time, with the remainder of the day characterized by cloudy or clear conditions. Because of this 'dilution' of the weather effect, relative risk estimates from daily data are lower than for 6-hour periods. Still, when translated into absolute risk, both daily and 6-hourly data provide nearly identical results[2].

Given that climate change projections for precipitation are not considered reliable at sub-daily scales, the most appropriate temporal unit of analysis for the climate-change safety analysis was determined to be the climatological (24-hour) day. This report thus provides risk estimates based on daily data. As 6-hour estimates of risk were initially calculated, they are provided in Appendix F.

3.4 Weather conditions included in the risk analysis

As explained in Section 2, precipitation is the main weather hazard affecting road safety in Canada. Both precipitation amount (measured in mm of rainfall or liquid equivalent of snowfall) and precipitation form (i.e., liquid, freezing, frozen) affect driving. In working with weather data for past events, daily and hourly weather records can be used to categorize days according to both accumulation and form. While the output from future climate simulations does provide accumulation data, it does not specify precipitation form. Rather, this must be inferred from daily temperature data.

[2] Consider, for example, a situation where the relative risk of collision, based on 6-hour data, is 1.8 and inclement weather occurs on average, for four of the six hours. Assuming that the remainder of the day is dry with a relative risk of 1.0, the daily relative risk would be 1.2 (i.e., the average of 1.8, 1.0, 1.0 and 1.0). In either case, the same increase in absolute risk would occur.

3.4.1 Precipitation categories

Precipitation form is determined by the temperature profile of the atmosphere. For example, when temperatures near and at the surface of the earth are well above 0 °C, precipitation falls in liquid form as drizzle or rain. When temperatures near and at the surface are well below 0 °C, precipitation falls in frozen form, typically as snow. However, the temperature band in between can produce rain, rain with snow, freezing rain or snow – depending on the vertical temperature profile of the lower atmosphere.

Since previous studies have indicated that rain and snow affect travel risks differently, and because only surface temperature is provided for future climate projections, it was necessary to devise a way to identify rainfall-only days from those that are likely to include freezing rain or snowfall. Surface temperature (daily minimum and maximum) is used for this purpose.

Table 3-9: Count of days with precipitation of different forms, by daily temperature, Toronto, 2000-2009

		Daily minimum temperature (°C)																											
		< -3		*-3 to -2.5*		*-2.5 to -2*		*-2 to -1.5*		*-1.5 to -1*		*-1 to -0.5*		*-0.5 to 0*		*0 to 0.5*		*0.5 to 1*		*1 to 1.5*		*1.5 to 2*		*2 to 2.5*		*2.5 to 3*		*≥ 3*	
Daily maximum temperature (°C))	*< -3*	190	1																										
		7																											
	-3 to -2.5	26																											
		3																											
	-2.5 to -2	25																											
	-2 to -1.5	29																											
		2																											
	-1.5 to -1	24																											
		5																											
	-1 to -0.5	26																											
		5		1		1																							
	-0.5 to 0	36																											
		2																											
	0 to 0.5	30	1	1		1						1																	
		3																											
	0.5 to 1	21	1					1																					
		4		1				1																					
	1 to 1.5	22	2	2		2				1		2	1	1	1														
		4	1									1																	
	1.5 to 2	12	6	2				4		2		1																	
			1	1						1			1																
	2 to 2.5	8	1	2		3	1	1		2	1			1			1												
		3		1	1	1								1		1													
	2.5 to 3	10	5	1		4			4		2	2	3					1											
		2	1	1				1		1					1		2	1											
	≥ 3	26	29	3	2	3	5	9	10	4	6	4	9	3	9	3	9	7	9		7		1		3		1		
		14	18	2	8	3	5	4	9	3	8	1	13	4	18	6	20	6	21	1	31	1	28		32		43	1	865

Legend for each box:	
Snow	Rain with snow
Freezing rain	Rain
Blank values indicate zero counts	

In the historical weather records, the best indication of observed precipitation form is provided by an hourly weather variable that is based on visual observations by trained personnel at the top of each hour; these are the same data that were used to construct Table 3-6 and Appendix C. Using these data, it is possible to tally the frequency with which different precipitation forms occur, for different minimum and maximum daily temperatures. The resulting frequencies are provided for Toronto in Table 3-9 and for all eight cities in Appendix G.

For Toronto, the frequency information shows the following:

- Precipitation days with a minimum temperature ≥ 1.5 °C are characterized by rain, almost exclusively. Of the 975 days with observed precipitation (at or above this temperature) that occurred between 2000 and 2009, all but seven days are characterized by liquid precipitation only (i.e., in the bottom row of Table 3-9, there are 975 days in the right-most 4 cells. Rain was observed on 968 of these days – as indicated in the bottom-right corner of each cell. The remaining 7 days were characterized by either freezing rain (2; bottom-left) or rain with snow (5; top-right)).
- Rainfall also dominates when the minimum daily temperature is between 0.5 and 1.5 °C; however, there are some instances of freezing rain or snowfall. The proportion of days with freezing rain or snowfall is 8/39 when the daily minimum temperature is between 1.0 and 1.5 °C and 24/45 when the daily minimum temperature is between 0.5 and 1.0 °C. In most of these cases, however, rainfall is observed with greater frequency than any other precipitation form, e.g., rain is observed for several consecutive hours and followed by an observation of falling snow.
- When the observed minimum temperature is below 0.5 °C, precipitation forms are more mixed.
- As such, for Toronto, it appears that a minimum temperature of 0.5 °C is a reasonable way to distinguish between rain days and winter precipitation days.
- For the other seven study areas, the results are similar. In all cases, at least 96% of precipitation days with minimum temperature ≥ 0.5 °C were comprised solely of observed rainfall.

Another way of checking the appropriateness of 0.5 °C minimum daily temperature as a cutoff value is to consider precipitation accumulation (i.e., measurable rain or measurable snow) rather than what was observed visually. Table 3-10 through Table 3-17 confirm that a minimum daily temperature of 0.5°C provides a reasonable way to separate days with rainfall only from those that have some measurable snowfall. At a lower threshold value (0.0 °C) snowfall is increasingly included in the rain category. At a higher threshold value (1.0 °C or higher), many days with measurable rainfall are removed from the rain category (indicated by smaller values of n) and placed into the winter precipitation category.

As such, all precipitation days – both past and future – are considered to be rain days if the minimum daily temperature is ≥ 0.5 °C. It follows then that all precipitation days – both past and future – with a minimum daily temperature < 0.5 °C are considered to be winter precipitation days.

There are various types of winter precipitation (e.g., snowfall, freezing rain, ice pellets), and our analysis confirms what is widely acknowledged by the meteorological community, which is that surface temperature alone is not sufficient to accurately determine precipitation form when temperature readings are near 0.0 °C (Gay and Davis, 1993).

However, on days where the temperature does not rise above -3.0 °C (top-left box in Table 3-9 and Appendix G), precipitation falls almost exclusively as snow, so days meeting this criterion may be considered the snowfall-only subset of winter precipitation days. For other winter precipitation days with a maximum temperature at or above -3.0 °C, risk estimates are provided using 1-degree bands of daily maximum temperature between -3.0 and +3.0 °C.

Table 3-10: Days with precipitation by daily minimum temperature, Vancouver, 2000-2009

	Weather observed by trained personnel					*Measured precipitation type (≥ 0.2 mm)*			
Daily minimum temperature	***n=***	***Rain***	***Snow***	***Rain with snow***	***Freezing rain***	***n=***	***Rain***	***Snow***	***Rain and snow***
≥ 0 °C	1,716	96.9%	0.2%	2.9%	0.0%	1,594	98.1%	0.1%	1.8%
≥ 0.5 °C	1,659	98.7%	0.1%	1.2%	0.0%	1,541	99.7%	0.0%	0.3%
≥ 1.0 °C	1,619	99.4%	0.0%	0.6%	0.0%	1,505	99.9%	0.0%	0.1%
≥ 1.5 °C	1,578	99.6%	0.0%	0.4%	0.0%	1,465	99.9%	0.0%	0.1%
≥ 2.0 °C	1,523	99.9%	0.0%	0.1%	0.0%	1,413	99.9%	0.0%	0.1%

Table 3-11: Days with precipitation by daily minimum temperature, Calgary, 2000-2009

	Weather observed by trained personnel					*Measured precipitation type (≥ 0.2 mm)* [a]			
Daily minimum temperature	***n=***	***Rain***	***Snow***	***Rain with snow***	***Freezing rain***	***n=***	***Rain***	***Snow***	***Rain and snow***
≥ 0 °C	714	92.6%	1.8%	4.8%	0.8%	571	95.8%	1.9%	2.3%
≥ 0.5 °C	678	95.7%	0.9%	2.8%	0.6%	542	99.1%	0.4%	0.6%
≥ 1.0 °C	657	97.6%	0.3%	1.7%	0.5%	529	99.8%	0.0%	0.2%
≥ 1.5 °C	631	98.6%	0.0%	1.0%	0.5%	512	100.0%	0.0%	0.0%
≥ 2.0 °C	604	99.2%	0.0%	0.5%	0.3%	493	100.0%	0.0%	0.0%

[a] Two days with measurable precipitation (≥ 0.2 mm) had rain and snow records that indicated 0 mm, so are not included in these counts.

Table 3-12: Days with precipitation by daily minimum temperature, Toronto, 2000-2009

	Weather observed by trained personnel					*Measured precipitation type (≥ 0.2 mm)*			
Daily minimum temperature	***n=***	***Rain***	***Snow***	***Rain with snow***	***Freezing rain***	***n=***	***Rain***	***Snow***	***Rain and snow***
≥ 0 °C	1,101	94.6%	1.0%	2.8%	1.5%	958	97.5%	0.3%	2.2%
≥ 0.5 °C	1,059	96.3%	0.8%	2.0%	0.9%	924	98.5%	0.1%	1.4%
≥ 1.0 °C	1,014	98.5%	0.0%	1.2%	0.3%	890	99.7%	0.0%	0.3%
≥ 1.5 °C	975	99.3%	0.0%	0.5%	0.2%	856	100.0%	0.0%	0.0%
≥ 2.0 °C	945	99.5%	0.0%	0.4%	0.1%	833	100.0%	0.0%	0.0%

Table 3-13: Days with precipitation by daily minimum temperature, Ottawa, 2000-2009

	Weather observed by trained personnel					*Measured precipitation type (≥ 0.2 mm)*			
Daily minimum temperature	***n=***	***Rain***	***Snow***	***Rain with snow***	***Freezing rain***	***n=***	***Rain***	***Snow***	***Rain and snow***
≥ 0 °C	1,084	95.8%	0.3%	3.4%	0.6%	993	97.9%	0.2%	1.9%
≥ 0.5 °C	1,042	97.7%	0.2%	1.9%	0.2%	954	99.3%	0.1%	0.6%
≥ 1.0 °C	1,004	98.7%	0.1%	1.1%	0.1%	920	99.7%	0.1%	0.2%
≥ 1.5 °C	970	99.4%	0.0%	0.5%	0.1%	889	99.9%	0.0%	0.1%
≥ 2.0 °C	940	99.7%	0.0%	0.3%	0.0%	862	99.9%	0.0%	0.1%

Table 3-14: Days with precipitation by daily minimum temperature, Montreal, 2000-2009

	Weather observed by trained personnel					*Measured precipitation type (≥ 0.2 mm)*			
Daily minimum temperature	***n=***	***Rain***	***Snow***	***Rain with snow***	***Freezing rain***	***n=***	***Rain***	***Snow***	***Rain and snow***
≥ 0 °C	1,133	95.1%	0.9%	3.2%	0.8%	977	96.6%	0.8%	2.6%
≥ 0.5 °C	1,095	97.5%	0.4%	1.6%	0.5%	943	99.0%	0.1%	0.8%
≥ 1.0 °C	1,055	98.6%	0.1%	1.0%	0.3%	907	99.8%	0.0%	0.2%
≥ 1.5 °C	1,024	99.2%	0.0%	0.5%	0.3%	880	100.0%	0.0%	0.0%
≥ 2.0 °C	992	99.5%	0.0%	0.3%	0.2%	853	100.0%	0.0%	0.0%

Table 3-15: Days with precipitation by daily minimum temperature, Quebec City, 2000-2009

	Weather observed by trained personnel					*Measured precipitation type (≥ 0.2 mm)* [a]			
Daily minimum temperature	***n=***	***Rain***	***Snow***	***Rain with snow***	***Freezing rain***	***n=***	***Rain***	***Snow***	***Rain and snow***
≥ 0 °C	1,115	94.5%	0.3%	4.2%	1.0%	145	86.9%	2.8%	10.3%
≥ 0.5 °C	1,076	96.6%	0.2%	2.6%	0.7%	121	94.2%	1.7%	4.1%
≥ 1.0 °C	1,030	98.1%	0.2%	1.3%	0.5%	97	96.9%	2.1%	1.0%
≥ 1.5 °C	997	99.0%	0.1%	0.6%	0.3%	81	97.5%	1.2%	1.2%
≥ 2.0 °C	967	99.6%	0.0%	0.2%	0.2%	69	97.1%	1.4%	1.4%

[a] The counts reported here are extremely low due to poor rain and snow records for Quebec City: 973 days with minimum temperature ≥ 0 °C received measurable precipitation (≥ 0.2 mm); of these, 36 records indicated 0 mm of rain or snow accumulation and 784 had blank (i.e., missing) rain or snow records.

Table 3-16: Days with precipitation by daily minimum temperature, Moncton, 2000-2009

	Weather observed by trained personnel					*Measured precipitation type (≥ 0.2 mm)*			
Daily minimum temperature	***n=***	***Rain***	***Snow***	***Rain with snow***	***Freezing rain***	***n=***	***Rain***	***Snow***	***Rain and snow***
≥ 0 °C	1,109	96.8%	0.2%	2.2%	0.9%	1,020	98.3%	0.1%	1.6%
≥ 0.5 °C	1,055	98.2%	0.1%	1.0%	0.7%	972	99.4%	0.0%	0.6%
≥ 1.0 °C	1,024	98.7%	0.1%	0.6%	0.6%	941	99.6%	0.0%	0.4%
≥ 1.5 °C	988	99.4%	0.1%	0.3%	0.2%	910	99.8%	0.0%	0.2%
≥ 2.0 °C	953	99.8%	0.0%	0.1%	0.1%	875	100.0%	0.0%	0.0%

Table 3-17: Days with precipitation by daily minimum temperature, Halifax, 2000-2009

	Weather observed by trained personnel					*Measured precipitation type (≥ 0.2 mm)*			
Daily minimum temperature	***n=***	***Rain***	***Snow***	***Rain with snow***	***Freezing rain***	***n=***	***Rain***	***Snow***	***Rain and snow***
≥ 0 °C	1,173	96.2%	0.4%	2.6%	0.7%	867	97.8%	0.6%	1.6%
≥ 0.5 °C	1,124	98.0%	0.2%	1.5%	0.4%	830	99.4%	0.0%	0.6%
≥ 1.0 °C	1,077	98.7%	0.2%	0.9%	0.2%	795	99.7%	0.0%	0.3%
≥ 1.5 °C	1,049	99.2%	0.2%	0.5%	0.1%	772	100.0%	0.0%	0.0%
≥ 2.0 °C	1,013	99.6%	0.1%	0.2%	0.1%	742	100.0%	0.0%	0.0%

3.4.2 Event and control definitions

As explained in Section 3.2, the risk analysis is based on the matched-pair approach, whereby precipitation days are compared to dry, seasonal conditions. Days with and without precipitation were identified according to the criteria in Table 3-18. It is important to note that the control days must meet multiple criteria: no precipitation accumulation, no hourly observations of fog, no sustained high winds and mostly dry roads. Also, holidays and other special days (e.g., long weekends, Christmas break) that typically alter traffic patterns were removed from both sets of days, for an average loss of 7-11 % of potential events and controls.

Table 3-18: Criteria used to define events and controls

Event Criteria	• Daily precipitation accumulation of at least 0.4 mm (liquid equivalent) to ensure sufficient moisture to wet roads • Rain or winter precipitation days classified according to daily minimum temperature, as explained in Section 3.4.1 • Holidays and other special days not included
Control Criteria	• Same day-of-week as the event, either one or two weeks prior or following • Daily precipitation accumulation equal to zero • Zero hourly observations of fog • Average hourly wind speed less than 40 km/h • Dry roads reported at the time of collision for at least 85% of collisions • Holidays and other special days not included

Table 3-19 provides a summary of all precipitation event days for the ten-year period, 2000-2009; additional details by precipitation accumulation are provided in Appendix H. The percentage of days meeting the event criteria ranges from 44.5% in Moncton (i.e., 880 rain days + 745 winter precipitation days / 3,653 total days) to 28.0% in Calgary. This is as would be expected, given the wet maritime climate of Moncton and Calgary's drier climate. Conversely, 54.1% of Calgary's total days meet the control criteria (i.e., dry conditions, no active weather), compared to a low of 31.3% in Halifax.

Table 3-19: Days meeting the criteria for events and controls, 2000-2009

	Count of days	*Average hours of observed precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
Rain event days (minimum temperature ≥ 0.5 °C)				
Vancouver	1,419	9.1	7.2	22.6
Calgary	363	8.0	6.2	9.3
Toronto	839	6.7	7.0	61.9
Ottawa	862	6.9	7.6	8.2
Montreal	894	6.9	7.5	23.2
Quebec City	870	7.9	8.4	5.8
Moncton	880	8.4	7.8	1.2
Halifax	733	9.9	12.0	2.6
Winter precipitation event days (minimum temperature < 0.5 °C)				
Vancouver	151	9.4	6.3	20.5
Calgary	353	12.5	2.4	10.0
Toronto	499	9.5	4.1	59.8
Ottawa	626	10.9	4.9	8.0
Montreal	617	11.1	5.8	19.6
Quebec City	748	11.8	5.1	5.0
Moncton	745	11.5	7.0	1.2
Halifax	676	12.2	7.9	2.8
Control days				
Vancouver	1,491			18.8
Calgary	1,383			9.0
Toronto	1,652			52.9
Ottawa	1,388			6.9
Montreal	1,421			21.2
Quebec City	1,157			5.4
Moncton	1,247			1.3
Halifax	1,142			2.6

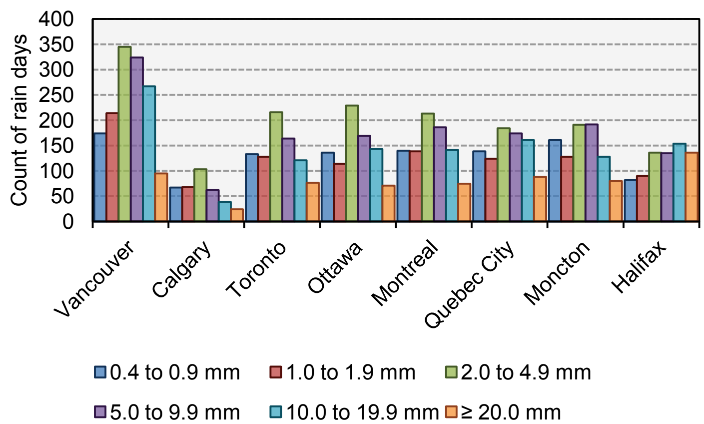
Typically, precipitation occurs during only part of most event days, but winter storms tend to have a longer duration than rain events. At the same time, rain events tend to result in larger precipitation accumulations than winter storms.

The average number of injury collisions per day varies widely from city to city, largely because of differences in population. In Toronto, for example, approximately 60 injury collisions occur each day, whereas in Moncton the average is one injury collision per day. As such, estimates of risk are more reliable for the larger cities. Also apparent in Table 3-19 is the fact that collision counts, on average, are higher during events than during controls – although these aggregate values do not account for day-of-week differences in traffic volumes, something which is indirectly controlled for in matched-pair analysis.

Figure 3-4 and Figure 3-5 summarize how precipitation frequency and amount vary across the study areas. For rainfall:

- Vancouver has both more rain days and many more days with moderate accumulation (2 mm to 19.9 mm) than the other study areas.
- Calgary has the fewest rain days, and many fewer heavy rains (≥ 20 mm per day) than the other study areas.
- Toronto, Ottawa, Montreal, Quebec City and Moncton all have similar distributions by accumulation, with overall fewer rain days than Vancouver but more than Calgary.
- Halifax has the second fewest rain days, but the highest number of days with ≥ 20 mm rainfall.

Figure 3-4: Distribution of rain days by precipitation amount, 2000-2009



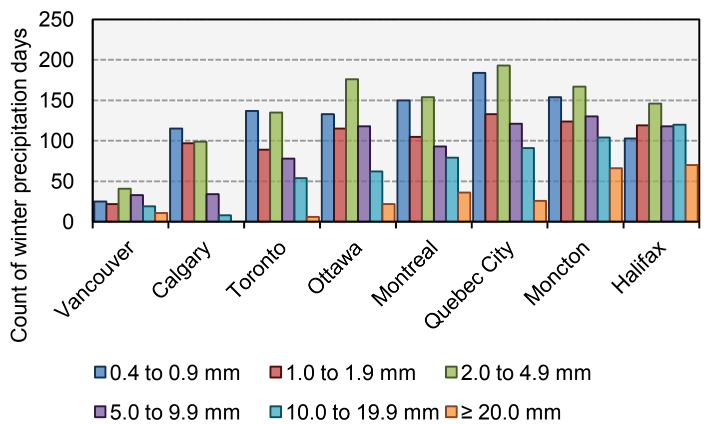
Halifax counts appear lower than would be expected from the 1971-2000 climate normals in Table 3-5 because the normals count a precipitation day as having measurable (i.e., ≥ 0.2 mm) accumulation, rather than the 0.4 mm cutoff used in the risk analysis. Also, many of Halifax's rain days are included in the winter precipitation category due to near-zero temperatures.

For winter precipitation days, the pattern is quite different:

- Vancouver's Pacific Coast climate results in few cold days, and thus few days of winter precipitation. Even when near- or below-freezing temperatures occur, precipitation accumulation tends to be light.
- Calgary experiences much colder temperatures than Vancouver, and thus has more winter precipitation days; but daily accumulation tends to be light to moderate.
- Toronto experiences many winter precipitation days with light and moderate accumulations.

- Ottawa, Montreal and Quebec City are all considerably snowier, and this is reflected by more days with winter precipitation overall and more days with daily accumulations ≥ 10 mm (liquid equivalent).
- The Atlantic Region cities of Moncton and Halifax have similar numbers of winter precipitation as Ottawa, Montreal and Quebec City, but a disproportionate number of days with high accumulations.

Figure 3-5: Distribution of winter precipitation days by precipitation amount, 2000-2009



3.5 Climate simulations

Global climate models (GCMs) are widely used to simulate past, present and future climate. However, due to heavy demand on computing resources, these models employ coarse resolution and thus are not capable of resolving meso-scale climate features (e.g., fronts) or the topographic variations that strongly affect the precipitation regime. Regional climate models (RCMs) were developed as a pragmatic tool to allow reaching higher resolution at an affordable computational cost. As RCMs have their computational domain over a limited area of the globe (e.g., North America), they can employ higher resolution and, for the same computational cost as a GCM, they resolve small-scale meteorological features over the domain of interest.

Simulations coming from both regional and global climate models contain an uncertainty due to the discretization scheme; continuous atmospheric processes are presented on the grid of points with a distance of few tens or hundreds of kilometres between them and evolve over time from one to the next time-step (e.g., 15 minutes). It is clear that some processes can take less than 15 minutes (one time-step of the model) to completely evolve and on a spatial scale smaller than the model's grid-points spacing. An example of one such process is a summer storm. These kinds of processes are called sub-grid processes and they are not resolved in the model, but rather 'parameterized'. This means that only their effects on the state of the atmosphere are taken into account. Employing different parameterization schemes in the model involves another source of uncertainty in climate simulations.

3.5.1 Selection of the simulations

The use of an ensemble of simulations is essential in climate change impact and adaptation studies. In this study we use an ensemble of nine simulations of the Canadian Regional Climate Model (Caya and Laprise, 1999; Music and Caya, 2007) version 4 (CRCM4) provided by Ouranos (Table 3-20). The CRCM4 was driven by three different GCMs:

- CGCM3 – version 3 of Canadian Global Climate Model (McFarlane et al., 2005; Scinocca et al., 2008)
- ECHAM5 – version 5 of German Max Planck Institute for Meteorology model (Roeckner et al., 2006)
- CNRM-CM3 – version 3 of French National Center for Meteorology model (Salas-Mélia et al., 2005)

Table 3-20: Climate simulations used in the study

Simulation reference #	*Driver*	*Driver member*	*Data frequency*	*Emission scenario*
1	CGCM3	5	3h	A2
2	CGCM3	1	6h	A2
3	CGCM3	2	6h	A2
4	CGCM3	3	6h	A2
5	CGCM3	4	6h	A2
6	CNRM-CM3	N/A	6h	A1B
7	ECHAM5	1	6h	A2
8	ECHAM5	2	6h	A2
9	ECHAM5	3	3h	A2

3.5.2 Model uncertainty

The main source of uncertainty in climate projections at the horizon of mid-2050s (i.e., 2041-2070), as suggested by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), is the driving model (GCM). Therefore, as the future period of interest in our study covers these years, the use of such an ensemble created with different GCMs takes this major uncertainty into account. The emission scenarios employed for eight of the nine future simulations is SRES A2, a higher-end emissions scenario characterized by largely independent or self-reliant nations, high population growth and a focus on economic development over social or environmental sustainability (Nakićenović et al., 2000). One of the nine simulations was based on the A1B scenario, which describes a convergent world with low population growth, rapid economic development, and a focus on balanced energy sources; however this simulation was missing records for March in nearly all years for all cities. As such, climate change futures are estimated for the eight simulations using the A2 scenarios. For the reference, the period 1971-2000 was used.

Another important source of uncertainty in simulating climate is natural variability. Two simulations of the same model initialized in slightly different moments (referred to as ‘members’ of the ensemble) will produce different weather patterns. This phenomenon is due to the non-linearity and chaotic nature of the climate system.

As we aim to use the CRCM4 to obtain the possible changes in future climate, we need to evaluate limits of its use on an urban-scale. The variable that we are interested in is precipitation. It has been shown that RCMs do not perform well in simulating extreme precipitation (e.g., Déqué, 2007) which is the product of convection that is not implicitly resolved in the model but rather parameterized (sub-grid process). The further challenge comes from the fact that we compare a grid-cell of the model with point-data (station). The amount of precipitation at the station location is measured over a few centimetres (gauge dimensions) whilst that simulated by the model represents the mean value over the one grid-cell (45 by 45 km). Therefore, it is not surprising that models often underestimate precipitation compared to the station. This is particularly true for extreme events and especially for those of shorter duration such as convective precipitation (e.g., Mailhot et al., 2012).

Figure 3-6: Normalized distribution of daily precipitation obtained from one simulation of CRCM4 compared to that of Toronto Pearson International Airport station for the reference period 1971-2000

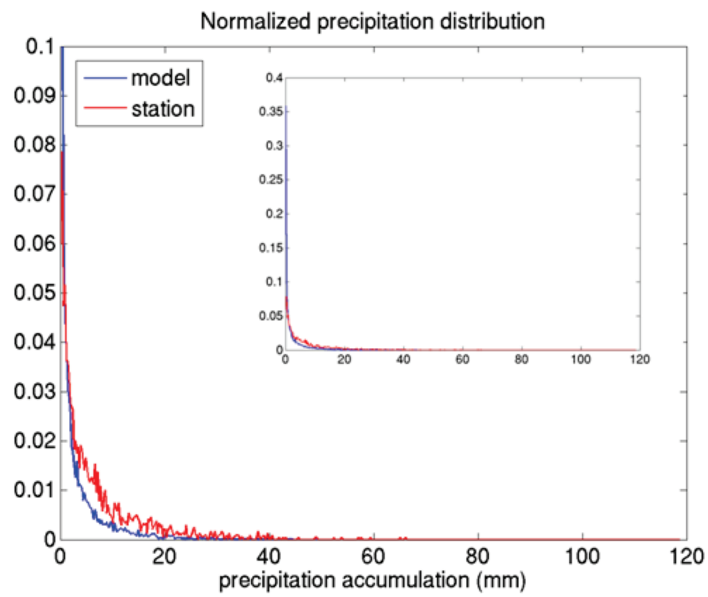
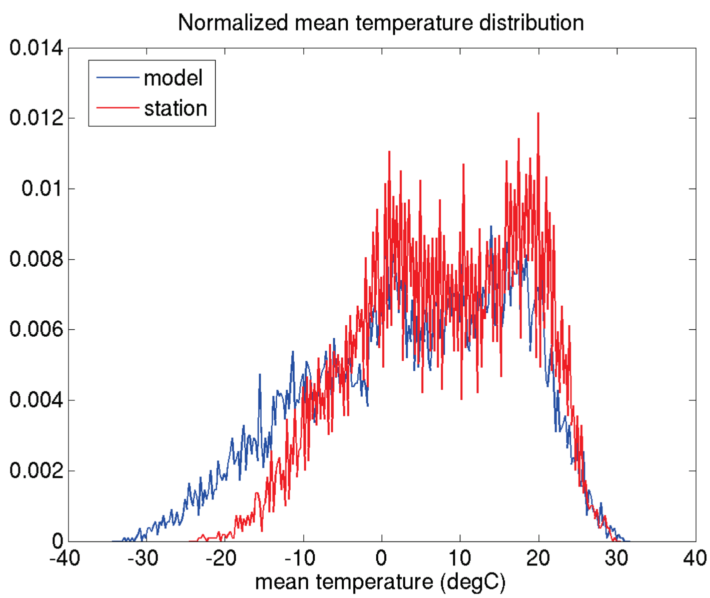


Figure 3-6 presents normalized probability density functions of 30-year series of daily precipitation accumulation obtained from one CRCM4 simulation from Toronto Pearson International Airport station. The normalized distribution (y-axis) represents the number of events having a given precipitation accumulation divided by the total number of events. The normalization was performed because observed and simulated data series don’t have the same length. Thus, in order to be compared on the same graph, normalization was necessary. We can see that CRCM4 generally underestimates precipitation compared to station data, especially for extremely high accumulations. Over a 30-year period (1971-2000) the model does not simulate any event with precipitation higher than 50 millimetres (the blue line falls to zero around 50 mm accumulation value), although such events were in fact observed (the red line has values higher than zero for accumulation values larger than 50 mm). As well, the model produces too many light precipitation events compared to observations (the blue line reaches values close to 0.35 while the red one comes only close to 0.08 for the accumulation values around zero (inner graph)). In other words, light precipitation occurs too often in the model.

In addition, CRCM4 has a cold temperature bias. Figure 3-7 represents the normalized probability density function of a 30-year series of daily mean temperature obtained from one CRCM4 simulation from Toronto Pearson International Airport station. We can see that the model is too cold at extremely low temperatures. Over a 30-year period (1971-2000) the model simulates events with temperatures below -25°C and even below -30°C while such events were not actually observed.

Figure 3-7: Normalized distribution of daily mean temperature obtained from one simulation of CRCM4 compared to that of Toronto Pearson International Airport station for the reference period 1971-2000



Because of this issue, it is recommended to do post-processing of the model raw data. The adjustment (or post-processing) of the simulated data is very important, particularly when analyses are based on a threshold value. This overcomes model biases and incompatibility of its resolution. The post-processing method employed here is a daily scaling method (also called 'quantile-quantile' mapping) introduced by Mpelasoka and Chiew (2009). In this method, for a given climate simulation, differences between future and reference climate are calculated individually for different percentiles of the distribution. Then, those differences are applied to the corresponding percentiles in the observed data series in order to obtain projected climate changes for each percentile rank.

The normalized difference between future and reference daily mean temperature (future minus reference) obtained by applying the daily scaling method for one simulation of CRCM4 for one particular month is shown in Figure 3-8. In this example, we can note that the difference between future and reference mean temperature is not the same for all percentile ranks of the distribution. This conclusion can be generalized to any other month. Even though the temperature increases for all percentiles, the increase is greater for the smallest percentiles (extremely cold events) than for the highest percentiles (extremely hot events), and in this particular case the increase in temperature is smallest around the 40th percentile (i.e., events that occur 40% of the time). Similar conclusions can be drawn for precipitation change; it will be the most pronounced for extremely severe events, i.e., the highest percentiles of the distribution (Figure 3-9).

Figure 3-8: Difference in daily mean temperature between future and reference simulations for different percentiles obtained from the daily scaling method

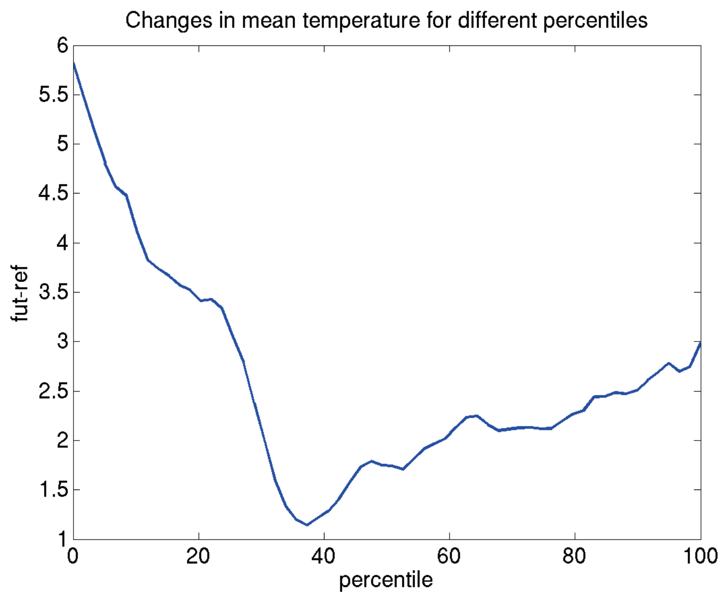
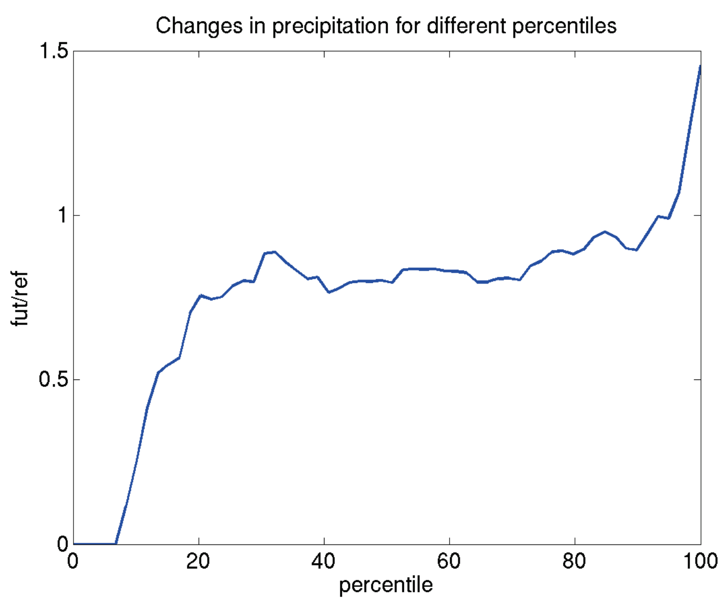


Figure 3-9: Difference in daily precipitation accumulation between future and reference simulations for different percentiles obtained from the daily scaling method



4 Results

This section presents the results of the analysis in five parts:

1. the safety analysis for present-day precipitation-related risks (Tasks 7 and 14);
2. projections of changes in precipitation under climate change (Tasks 12 and 16);
3. the safety analysis for future precipitation-related risks (Tasks 13, 14 and 16);
4. explorations of other weather-related hazards (Task 9); and
5. comparison of collision attributes during precipitation versus dry conditions (Task 11).

4.1 Precipitation-related collision risk, 2000-2009

The safety analysis produces point estimates of relative risk using odds ratios as explained in Section 3.2 and Appendix D. More specifically, each relative risk value provides a best estimate of the risk of injury collision during precipitation as compared to seasonal conditions when the roads are mostly dry and the other control conditions are met (i.e., no measurable precipitation, fog or high winds).

Results of the safety analysis, for all eight cities combined, are provided in Table 4-1. The top row provides information on rain-related travel risks for 5,230 rain days and their matched control days; these estimates are based on more than 185,000 injury collisions that occurred over a 10-year period. Given this large sample size, it is not surprising that the confidence intervals for the point estimates are very narrow; indicating that risk estimates – at the aggregate level – are highly reliable.

Overall, the relative risk on rain days is 1.13, which indicates that, across the eight study areas, collision rates are 13% higher on days with measurable rainfall than on control days. The estimate for PDO collisions is 1.14, and that for collisions resulting in minimal or minor injury only marginally lower (1.12). However, for collisions resulting in major or fatal injury, the estimate is 1.00, which indicates no significant change in serious injury collision rates on rain days versus dry days. This result is not surprising, given what has been found in other studies (Eisenberg, 2004) and given what is known about weather-related travel speed reductions (Hogema, 1996; Unrau and Andrey, 2006; Camacho et al., 2010).

Table 4-1 also provides insights into the progression of risk as daily rainfall amount increases. For the lowest accumulation category (0.4 to 0.9 mm), relative risk values are approximately 1.0, again indicating no significant increase on these rain days. However, as rainfall amount increases (and by extension rainfall duration or intensity also increase), travel risks become elevated. For PDO collisions, the increases are modest at lower rainfall accumulations (1.06 and 1.11 at accumulations of 1.0 to 1.9 mm and 2.0 to 4.9 mm, respectively) but increase significantly for the 45% of rain days with accumulations of 5.0 mm or more. The point estimate for PDO collisions on days with 20 mm or more of rainfall is 1.31. For collisions resulting in minimal or minor injury, risk estimates are not significantly elevated until daily accumulations reach at least 2.0 mm, at which point relative risks mirror those for PDO collisions. For all rainfall accumulation categories, relative risk is not significantly above 1.0 for major and fatal collisions.

Table 4-1: Daily risk estimates (with 95% confidence intervals in brackets) for different collision severities, 8 cities combined, 2000-2009

Daily precipitation type/amount	*Matched pair count*	*Total collisions*	*Property-damage-only collisions*	*Injury collisions*	*Minimal or minor injury*	*Major or fatal injury*
Rain days (minimum temperature ≥ 0.5 °C)						
All amounts (≥ 0.4 mm)	5,230	1.13 (1.13-1.14)	1.14 (1.13-1.14)	1.12 (1.11-1.13)	1.12 (1.11-1.13)	1.00 (0.96-1.03)
0.4 to 0.9 mm	800	1.01 (0.99-1.03)	1.02 (1.00-1.04)	0.99 (0.97-1.02)	1.01 (0.98-1.04)	0.94 (0.85-1.03)
1.0 to 1.9 mm	787	1.04 (1.02-1.06)	1.06 (1.03-1.08)	1.01 (0.99-1.04)	1.01 (0.98-1.05)	0.92 (0.84-1.01)
2.0 to 4.9 mm	1,229	1.11 (1.10-1.12)	1.11 (1.10-1.12)	1.09 (1.07-1.12)	1.09 (1.07-1.11)	0.98 (0.91-1.06)
5.0 to 9.9 mm	1,068	1.17 (1.16-1.18)	1.17 (1.16-1.19)	1.16 (1.14-1.18)	1.16 (1.14-1.18)	1.01 (0.93-1.09)
10.0 to 19.9 mm	862	1.24 (1.21-1.26)	1.24 (1.21-1.26)	1.22 (1.19-1.26)	1.21 (1.17-1.25)	1.10 (1.01-1.20)
≥ 20.0 mm	484	1.31 (1.27-1.34)	1.31 (1.27-1.35)	1.28 (1.23-1.33)	1.28 (1.23-1.34)	1.08 (0.96-1.22)
Winter precipitation days (minimum temperature < 0.5 °C)						
All amounts (≥ 0.4 mm)	2,229	1.40 (1.39-1.41)	1.44 (1.43-1.45)	1.22 (1.20-1.24)	1.22 (1.20-1.24)	1.06 (1.00-1.12)
0.4 to 0.9 mm	490	1.15 (1.11-1.19)	1.18 (1.14-1.22)	1.05 (1.01-1.10)	1.05 (1.00-1.10)	0.94 (0.83-1.06)
1.0 to 1.9 mm	418	1.28 (1.23-1.34)	1.31 (1.25-1.37)	1.15 (1.10-1.21)	1.15 (1.09-1.22)	0.99 (0.87-1.14)
2.0 to 4.9 mm	544	1.35 (1.30-1.41)	1.40 (1.34-1.46)	1.23 (1.18-1.29)	1.21 (1.16-1.27)	1.16 (1.03-1.29)
5.0 to 9.9 mm	370	1.37 (1.31-1.45)	1.41 (1.33-1.49)	1.27 (1.20-1.34)	1.26 (1.18-1.34)	1.09 (0.94-1.26)
10.0 to 19.9 mm	289	1.46 (1.38-1.55)	1.51 (1.42-1.62)	1.36 (1.26-1.46)	1.33 (1.23-1.44)	1.15 (0.97-1.37)
≥ 20.0 mm	118	1.35 (1.21-1.51)	1.40 (1.24-1.59)	1.35 (1.23-1.49)	1.25 (1.10-1.42)	1.05 (0.77-1.42)

During winter precipitation events (i.e., days with at least 0.4 mm precipitation and minimum temperature below 0.5 degrees Celsius), collision risk is considerably more elevated than what was found for rainfall. The overall relative risk estimate for PDO collisions is 1.44 and that for injury collisions is 1.22. Risks are significantly above 1.00 even for small precipitation accumulations. In fact, there is no clear progression in risk as daily accumulations exceed 2.0 mm (liquid precipitation equivalent). Risks during winter precipitation events are also significantly elevated for major and fatal collisions, albeit to a lesser extent; the risk estimate is 1.06 and there is no clear progression in risk as precipitation amount increases. This suggests some degree of driver adjustment to the most hazardous driving conditions.

Table 4-2 also provides risk estimates for winter precipitation, this time based on different temperature categories. For those winter precipitation days with minimum temperature near or below freezing (i.e., < 0.5 °C) but maximum temperature several degrees above zero (i.e., ≥ 3 °C), the relative risk is 1.14 for PDOs and 1.12 for minimal or minor injury. Both estimates are significantly above the baseline value of 1.00, but they are not highly elevated. This is because, during many of these events, snow does not accumulate on the road because of higher air or pavement temperatures (especially in autumn or spring). For example, one-third of these events occurred before December 1, and an additional one-quarter occurred in the spring months of April and May. Also, many of these days had precipitation other than snowfall; 35% were rainfall only, 32% had both rain and snow observed, 19% were characterized by freezing rain and < 12% were snowfall only. When the maximum daily temperature is below 1 °C, relative risks are significantly elevated for PDOs (1.53 to 1.69 depending on the temperature), and appear to be higher for minimal and minor injuries as well, although in the latter case, confidence intervals are comparatively wide because of smaller sample sizes.

Table 4-2: Daily risk estimates (with 95% confidence intervals in brackets) for different collision severities, by daily maximum temperature, 8 cities combined, 2000-2009

Daily maximum temperature	*Matched pair count*	*Total collisions*	*Property-damage-only collisions*	*Injury collisions*	*Minimal or minor injury*	*Major or fatal injury*
Winter precipitation days (minimum temperature < 0.5 °C)						
≥ 3 °C	1,007	1.13 (1.10-1.16)	1.14 (1.11-1.17)	1.13 (1.10-1.17)	1.12 (1.08-1.16)	1.02 (0.93-1.11)
≥ 2 °C to < 3 °C	186	1.27 (1.18-1.36)	1.30 (1.20-1.40)	1.19 (1.11-1.28)	1.18 (1.09-1.28)	1.23 (1.00-1.51)
≥ 1 °C to < 2 °C	183	1.29 (1.21-1.39)	1.36 (1.26-1.47)	1.13 (1.06-1.20)	1.09 (1.00-1.18)	0.95 (0.77-1.16)
≥ 0 °C to < 1 °C	176	1.47 (1.37-1.57)	1.53 (1.42-1.64)	1.26 (1.16-1.36)	1.22 (1.11-1.33)	1.05 (0.85-1.31)
≥ -1 °C to < 0 °C	137	1.57 (1.44-1.71)	1.63 (1.49-1.79)	1.29 (1.17-1.43)	1.29 (1.15-1.44)	1.02 (0.81-1.29)
≥ -2 °C to < -1 °C	112	1.51 (1.36-1.67)	1.58 (1.41-1.77)	1.40 (1.27-1.55)	1.39 (1.25-1.54)	1.10 (0.86-1.42)
≥ -3 °C to < -2 °C	65	1.60 (1.41-1.81)	1.67 (1.46-1.90)	1.35 (1.18-1.54)	1.34 (1.14-1.56)	1.37 (1.01-1.87)
< -3 °C	363	1.60 (1.53-1.68)	1.69 (1.61-1.78)	1.26 (1.18-1.34)	1.28 (1.20-1.37)	1.07 (0.94-1.23)

In the next two tables, we present the results of the risk analysis for individual study areas. Table 4-3 shows the number of matched event-control pairs for each city. The number of matched rain days, over the 10-year study period, varies from a low of 316 in Calgary to a high of 874 in Vancouver. The number of matched winter precipitation days is much less, ranging from 46 in Vancouver to 433 in Moncton. These variations reflect differences in regional climates, as well as some random variations associated with the matching exercise. There are also differences in the number of injury collisions on which risk estimates are based – partly because of variations in the number of matched events but also because of differences in population; these translate into differences in the absolute frequency of injury collisions. For example, for rain-related risk, Toronto's estimates are based on 715 rain days and nearly 85,000 injury collisions; whereas those for Moncton are based on nearly as many rain days but fewer than 2,000 injury collisions. As a result, risk estimates are more reliable for Toronto than for Moncton. For winter precipitation, Vancouver experiences few days with measurable snowfall or freezing rain; thus it is not surprising that Vancouver's risk estimates for winter precipitation are based on only 46 event days, and fewer than 2,000 injury collisions. This stands in contrast to both Toronto and Montreal, with between 260 and 300 winter precipitation days and tens of thousands of related injury collisions.

Table 4-3: Summary of the data used in the safety analysis, 2000-2009

Daily precipitation type/amount	*Vancouver*	*Calgary*	*Toronto*	*Ottawa*	*Montreal*	*Quebec City*	*Moncton*	*Halifax*
# injury collisions that occurred during matched precipitation events and their controls								
Rain	35,776	6,207	84,813	11,008	34,725	8,074	1,740	2,838
Winter precipitation	1,688	5,090	33,193	4,249	10,156	2,126	1,047	2,051
# matched rain days (minimum temperature ≥ 0.5 °C)								
All amounts (≥ 0.4 mm)	874	316	715	692	760	702	663	508
0.4 to 0.9 mm	117	56	107	109	117	115	123	56
1.0 to 1.9 mm	138	61	113	87	123	99	98	68
2.0 to 4.9 mm	217	90	189	181	177	138	150	87
5.0 to 9.9 mm	206	51	133	138	159	154	137	90
10.0 to 19.9 mm	148	35	108	118	116	126	99	112
≥ 20.0 mm	48	23	65	59	68	70	56	95
# matched winter precipitation days (minimum temperature < 0.5 °C)								
All amounts (≥ 0.4 mm)	46	276	300	297	263	228	433	386
0.4 to 0.9 mm	6	83	80	64	56	55	86	60
1.0 to 1.9 mm	11	74	52	59	46	35	71	70
2.0 to 4.9 mm	9	83	87	71	65	50	104	75
5.0 to 9.9 mm	14	30	46	53	38	46	73	70
10.0 to 19.9 mm	5	6	31	41	42	35	63	66
≥ 20.0 mm	1	0	4	9	16	7	36	45

Table 4-4 provides the risk estimates for each of the study areas, which highlight that there are regional differences in the extent to which injury collision rates are affected by precipitation. Vancouver has the highest point estimates – 1.23 for rain days and 1.27 for winter precipitation days. Toronto and Ottawa are similar to one another, overall: for rain days, their relative risks are 1.12 and 1.10, respectively, and for winter precipitation days the values are 1.26 and 1.24. Montreal has marginally lower risk estimates than either Toronto or Ottawa. Both Calgary and Quebec City have elevated risk levels on winter precipitation days but no significant increases during rainfall. The cities of Moncton and Halifax show no significant increase on either rain or winter precipitation days. This may, in part, be due to the smaller populations of these cities and the associated challenges of defining accurate and reliable estimates of risk. It may also reflect regional acclimatization to weather.

Table 4-4: Daily risk estimates (with 95% confidence intervals in brackets) for injury collisions, 2000-2009

Daily precipitation type/amount	*Vancouver*	*Calgary*	*Toronto*	*Ottawa*	*Montreal*	*Quebec City*	*Moncton*	*Halifax*
Rain days (minimum temperature ≥ 0.5 °C)								
All amounts (≥ 0.4 mm)	1.23 (1.20-1.27)	0.94 (0.89-0.99)	1.12 (1.10-1.14)	1.10 (1.06-1.14)	1.07 (1.04-1.09)	1.02 (0.97-1.07)	0.95 (0.86-1.05)	1.03 (0.96-1.12)
0.4 to 0.9 mm	1.01 (0.94-1.08)	0.86 (0.76-0.97)	1.00 (0.95-1.05)	0.96 (0.86-1.06)	1.03 (0.98-1.09)	0.90 (0.80-1.01)	0.96 (0.76-1.21)	0.95 (0.74-1.22)
1.0 to 1.9 mm	1.07 (1.01-1.13)	0.88 (0.79-0.99)	1.05 (1.00-1.11)	0.96 (0.86-1.08)	0.97 (0.91-1.03)	0.96 (0.85-1.08)	0.89 (0.69-1.16)	1.00 (0.81-1.25)
2.0 to 4.9 mm	1.19 (1.13-1.25)	0.96 (0.87-1.06)	1.12 (1.08-1.15)	1.08 (0.99-1.16)	1.01 (0.96-1.07)	1.00 (0.90-1.11)	0.83 (0.67-1.02)	1.02 (0.83-1.25)
5.0 to 9.9 mm	1.31 (1.25-1.38)	0.97 (0.85-1.10)	1.15 (1.11-1.20)	1.14 (1.05-1.24)	1.10 (1.04-1.17)	1.00 (0.91-1.11)	1.02 (0.83-1.25)	0.90 (0.75-1.08)
10.0 to 19.9 mm	1.44 (1.36-1.52)	1.00 (0.86-1.16)	1.17 (1.12-1.23)	1.27 (1.14-1.41)	1.14 (1.07-1.22)	1.15 (1.03-1.28)	0.90 (0.69-1.18)	1.10 (0.94-1.29)
≥ 20.0 mm	1.56 (1.44-1.70)	1.10 (0.91-1.32)	1.26 (1.18-1.35)	1.22 (1.08-1.39)	1.24 (1.14-1.35)	1.15 (1.00-1.32)	1.31 (0.95-1.81)	1.18 (0.98-1.41)
Winter precipitation days (minimum temperature < 0.5 °C)								
All amounts (≥ 0.4 mm)	1.27 (1.13-1.44)	1.22 (1.13-1.30)	1.26 (1.21-1.31)	1.24 (1.15-1.34)	1.12 (1.07-1.18)	1.11 (1.01-1.21)	0.98 (0.87-1.12)	1.04 (0.95-1.15)
0.4 to 0.9 mm	1.19 (0.76-1.84)	1.03 (0.92-1.14)	1.06 (1.00-1.14)	1.12 (0.98-1.29)	1.04 (0.93-1.15)	0.96 (0.80-1.16)	0.89 (0.68-1.16)	1.01 (0.80-1.27)
1.0 to 1.9 mm	1.10 (0.89-1.34)	1.28 (1.12-1.47)	1.14 (1.04-1.24)	1.28 (1.10-1.48)	1.11 (1.01-1.23)	1.01 (0.79-1.31)	1.00 (0.74-1.36)	1.01 (0.80-1.28)
2.0 to 4.9 mm	1.35 (1.10-1.66)	1.31 (1.15-1.50)	1.37 (1.28-1.46)	1.15 (0.97-1.36)	1.07 (0.98-1.18)	1.01 (0.80-1.29)	0.95 (0.73-1.24)	0.94 (0.77-1.16)
5.0 to 9.9 mm	1.26 (1.05-1.50)	1.26 (1.01-1.57)	1.33 (1.19-1.48)	1.32 (1.14-1.52)	1.15 (1.03-1.27)	1.28 (1.05-1.56)	1.08 (0.80-1.48)	1.23 (0.99-1.52)
10.0 to 19.9 mm	2.05 (1.48-2.84)	2.04 (1.36-3.07)	1.61 (1.40-1.85)	1.37 (1.10-1.70)	1.22 (1.06-1.40)	1.25 (1.00-1.56)	1.05 (0.77-1.44)	1.08 (0.87-1.35)
≥ 20.0 mm	--	--	1.50 (1.03-2.18)	1.60 (0.89-2.88)	1.42 (1.22-1.65)	1.29 (0.80-2.08)	1.00 (0.61-1.64)	1.00 (0.76-1.32)

4.2 Projected climate change impacts, 2050s

Having established that collision risks tend to increase on days with measurable precipitation, and that there are regional differences in associated risks, the next section begins the process of looking ahead to the implications of climate change for road safety in these different cities of Canada. This part of the analysis is restricted to six cities only: Vancouver, Calgary, Toronto, Montreal, Quebec City and Halifax.

As noted in Section 3.5.1, an ensemble of climate change projections was used in order to quantify the extent to which climate change is likely to affect road safety in the 2050s. Each climate change simulation provides an independent estimate of the relative frequency with which different weather conditions will occur in the future. Table 4-5 shows the main changes in climate that are expected in the coming decades for three of the simulations; details on all of the models runs are provided in Appendix I. The low estimate represents the projection that shows the greatest reduction (or smallest increase) in weather-related injury collisions. The high estimate represents the projection that is associated with the largest increase (or smallest reduction) in weather-related injury collisions. The median estimate is as the name suggests; half the projections are higher and half are lower.

Table 4-5: Projections of climate change, 1971-2000 to 2041-2070

Simulation (reference # in brackets) [a]	***Δ annual mean temperature (°C)***	***Δ annual total precipitation (mm)***	***Δ annual total precipitation (%)***	***Δ annual precipitation days ≥ 1 mm***
Vancouver				
Low (9)	+1.7	+38.4	+3.2%	-1.7
Median (3)	+2.4	+112.2	+9.4%	-1.5
High (4)	+2.0	+166.2	+13.9%	+0.1
Calgary				
Low (9)	+1.9	-6.9	-1.7%	-1.9
Median (4)	+1.9	+34.4	+8.4%	+1.3
High (8)	+1.9	+62.5	+15.2%	+2.0
Toronto				
Low (1)	+3.6	+65.5	+8.3%	+0.3
Median (3)	+3.7	+88.4	+11.1%	+0.3
High (2)	+3.1	+60.7	+7.7%	-0.8
Montreal				
Low (5)	+3.1	+50.0	+5.1%	-5.9
Median (9)	+2.6	+80.8	+8.2%	-4.4
High (7)	+2.3	+104.3	+10.6%	-5.2
Quebec City				
Low (3)	+3.1	+128.2	+12.6%	+1.5
Median (8)	+2.4	+150.1	+14.8%	-0.3
High (9)	+2.4	+121.2	+12.0%	+0.6
Halifax				
Low (2)	+2.7	+121.2	+8.4%	+1.3
Median (9)	+2.3	+20.8	+1.4%	-3.6
High (4)	+3.0	+170.3	+11.8%	+0.2

[a] Projected changes in safety were ranked; the low and high estimates represent the simulations that show the greatest reduction (or smallest increase) and largest increase (or smallest reduction), respectively, in weather-related injury collisions.

As expected, all of the simulations project warming, as indicated by the column that specifies anticipated changes in annual mean temperature. Expected changes in annual total precipitation are also mostly positive, consistent with the review in Section 2.7.1. Expected changes in annual precipitation days are more variable. In fact, for five of the six study areas (not Montreal), the different simulations have different bottom lines, with one model suggesting an increase in precipitation days and another indicating a decrease in precipitation days. This is a reasonable outcome, given that the change in frequency of precipitation is expected to be small. For Montreal, all projections indicate that there will be fewer precipitation days in the future. Mean monthly climate changes (from present) are depicted in graphical form in Figure 4-1to Figure 4-6.

Figure 4-1: Projections of climate change by month, Vancouver, 1971-2000 to 2041-2070

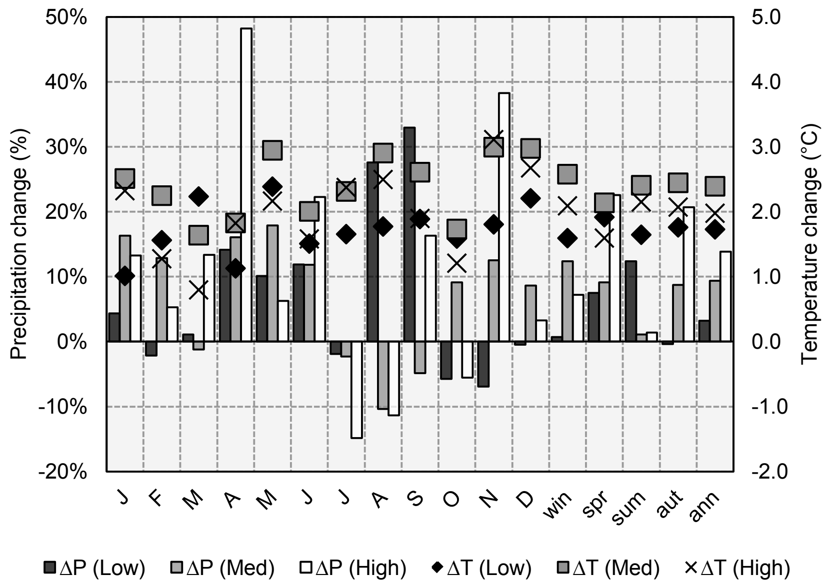


Figure 4-2: Projections of climate change by month, Calgary, 1971-2000 to 2041-2070

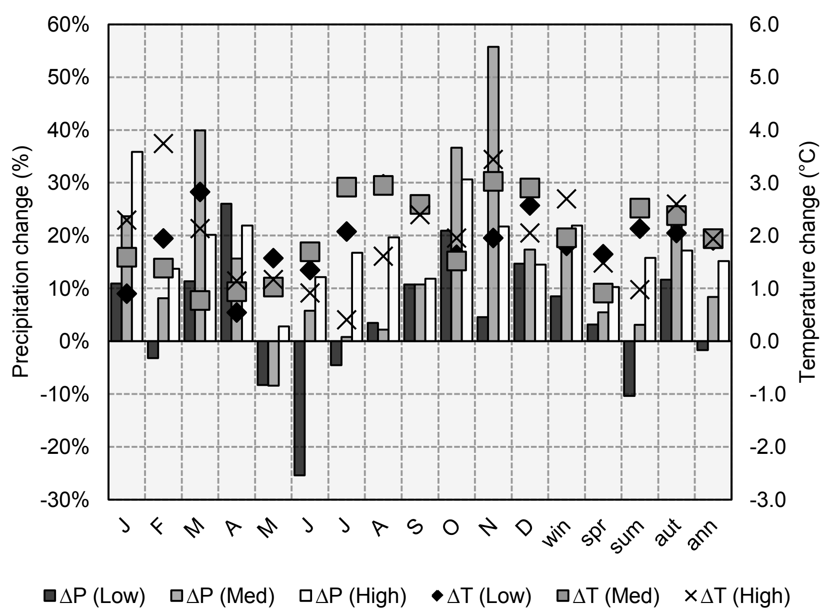


Figure 4-3: Projections of climate change by month, Toronto, 1971-2000 to 2041-2070

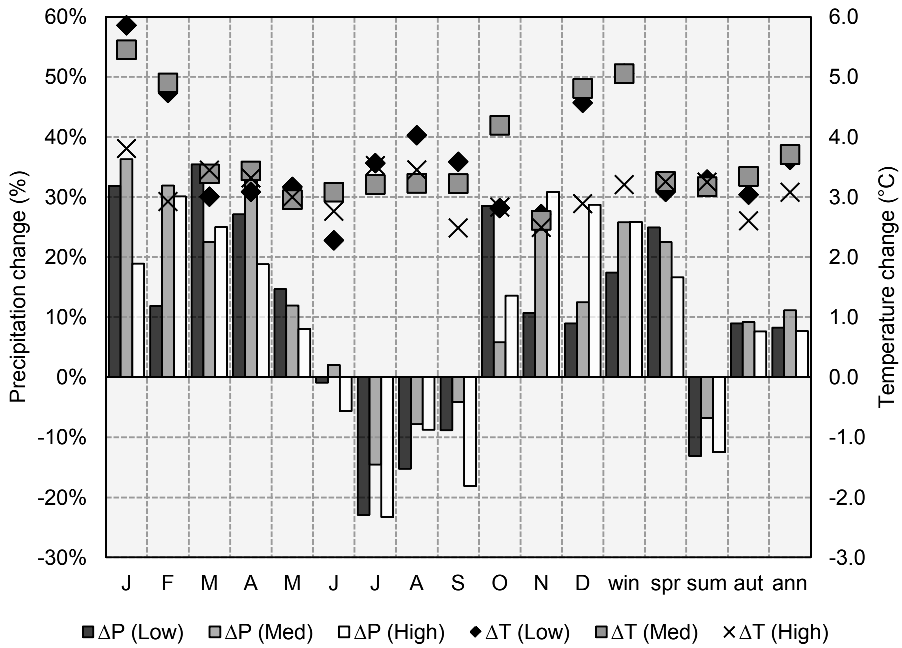


Figure 4-4: Projections of climate change by month, Montreal, 1971-2000 to 2041-2070

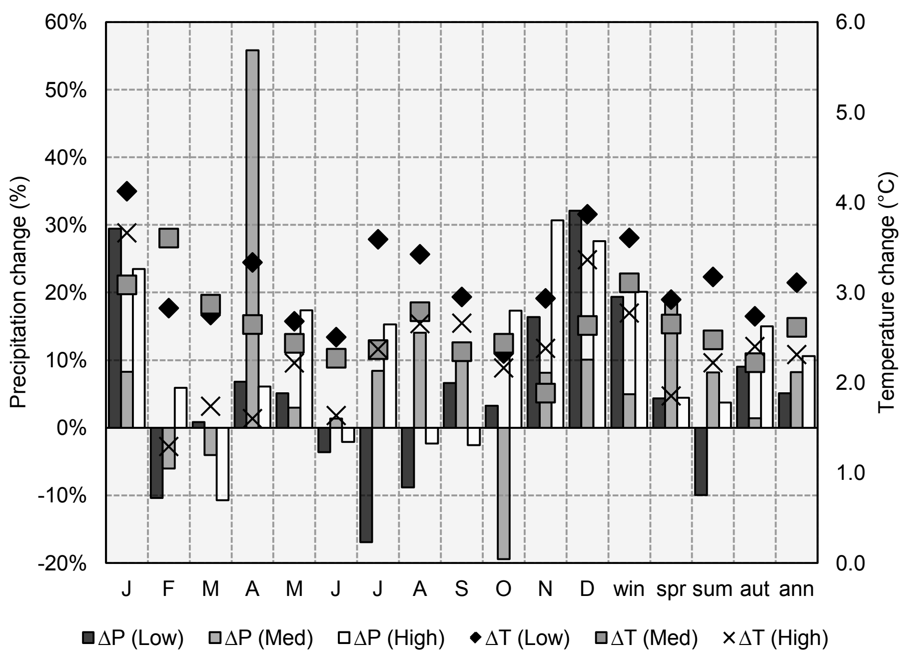


Figure 4-5: Projections of climate change by month, Quebec City, 1971-2000 to 2041-2070

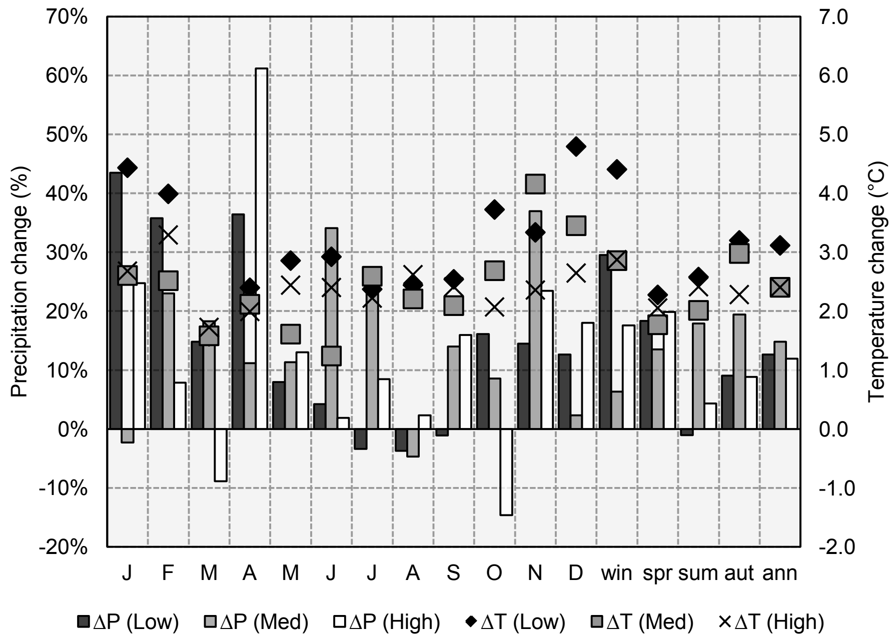
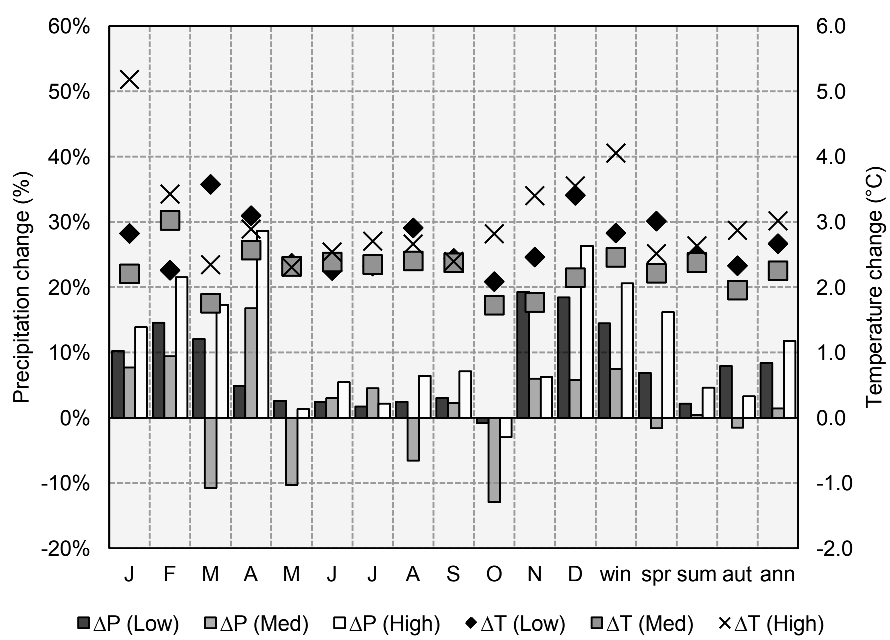


Figure 4-6: Projections of climate change by month, Halifax, 1971-2000 to 2041-2070



Given that precipitation amount is expected to increase, but the frequency of precipitation days may either increase or decrease, the safety effects of climate change will depend on the nature of changes in each region. Table 4-6 summarizes both current precipitation days and projections of future precipitation days, based on both precipitation form (rain or winter) and daily accumulation/amount (five categories).

Table 4-6: Average annual days with precipitation, 1971-2000 and 2041-2070

	Rain days by precipitation amount (mm)					***Winter precipitation days by precipitation amount (mm)***					***All precipitation days (sum)***
Simulation (reference # in brackets) [a]	***1.0 - 1.9***	***2.0 - 4.9***	***5.0 - 9.9***	***10.0 - 19.9***	***≥ 20.0***	***1.0 - 1.9***	***2.0 - 4.9***	***5.0 - 9.9***	***10.0 - 19.9***	***≥ 20.0***	
Vancouver											
1971-2000 normals	17.3	34.5	31.7	27.0	12.4	2.4	4.1	3.0	2.3	0.9	135.5
Change in annual # days, 2041-2070, relative to 1971-2000 normals											
Low (9)	+0.8	+0.1	+3.1	+1.6	+1.2	-1.7	-2.6	-2.1	-1.6	-0.6	-1.7
Median (3)	+0.6	-1.0	+1.8	+3.4	+3.5	-1.7	-3.2	-2.3	-1.9	-0.7	-1.5
High (4)	-0.2	+0.4	-0.2	+4.5	+4.5	-1.7	-2.7	-2.2	-1.6	-0.7	+0.1
Calgary											
1971-2000 normals	8.8	13.2	9.7	6.5	2.7	11.5	11.5	3.7	1.4	0.2	69.2
Change in annual # days, 2041-2070, relative to 1971-2000 normals											
Low (9)	+1.5	+0.6	+1.8	-0.1	-0.5	-3.0	-0.8	-0.8	-0.3	-0.1	-1.9
Median (4)	+1.1	+1.4	+0.3	+0.9	+0.2	-1.8	-0.8	+0.3	-0.2	-0.1	+1.3
High (8)	-0.2	+1.3	+1.0	+1.1	+1.2	-0.8	-0.6	-0.4	-0.3	-0.1	+2.0
Toronto											
1971-2000 normals	11.4	19.6	15.8	12.6	6.5	9.6	12.8	8.6	4.4	1.2	102.6
Change in annual # days, 2041-2070, relative to 1971-2000 normals											
Low (1)	+2.9	+3.0	+5.0	+3.7	+1.0	-3.2	-5.9	-4.0	-1.7	-0.5	+0.3
Median (3)	+3.1	+4.2	+2.5	+4.1	+2.4	-4.4	-5.2	-4.4	-1.6	-0.4	+0.3
High (2)	+2.4	+1.9	+2.8	+1.6	+1.7	-3.8	-3.8	-3.0	-0.3	-0.2	-0.8
Montreal											
1971-2000 normals	12.8	21.3	17.0	14.1	7.4	12.0	15.8	10.7	7.9	3.1	122.0
Change in annual # days, 2041-2070, relative to 1971-2000 normals											
Low (5)	+1.8	+1.5	+1.4	+2.4	+1.3	-3.8	-5.7	-3.2	-1.7	+0.1	-5.9
Median (9)	+0.6	+1.8	-0.3	+1.0	+3.5	-2.3	-2.9	-3.5	-2.0	-0.4	-4.4
High (7)	-1.6	+0.3	+0.4	+1.2	+3.0	-3.5	-2.6	-2.1	-0.8	+0.5	-5.2
Quebec City											
1971-2000 normals	8.6	16.2	14.8	13.1	8.9	11.2	18.3	11.7	8.9	3.3	115.0
Change in annual # days, 2041-2070, relative to 1971-2000 normals											
Low (3)	+2.4	+2.5	+1.7	+2.1	+2.7	-1.2	-4.7	-2.7	-2.0	+0.6	+1.5
Median (8)	+0.7	+2.1	+2.9	+3.7	+3.1	-3.6	-4.4	-2.4	-2.3	-0.1	-0.3
High (9)	+1.0	+0.0	+3.1	+1.9	+2.9	-0.9	-5.5	-0.7	-1.0	-0.1	+0.6
Halifax											
1971-2000 normals	9.6	17.0	15.0	14.5	12.9	11.8	15.6	12.2	11.4	8.7	128.7
Change in annual # days, 2041-2070, relative to 1971-2000 normals											
Low (2)	+3.7	+3.1	+3.5	+5.1	+4.3	-2.4	-4.1	-6.2	-4.5	-1.2	+1.3
Median (9)	+1.4	+2.5	+2.6	+3.0	+3.2	-1.5	-4.3	-4.3	-4.0	-2.1	-3.6
High (4)	+1.4	+4.2	+3.3	+5.6	+4.2	-4.3	-4.5	-4.3	-4.3	-1.2	+0.2

[a] Projected changes in safety were ranked; the low and high estimates represent the simulations that show the greatest reduction (or smallest increase) and largest increase (or smallest reduction), respectively, in weather-related injury collisions.

In terms of present climate (1971-2000 normals):

- Vancouver has a Pacific coast climate, and experiences an average of 136 days per year where precipitation accumulation is at least 1 mm. The vast majority of these are rain days.
- Calgary has a Prairie climate, and experiences an average of 69 days per year where precipitation accumulation is at least 1 mm. Forty-one of these are rain days and 28 are winter precipitation days.
- Toronto is located in the Great Lakes-St. Lawrence climatic region, and experiences an average of 103 days per year where precipitation accumulation is at least 1 mm. Nearly two-thirds of these are rain days and the remainder are winter precipitation days.
- Montreal is also located in the Great Lakes-St. Lawrence climatic region. Montreal experiences an average of 122 days per year with precipitation accumulation of 1 mm or more. Of these, 50 are winter precipitation days and the remainder are rain days.
- Quebec City is also located in the Great Lakes-St. Lawrence climatic region and experiences an average of 115 days per year where precipitation accumulation is at least 1 mm. Of these, 53 are winter precipitation days and the remainder are rain days.
- Halifax has an Atlantic climate and experiences an average of 129 days per year where precipitation accumulation is at least 1 mm. Of these, 69 are rain days and 60 are winter precipitation days.

In the 2050s, the six study areas are expected to experience very similar numbers of precipitation days overall as what they currently experience. However, the model data suggest that we should expect that each of these regions will experience changes in the frequency with which precipitation days of different forms and amounts occur. All of the study areas are likely to experience fewer days with winter precipitation and more days with rainfall. Also, most models indicate that the number of days with rainfall accumulations of 10 mm or more will increase, and this holds true for all six study areas. This has implications for road safety, as summarized in Table 4-7 and as discussed below. Indeed, any changes in road safety are more likely to be associated with changes in precipitation form and/or amount than with the frequency of precipitation days.

Table 4-7 provides estimates of how changing precipitation regimes are expected to affect road safety in the six study areas. Interpretations also require backward reference to Table 4-4 and Table 4-6.

- Overall, climate change is expected to have regionally specific effects on road safety in Canadian cities. The net effect, which considers changes in the frequency, form and intensities of precipitation days, varies from a reduction of 118 injury collisions per year in Toronto to an increase of 29 injury collisions per year in Vancouver. These estimates, however, assume constant population and travel, and no substantive changes in road safety levels overall – issues that are taken up in the final section of the report.
- In Vancouver, climate change is likely to result in a small increase in injury collisions because of an increase in the number of days with moderate (5 to 9.9 mm, and 10.0 to 19.9 mm) and heavy (≥ 20.0 mm) rainfall. All of the models suggest that these days of moderate or heavy rainfall will increase by as many as 6 to 9 days per year (from the current normal of 71 days per year), but this will be partially offset by fewer days with winter precipitation. Indeed, climate change

projections suggest that Vancouver is likely to experience only 3 or 4 winter precipitation days per year in the 2050s, down from 13 days per year in the current normal.

- In Calgary, climate change is expected to result in a small decrease in injury collisions, from 6 to 16 fewer per year, because of fewer days with winter precipitation (2 to 5 fewer days per year, depending on the model; the average for the current normal is 28 days per year). A small increase in rain days of all amounts is also expected, but these have much less effect on injury collisions than do changes in winter precipitation, because of the significantly higher risk levels in Calgary during winter precipitation.
- In Toronto, climate change is expected to produce a safety benefit – between 65 and 118 fewer injury collisions per year. This is because of fewer days with winter precipitation (between 11 and 16 fewer per year; the average days currently is 37). An almost identical increase in rain days is expected (10 to 16 more per year). However, travel risks are higher in Toronto during winter precipitation than during rainfall, which accounts for the overall safety improvement.
- In Montreal, the implications of climate change for injury collisions are less clear. Injury collisions may be reduced (up to 12 fewer injury collisions per year) or increased (up to 8 more injury collisions per year). The models are in agreement that there will be fewer winter precipitation days and more rain days in the future. There is also consistency in projections of modest increases in the number of moderate and heavy rain days. Differences in safety outcomes are mainly due to the extent to which these heavier rain days are expected to change. Some models project increases of 3 or 4 days per year with rainfall $\geq$ 20 mm rain, which largely offsets the safety benefit of fewer snow days. In other cases, heavy rains are expected to increase by only one day per year even while winter precipitation days of various accumulations decrease.
- Quebec City is expected to experience virtually no change in weather-related injury collisions under climate change (from a decrease of 2 to an increase of 1 injury collision per year). All models project that winter precipitation days will decline and rain days will increase by the 2050s. These decreases in winter precipitation events and increases in rain days are expected across the entire range of accumulation amounts, with the net effect that the total number of precipitation days is essentially the same as under current climate (115 days per year). Also, the relative risks in Quebec City are close to 1.0 for light precipitation and less elevated at higher precipitation amounts than what occurs for Vancouver, Toronto and Montreal.
- Finally, Halifax, which currently experiences more precipitation days than any of the other study areas except Vancouver, and has an almost equal number of rain days and winter precipitation days, is not likely to be affected by climate change in a significant way. At present, relative risk levels during inclement weather are modest. As well, while increases in moderate and heavy rain are expected for Halifax, these will be offset by fewer winter precipitation days of moderate accumulations. As such, the net effect on injury collisions is virtually zero.

Table 4-7: Average annual change in injury collisions associated with future climate

Simulation (reference # in brackets) [a]	*# injury collisions on rain days by precipitation amount (mm)*					*# injury collisions on winter precipitation days by precipitation amount (mm)*					*Sum of injury collisions on days with*		
	1.0 - 1.9	*2.0 - 4.9*	*5.0 - 9.9*	*10.0 - 19.9*	*≥ 20.0*	*1.0 - 1.9*	*2.0 - 4.9*	*5.0 - 9.9*	*10.0 - 19.9*	*≥ 20.0*	*Rain*	*Winter precipitation*	*All days*
Vancouver													
Low (9)	+1.0	+0.2	+17.7	+12.6	+12.4	-3.0	-14.7	-8.7	-16.9	-6.1	+44.0	-49.3	-5.4
Median (3)	+0.7	-3.4	+10.0	+27.1	+35.6	-3.0	-17.6	-9.8	-20.8	-7.2	+70.0	-58.5	+11.5
High (4)	-0.3	+1.5	-1.1	+35.3	+45.7	-3.1	-15.0	-9.4	-17.2	-7.2	+81.0	-52.0	+29.0
Calgary													
Low (9)	-1.9	-0.2	-0.6	+0.0	-0.5	-6.5	-2.1	-1.9	-1.6	-0.5	-3.2	-12.7	-15.9
Median (4)	-1.5	-0.5	-0.1	-0.0	+0.2	-3.8	-2.0	+0.6	-1.1	-0.7	-1.8	-6.9	-8.7
High (8)	+0.3	-0.5	-0.3	-0.0	+1.1	-1.8	-1.6	-1.0	-1.8	-0.5	+0.5	-6.8	-6.2
Toronto													
Low (1)	+8.0	+19.6	+40.7	+36.7	+15.5	-21.1	-96.4	-64.5	-45.4	-11.6	+120.6	-238.9	-118.3
Median (3)	+8.6	+27.4	+20.8	+40.7	+36.6	-28.7	-85.0	-72.1	-41.9	-9.4	+134.0	-237.1	-103.0
High (2)	+6.6	+12.1	+22.7	+15.5	+25.6	-24.6	-61.5	-49.3	-8.7	-3.6	+82.5	-147.8	-65.3
Montreal													
Low (5)	-1.2	+0.4	+3.1	+7.4	+7.5	-7.3	-7.6	-8.3	-6.0	+0.4	+17.2	-28.8	-11.6
Median (9)	-0.4	+0.5	-0.6	+3.0	+20.0	-4.4	-3.8	-9.0	-7.3	-2.5	+22.5	-27.0	-4.5
High (7)	+1.1	+0.1	+0.9	+3.8	+17.2	-6.8	-3.5	-5.5	-2.9	+3.3	+23.1	-15.3	+7.8
Quebec City													
Low (3)	-0.6	+0.0	+0.0	+1.6	+2.3	-0.1	-0.3	-3.5	-2.2	+0.7	+3.3	-5.4	-2.1
Median (8)	-0.2	+0.0	+0.1	+2.9	+2.6	-0.2	-0.3	-3.1	-2.6	-0.1	+5.4	-6.3	-0.9
High (9)	-0.2	+0.0	+0.1	+1.5	+2.5	-0.1	-0.4	-0.9	-1.1	-0.1	+3.8	-2.6	+1.2
Halifax													
Low (2)	+0.0	+0.1	-1.0	+1.4	+1.8	-0.1	+0.7	-3.4	-1.0	-0.0	+2.5	-3.8	-1.4
Median (9)	+0.0	+0.1	-0.7	+0.8	+1.4	-0.0	+0.8	-2.4	-0.9	-0.0	+1.6	-2.6	-1.0
High (4)	+0.0	+0.2	-0.9	+1.6	+1.8	-0.1	+0.8	-2.4	-1.0	-0.0	+2.7	-2.7	-0.0

[a] Projected changes in safety were ranked; the low and high estimates represent the simulations that show the greatest reduction (or smallest increase) and largest increase (or smallest reduction), respectively, in weather-related injury collisions.

In Table 4-8, absolute changes in safety are expressed as percent change from present. As shown here, weather effects on road safety vary across the country. There are regional differences in the types of weather hazards that affect travellers, and also in the collision rates during these conditions. In Vancouver, for example, rainfall is the most pervasive weather hazard, and it accounts for nearly 10% of collisions in that city. By contrast, Quebec City and Halifax frequently experience both rain and snow, but these conditions account for only 1 to 2% of current collisions. Regional differences have been observed in other studies of weather-related risks, suggesting that local factors, e.g., road mix, driver demographics, safety initiatives and culture, matter.

Of particular note for the current study, however, is the fact that climate change is expected to affect only modest changes in road safety in Canada – from a decrease of 0.6% to an increase in 0.4% in injury collisions overall. Indeed, some locales (Calgary, Toronto) are expected to have substantially fewer weather-attributable injury collisions by the 2050s because of milder winters and fewer days with winter precipitation.

Table 4-8: Magnitude of change in injury collisions associated with future climate

Simulation (reference # in brackets) [a]	*Average annual injury collisions* [b]	*Average annual injury collisions attributable to weather*	*Overall change in injury collisions*	*Change in injury collisions attributable to weather*
Vancouver				
Low (9)	7,421	729	-0.1%	-0.7%
Median (3)			+0.2%	+1.6%
High (4)			+0.4%	+4.0%
Calgary				
Low (9)	3,359	55	-0.5%	-29.2%
Median (4)			-0.3%	-16.0%
High (8)			-0.2%	-11.4%
Toronto				
Low (1)	20,518	1,065	-0.6%	-11.1%
Median (3)			-0.5%	-9.7%
High (2)			-0.3%	-6.1%
Montreal				
Low (5)	7,773	240	-0.1%	-4.8%
Median (9)			-0.1%	-1.9%
High (7)			+0.1%	+3.2%
Quebec City				
Low (3)	1,985	47	-0.1%	-4.4%
Median (8)			-0.0%	-1.9%
High (9)			+0.1%	+2.5%
Halifax				
Low (2)	975	14	-0.1%	-10.2%
Median (9)			-0.1%	-7.3%
High (4)			-0.0%	-0.2%

[a] Projected changes in safety were ranked; the low and high estimates represent the simulations that show the greatest reduction (or smallest increase) and largest increase (or smallest reduction), respectively, in weather-related injury collisions.
[b] Based on collision records with complete date and time information; counts are therefore slightly lower than in Table 3-4.

Given that the analysis identifies heavy rains as an area of concern, because of higher risk levels today and projections of more frequent heavy rains in the future, these data are presented in graphical form in Figure 4-7 through Figure 4-10. As shown here, it is expected that heavy rainfalls will be an issue of growing concern as the climate changes.

Figure 4-7: Average annual days with 10.0 to 19.9 mm rainfall, 1971-2000 and 2041-2070

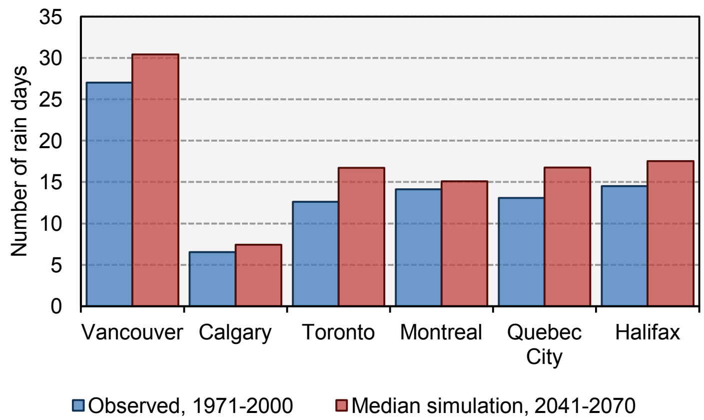


Figure 4-8: Average annual injury collisions attributable to rainfalls between 10.0 and 19.9 mm, 1971-2000 and 2041-2070

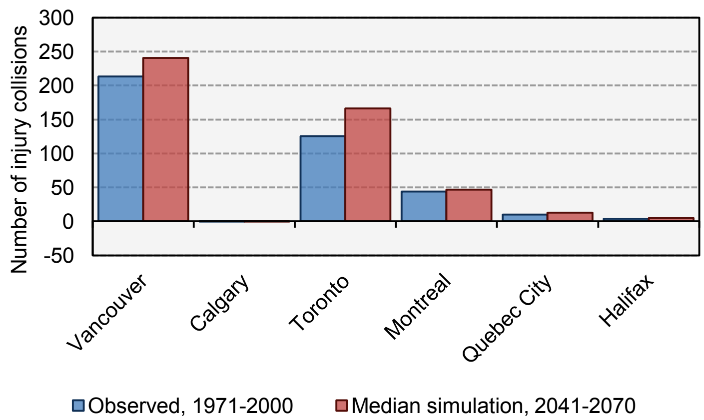


Figure 4-9: Average annual days with ≥ 20.0 mm rainfall, 1971-2000 and 2041-2070

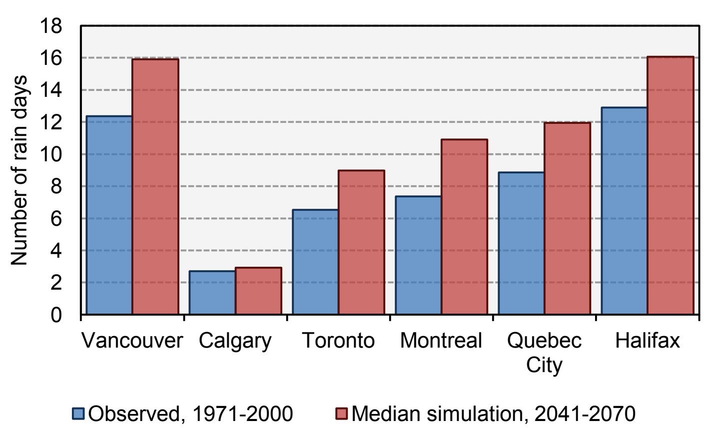
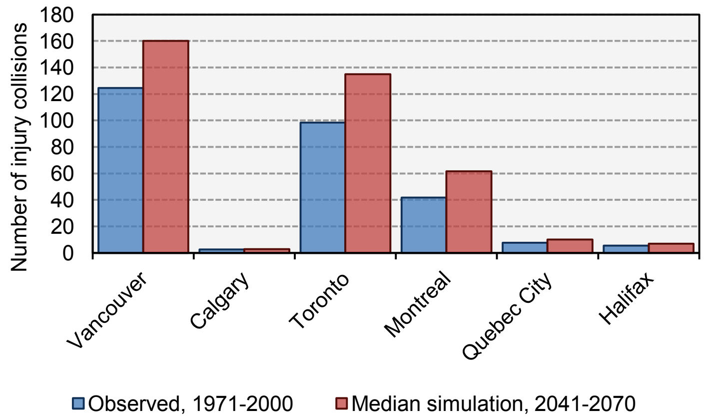


Figure 4-10: Average annual injury collisions attributable to rainfalls ≥ 20.0 mm, 1971-2000 and 2041-2070



4.3 Other weather hazards for which exploratory work was completed

Precipitation is the dominant weather-related road hazard in Canada due to the frequency with which rain, snow and other types of precipitation occur and also because collision rates during precipitation tend to be significantly and substantially higher when compared to dry conditions. However, other situations sometimes also produce potentially hazardous travel conditions. These conditions, as identified in Table 2-2, include:

- Fog → reduced visibility
- Blowing snow → reduced visibility, potentially reduced surface friction
- High winds → more difficult vehicle handling, possible truck turnovers, sign damage
- Extreme heat → increased aggression, possibly reduced friction due to asphalt bleeding
- Wet, snowy or icy roads → reduced friction following precipitation events or when black ice is present

For each of the conditions, exploratory analysis was done on the potential implications of current weather and climate change for safety. This exploratory analysis is based on data for Toronto. Questions that are addressed include:

1. What are the threshold values or ranges associated with potentially hazardous driving?
2. How often and when does this condition occur?
3. In comparing the percentage of collisions that occur in this condition to the percent time when this condition occurs, is there evidence of elevated levels of risk?
4. Based on the literature, is this condition expected to occur more or less frequently under scenarios of climate change?

4.3.1 Fog and other conditions that reduce atmospheric visibility

Fog, and other conditions that contribute to reduced atmospheric visibility, are common occurrences in most parts of Canada (Appendix C). Fog forms when condensation occurs near ground level. When the atmosphere contains water droplets (mist, fog) or ice crystals (ice fog), the transparency of the atmosphere, and thus sight distance, is reduced. Atmospheric visibility is typically measured in sight distance; dense fog produces visibilities less than 40 metres, thick fog distances between 40 and 200 metres and fog between 200 and 1000 metres (Musk, 1991). Other conditions, such as haze, smog and smoke, also contribute to reduced visibility distance.

The approach taken here is to isolate those occurrences when atmospheric visibility was reduced to less than 1000 metres, and also less than 200 metres. Low visibility occurrences were further subdivided according to whether they occurred during precipitation. These percent frequencies were then compared with the percent of collisions that occurred under these conditions. If risks are elevated, the percent of collisions would be greater than the corresponding percent of occurrences.

As Table 4-9 shows, visibility distances < 1000 metres occur less than 1% of the time. Most often, such reduced visibility occurs when precipitation is not falling, and during these times there is little evidence that collision risks are elevated. When precipitation is falling, however, and visibility distance is < 1000 metres, the data suggest that collision risks are nearly twice as high as would be expected. For visibility distances < 200 metres, collision risks also appear to be elevated – regardless of whether precipitation is occurring. Thus there is evidence that fog and other conditions that seriously reduce visibility are hazards – notwithstanding the relatively low frequency with which such conditions currently occur. At present, this hazard occurs most often in autumn and late winter. Of relevance to the current study is the fact that the scientific literature indicates a decrease in fog occurrence in much of southern Canada over the past 60 years (Wang, 2006).

Table 4-9: Frequency of poor visibility at Toronto Pearson International Airport, 2000-2009

Visibility distance	*# hours*	*% of all hours*	*# collisions (all severities)*	*% of all collisions*
Precipitation observed				
< 200 m	1	0.001%	19	0.002%
< 1000 m	236	0.27%	4,523	0.53%
Precipitation not observed				
< 200 m	9	0.010%	91	0.011%
< 1000 m	307	0.35%	1,824	0.22%

4.3.2 Blowing snow

Blowing and drifting snow occurs when snow particles are lifted from the surface and suspended by wind. Frequently these conditions occur during precipitation events, but they may also occur after precipitation accumulation. Much of the research on blowing snow is undertaken from a hydrological perspective, and only limited research has been conducted on blowing snow that results in significant reductions in driver visibility (Baggaley and Hanesiak, 2005). In Canada, blowing snow occurs most frequently in the Arctic and Prairie provinces; in these regions 15-40% of blowing-snow events occur when precipitation is not falling (Baggaley and Hanesiak, 2005). Meteorological observations suggest, however, that blowing snow occurs infrequently in most urban regions of Canada.

In this exploratory work, the frequency of blowing snow is estimated, based on hourly meteorological observations at Pearson International Airport (Table 4-10). Results show that blowing snow is recorded in only a very small fraction of all hours, i.e., less than one percent of the time, and mostly while snow is falling. Thus most of the blowing snow conditions, at least in Toronto, would be included in the safety analysis completed for winter precipitation days. For those times when blowing snow was observed, and snow was not falling, collision rates appear to be elevated, but the overall frequency of such occurrences is too small to be sure of the signal. It goes without saying that blowing snow is a winter hazard; it occurs almost exclusively from December to March in Toronto. Over the past 60 years, it is evident that incidences of blowing snow have decreased significantly across Canada (Wang, 2006); and with warmer winter temperatures and less snowfall projected under climate change, it is likely to be of less concern in a future climate.

Table 4-10: Frequency of blowing snow at Toronto Pearson International Airport, 2000-2009

Falling snow observed	*# hours*	*% of all hours*	*# collisions (all severities)*	*% of all collisions*
Yes	67	0.08%	1,733	0.20%
No	10	0.01%	164	0.02%

4.3.3 Wind

High winds affect vehicle handling (lane maintenance) and sliding (when roads are wet), and potentially lead to vehicle turnover. Various studies suggest that weather station data provides an adequate predictor of regional-level wind-related crashes due to overturning or wind-related course deviation. Edwards (1994) showed that overall accident rates are nearly twice as high as expected when wind speed exceeds 40 km/h. Most other studies have focused on specific vehicle classes – most notably trucks – and consider both hourly wind speed as well as gustiness (Baker and Reynolds, 1992; Young and Liesman, 2007).

In this exploratory work, the frequency with which hourly wind speed greater than 40 km/h is calculated for Toronto, again based on hourly meteorological observations at Pearson International Airport (Table 4-11). Hourly wind speed records indicate that this condition occurs less than three percent of the time, and usually when precipitation is not falling. Wind gusts over 40 km/h also occur, approximately three times as often, and again mostly when precipitation is not observed. In both cases, collision rates appear to be elevated during high winds. At present, in Toronto, these events occur mostly from November to April.

Table 4-11: Frequency of high winds at Toronto Pearson International Airport, 2000-2009

Hourly wind speed	*# hours*	*% of all hours*	*# collisions (all severities)*	*% of all collisions*
Precipitation observed				
≥ 40 km/h	523	0.60%	7,444	0.88%
Gust ≥ 40 km/h	1,496	1.71%	22,328	2.63%
Precipitation not observed				
≥ 40 km/h	1,792	2.04%	22,473	2.65%
Gust ≥ 40 km/h	6,068	6.92%	72,586	8.56%

4.3.4 Extreme heat

Considerable research has established an empirical link between temperature and aggression (Anderson, 1989 and 2001; Bushman et al., 2005), and some research in other countries suggests that collision rates may be higher during heat spells (Stern and Zehavi, 1990). While the discomfort experienced by humans is mostly related to 'apparent temperature', i.e., a measure that considers both ambient temperature and humidity, ambient temperature readings provide a first view of this as a potential issue for road safety in Canada. At ambient temperatures greater than 32 degrees Celsius (90 degrees Fahrenheit), humans are likely to experience some physiological effects. At 38 degrees (approximately 100 degrees F), the effects are more pronounced.

Accordingly, the frequency with which hourly temperature exceeds 32 and 38 degrees Celsius was calculated for Toronto, based on hourly meteorological observations at Pearson International Airport (Table 4-12). Results show that hourly temperature has seldom exceeded 38 °C. There are instances in most summers, however, when daytime highs exceed 32 °C. Again, collision rates appear to be elevated when temperatures are this high; and so this issue may also warrant additional attention, as extreme high temperatures are projected to occur more often under climate change throughout most of southern Canada (Diffenbaugh et al., 2005; Christensen et al., 2007).

Table 4-12: Frequency of extreme temperatures (no precipitation observed) at Toronto Pearson International Airport, 2000-2009

Hourly temperature	*# hours*	*% of all hours*	*# collisions (all severities)*	*% of all collisions*
≥ 32 °C	306	0.35%	5,885	0.69%
≥ 38 °C	--	0%	--	0%

High temperatures may also be an issue for road surface friction. The dominant influences on road surface friction are the road surface texture and condition. That said, there is evidence that prolonged periods of extreme heat can lead to asphalt bleeding, which is associated with reduced surface friction. Based on a detailed study on the potential implications of climate change for paved roads in Canada (Mills et al., 2007), it is reasonable to suggest that seven-day maximum air temperatures above 35 °C would exceed the design specifications in some areas, and temperatures above 38 °C would exceed the design specifications in most parts of Canada. However, neither condition occurred in Toronto from 2000-2009, and indeed a seven-day maximum temperature of 35 °C was reached only once in the entire

70 years of record – from August 23-29, 1948. Again, however, hotter summers across southern Canada may contribute to more of such incidences.

4.3.5 Wet, snowy or icy roads

Precipitation is well appreciated to be a road hazard because of the ways in which it compromises road surface friction, driver visibility and even vehicle handling. The most hazardous driving occurs when all three hazardous conditions are present – thus justifying the focus on precipitation events. However, even after precipitation ends, roads may remain wet, snowy or icy for several hours or even days. Andrey and Yagar (1993) examined this issue for rainfall in Alberta, and found that collision risk quickly returned to normal when precipitation ended, even though most roads remained wet for some time. However, on the whole, drying times in Alberta would be shorter than in most other parts of Canada because of lower humidity; and the analysis was not extended to winter precipitation.

One way to explore the implications of wet, snowy or icy conditions (in the absence of precipitation) on collision frequency is to examine information from collision reports. Most reporting agencies provide information on the road surface condition at the time of the collision. These data were examined for Toronto, using six-hour periods when precipitation was occurring, as well as the subsequent six-hour period when precipitation was no longer occurring (as in Andrey and Yagar, 1993).

The relative risk for events and post-events are provided in Table 4-13, and reported road conditions are also provided for different types of precipitation events[3] and post-events (Table 4-14). Relative risks are high – as would be expected – for precipitation events, being much higher for snow and those autumn/spring conditions that are near freezing than for rain. For the post-event period, relative risk is immediately reduced to just above baseline (1.04), suggesting that whatever friction hazard remains is compensated for by driver adaptations. For winter precipitation events, however, the post-event period remains hazardous; with relative risk values of 1.32 for the 6-hour periods following ‘transition/near freezing’ events and 1.69 for the 6-hour periods following snowfalls.

At present, in Toronto, snowfall and ‘transition’ weather occurs mostly from November to March. Under climate change, incidences of wet, snowy or icy roads are likely to decrease due to warming temperatures and less snowfall.

[3] Event categories for this exploratory work coincide with those used during the initial 6-hourly safety analysis provided in Appendix F. These are defined as follows: rain (6-hour average temperature of at least 2 °C), transition/near-freezing precipitation (6-hour average temperature between -3 °C and + 2 °C), and snow (6-hour average temperature below -3 °C).

Table 4-13: Collision counts and risk estimates for 6-hour event and post-event periods, Toronto, 2000-2009

	Rain (n=619)			*Transition/near-freezing (n=81)*			*Snow (n=48)*		
Period	***Event collisions***	***Control collisions***	***Risk estimate***	***Event collisions***	***Control collisions***	***Risk estimate***	***Event collisions***	***Control collisions***	***Risk estimate***
Event	47,832	35,391	1.35	9,351	4,215	2.22	4,931	2,184	2.26
Post-event	32,107	30,999	1.04	6,012	4,571	1.32	4,013	2,369	1.69

Table 4-14: Road surface condition for 6-hour event and post-event periods, Toronto, 2000-2009

		Rain		*Transition/near-freezing*		*Snow*	
Period	***Road surface***	***Events***	***Controls***	***Events***	***Controls***	***Events***	***Controls***
Event	Dry	40.9%	97.9%	14.7%	93.1%	14.5%	92.2%
	Wet	58.5%	1.7%	29.6%	4.4%	17.0%	4.3%
	Snowy/Icy	0.4%	0.2%	55.7%	2.3%	68.4%	3.3%
Post-event	Dry	75.6%	97.6%	42.1%	94.8%	27.2%	92.8%
	Wet	23.4%	1.9%	29.7%	3.5%	27.4%	4.7%
	Snowy/Icy	0.9%	0.2%	28.1%	1.5%	45.2%	2.4%

4.4 Other considerations about climate change and road safety

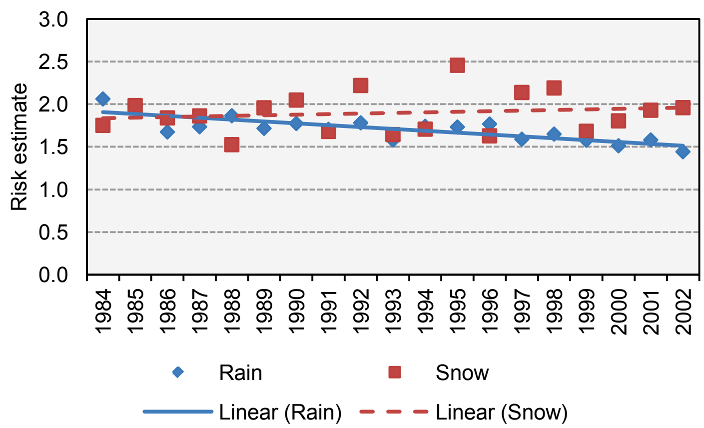
4.4.1 Long-term trends in relative risk

The previous analysis examines how climate change may affect road safety in Canadian cities. The relative-risk approach provides a way of estimating risk that is comparable across cities and extendible into the future. This is because collision propensity during weather is expressed relative to that during dry, seasonal conditions. It is reasonable to expect that these relative risk values are stable over time – unless the way in which motorists and other road users respond to weather hazards changes over time.

In a recent study, Andrey (2010) analyzed the long-term trend in the relative risk of injury during precipitation. The analysis was done using data at 6-hour increments, which produces relative risk values that are higher than what was recorded in the current study. The results are still comparable, however, as most six-hour periods have active weather during most of the period, whereas days with precipitation have active weather only one-third of the time, on average. Therefore we would expect 6-hour increases to be two to three times as high as daily increases (e.g., a relative risk of 1.6 for 6-hour data, i.e., 60% increase during precipitation, would be equivalent to a relative risk of 1.2 or 1.3 for daily data, i.e. 20 to 30% increase on days with precipitation. Figure 4-11, reproduced from Andrey (2010) shows that the relative risk of injury collision during winter precipitation has not changed over time. At the same time, rain has become a less serious hazard as relative risk has decreased from approximately 1.9 to 1.5 between 1984 and 2002.

It is difficult to know why relative risk during rainfall has decreased to the extent that it has; it is likely that antilock brakes and other safety interventions related to both engineering and human factors have played roles. Whether the downward trend in relative risk will continue is unknown. If it does, then a milder climate that produces more rainfall and less snowfall would be a safety benefit for Canada.

Figure 4-11: Long-term trend in relative risk of injury during precipitation, 10 Canadian cities, 1984-2002



Reproduced from: Andrey (2010)

4.4.2 Climate change across Canada

It is also important to consider the extent to which the findings for the six study cities might be extrapolated to other parts of Canada. First, it is important to note that collision rates, overall, vary considerably (Figure 4-12). As well, the risks associated with weather hazards vary, as estimated in Table 4-1. This suggests that extrapolations should be done cautiously.

Figure 4-12: Road casualty rates (fatalities and injuries per billion vehicle-kilometres) by province/territory, 2008-2009

	Fatalities[1]		*Injuries[2]*	
	2008[R]	*2009[E]*	*2008[R]*	*2009[E]*
Canada	7.4	6.6	541.9	515.6
Newfoundland and Labrador	8.0	9.1	385.9	439.6
Prince Edward Island	14.9	10.2	498.0	589.2
Nova Scotia	8.6	7.1	503.1	474.7
New Brunswick	9.6	8.3	482.2	480.7
Quebec	8.1	7.1	632.1	592.2
Ontario	5.0	4.3	502.7	492.6
Manitoba	8.1	7.3	686.6	615.9
Saskatchewan	12.2	12.0	537.3	524.0
Alberta	8.6	7.1	464.2	385.6
British Columbia	9.9	9.9	611.9	614.3
Yukon	15.4	13.7	463.4	341.1
Northwest Territories	11.8	15.9	408.8	473.9
Nunavut	132.5	65.1	1,357.6	1,368.1

Notes: R = Revised. E = Estimated. Data for Ontario are preliminary for 2008 and 2009.
1 "Fatalities" include all those who died as a result of involvement in a reportable traffic collision within 30 days of its occurrence, except in Quebec (8 days).
2 "Injuries" include all those who suffered any visible injury or complained of pain.

Sources: Collision statistics: Transport Canada, Road Safety and Motor Vehicle Regulation, National Collision Database (NCDB). Vehicle-Kilometres: Statistics Canada, Cat. 53-223-XIE, "Canadian Vehicle Survey"

Source: Transport Canada (2011)

Still, it is informative to examine general climate change projections for North America. The Intergovernmental Panel on Climate Change (IPCC) is an international agency that provides regular reports on climate change science as well as information on the human dimensions of climate change (i.e., impacts, adaptations, vulnerabilities and carbon mitigation). Figure 4-13 is based on the most recent IPCC report (IPCC, 2007); it provides projections of temperature and precipitation changes over North America up to the end of the current century. As shown here, Canada in particular is expected to experience considerable warming, especially in the north and during the winter months. Precipitation changes are expected to vary across the country, but changes are relatively modest in the most urbanized parts of Canada, except in the Prairies where there is a strong signal. Thus, as indicated earlier in the report, the safety implications of climate change have more to do with the types and intensities of precipitation, than with its overall frequency or even amount. The quantity of snowfall is generally expected to increase in the coldest areas, but throughout most of settled Canada less snowfall is anticipated in the winter months (Räisänen, 2008). There is also a clear signal that heavy precipitation events, especially rainfall, are generally expected to increase (Mailhot et al., 2012). These two trends – less snow but more heavy rains – have offsetting effects on risk; the net effect will depend on local weather and local sensitivities to weather. Adding to the complexity is the fact that freezing rain occurrences are projected to change, both spatially and in terms of frequency – reinforcing the conclusion that climate change effects are likely to be region-specific (Cheng et al., 2011; Lambert and Hansen, 2011).

Figure 4-13: Projected changes in temperature and precipitation over North America, 1980-1999 to 2080-2099

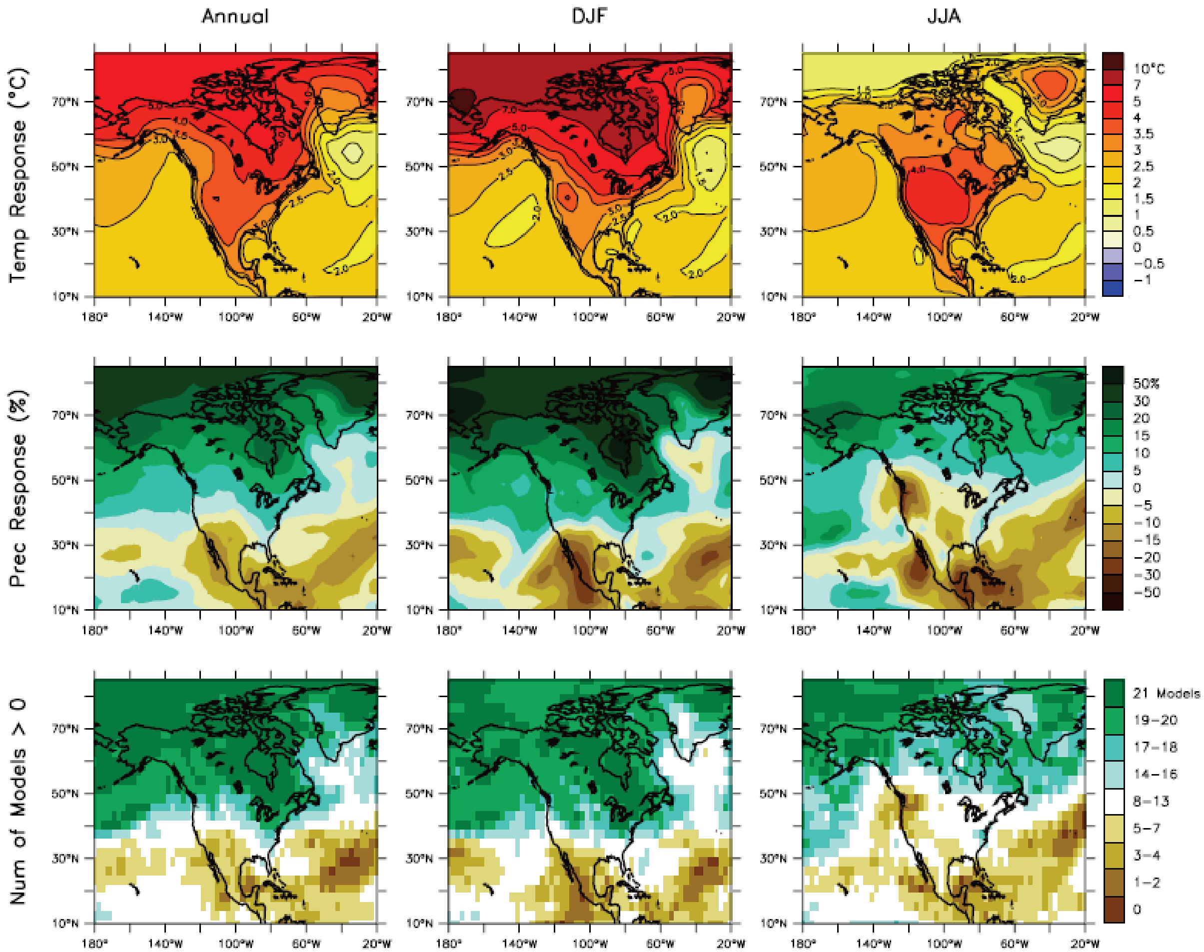


Figure 11.12. *Temperature and precipitation changes over North America from the MMD-A1B simulations. Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Middle row: same as top, but for fractional change in precipitation. Bottom row: number of models out of 21 that project increases in precipitation.*

Top row: projected changes in average annual and seasonal temperature (°C), where blue represents a decrease in mean temperature and red an increase. Middle row: mean annual and seasonal changes in precipitation (% change), where brown indicates less precipitation and green an increase. Bottom row: number of global climate models out of 21 that project precipitation increases (green = 21, brown = 0). DJF and JJA refer to December-January-February and June-July-August, respectively. *Source*: Christensen et al. (2007)

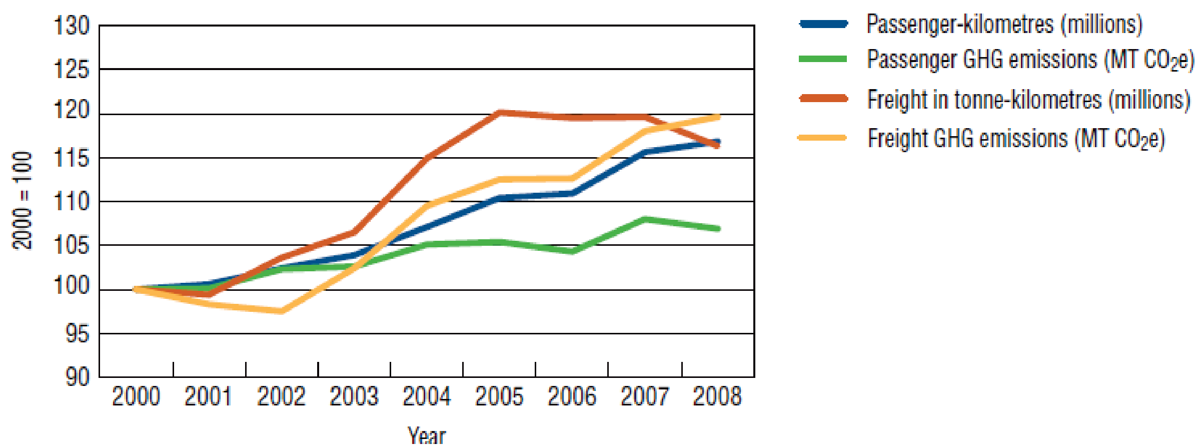
4.4.3 Traffic and mobility trends

While most of the analyses were based on relative risk, Section 4.2 translates risk estimates into counts of absolute injury collisions. This translation is based on the assumption that travel amount and patterns will not change. This *ceteris paribus* assumption is typical of climate-change impact assessments, but of course is not reasonable as the transport system is highly dynamic.

The most powerful explanatory variable in road safety is 'exposure', i.e., a measure of the quantity and quality of transport activity that occurs (Andrey, 2000). The most common metric for measuring quantity of exposure is person- or vehicle-kilometres. Transport Canada's Annual Reports document road transport trends, as presented in Figure 4-14. As shown here, motorized travel has increased by approximately 16% from 2000 to 2008. This increase is broadly consistent with those reported for the US in *Traffic Volume Trends* (FHWA, 2012).

Given projections of continued growth in Canada's population, it is reasonable to expect that road travel will continue to increase. Growth may be dampened or even reversed, however, should increased attention be given to transportation demand management, carbon pricing or other sustainability measures.

Figure 4-14: Trends in transportation activity and greenhouse gas emissions, Canada, 2000-2008



Notes: Transportation activity includes all modes. Mt of CO_2e = Megatonnes of carbon dioxide equivalent.

Source: Natural Resources Canada, Office of Energy Efficiency, Energy Use Data Handbook, 1990 to 2008

Source: Transport Canada (2011)

4.5 Collision attributes during weather events, 2000-2009

Road collision databases provide an opportunity to identify those subsets of collisions that are over-represented during inclement weather. This provides a way of identifying issues that are of current concern – given present-day climate – and potentially of concern in the future, given the changing nature of climate in Canada.

Information in the National Collision Database is organized in three general categories: collision-level (one record per collision), vehicle level (one record per involved vehicle) and person-level (one record per involved person). This categorization is used to order the discussion of collision attributes in this section of the report. Considering available data, the attributes listed in Table 4-15 were examined for all injury collisions that were included in the matched-pair analysis reported earlier in Section 4.1.

Table 4-15: List of collision attributes examined

Collision-level variables	Collision configuration	All study areas except Montreal and Quebec City (data not compatible with other cities)
	Roadway configuration	All study areas except Moncton (inconsistent data)
	Light condition	All 8 study areas
	Road classification III	1 study area (Toronto)
	Road alignment	All 8 study areas
	Traffic control	All 8 study areas
	Posted speed limit	All study areas except Calgary (data not provided)
Vehicle-level variables	Vehicle type	Data provided only for Montreal and Quebec City
	Vehicle event(s)	All study areas except Calgary (data not sufficiently complete), Montreal and Quebec City (data not provided)
	Contributing factor(s)	All study areas except Montreal and Quebec City (data not provided)
Person-level variables	Driver sex	1 study area (Toronto)
	Driver age	1 study area (Toronto)
	Pedestrian action	1 study area (Toronto)

This discussion draws on Table 4-16, Table 4-18 and Table 4-20, which indicate (using a '+' sign for over-representation, or more collisions during hazardous weather, and a '-' sign for under-representation, or fewer collisions) differences that are statistically significant at the 95% confidence level based on chi-squared analysis, and Appendix J, which provides detailed percent frequency data.

For each variable, the results are presented in Table 4-17, Table 4-19 and Table 4-21:

- First, collision attributes that are over-represented on days with rainfall are identified. This is of particular importance in the context of the current project, as more days with rainfall are expected in the future, and collision risks are higher on days with rainfall relative to days when roads are mostly dry.
- Second, collision attributes that are over-represented on days with winter precipitation are identified. This is of importance because, under current climates, collision risks are particularly elevated during snowfall, freezing rain and other winter precipitation conditions, relative to mostly dry, seasonal conditions. These conditions are expected to occur less frequently, however, in the future.

Table 4-16: Significant differences in collision-level attributes during precipitation relative to dry conditions

	Rain days								*Winter precipitation days*							
	Vancouver	Calgary	Toronto	Ottawa	Montreal	Quebec City	Moncton	Halifax	Vancouver	Calgary	Toronto	Ottawa	Montreal	Quebec City	Moncton	Halifax
Collision configuration																
Single vehicle																
Hit object or parked vehicle				-							+					
Ran off road									+						+	+
Other non-collision			+								+					
Two vehicles, same direction																
Rear-end				+							-				-	
Sideswipe				-			+			+	+				+	-
Passing or turning conflict	-															
Two vehicles, different direction																
Head-on or approaching sideswipe	+		+						+	+	+	+				+
Left turn across opposing traffic								+	-	-						-
Right turn or turning conflict			-	-												
Two vehicles - other configuration			-				+				-	-				
Roadway configuration																
Non-intersection			-		-			-	+	+	+	+				
Intersection of 2+ public roads	+		+		+	+			-	-	-	-				
Intersection with parking lot access, driveway, or lane	-		-					+			-					-
Railway crossing																
Bridge, overpass, or viaduct											+					
Ramp				-							+					
Other configuration (e.g., tunnel, traffic circle)													+			
Light condition																
Daylight	-	-	-	-	-	-		-	-		-	-	-	-	-	-
Dawn or dusk	+		+		+	+					+		+			
Darkness	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+
Road classification III																
One-way											-					
Undivided, two-way											-					
Divided											+					

Table 4-16: Significant differences in collision-level attributes during precipitation relative to dry conditions

	Rain days								*Winter precipitation days*							
	Vancouver	Calgary	Toronto	Ottawa	Montreal	Quebec City	Moncton	Halifax	Vancouver	Calgary	Toronto	Ottawa	Montreal	Quebec City	Moncton	Halifax
Road alignment																
Straight and level	-		-		-				-		-	-	-	-	-	-
Straight with gradient											+	+			+	
Curved and level			+		+						+	+	+	+	+	
Curved with gradient	+		+	-	+				+		+		+	+		+
Top of hill/gradient								-								
Bottom of hill/gradient																
Traffic control																
Traffic signal	+		+	+	+	+		+	-		-	-			-	
Stop sign					+						-			-		
Yield sign																
Pedestrian crosswalk or school crossing						-				-						
Police officer, crossing guard, or flagman			+										-			
Other control																
No control present	-		-		-	-			+		+	+			+	
Posted speed limit																
40 km/h or less			-		-						-					
50 km/h					+						-	-		-	-	-
60 km/h			+	+							-					
70 km/h								-								
80 km/h											+	+	-		-	
90 km/h				-		+										
100 or 110 km/h			-	-	-						+		+		+	

Differences that are statistically significant at the 95% confidence level based on chi-squared analysis are denoted with a '+' or '-' sign; these indicate over-representation (i.e., more collisions during hazardous weather), or under-representation (fewer collisions), respectively.

Table 4-17: Discussion of significant differences in collision-level attributes

	Days with rain relative to dry, seasonal conditions	***Days with winter precipitation relative to dry, seasonal conditions***
Collision configuration	There are significantly more two-vehicle collisions that are head-on or approaching side-swipe in Vancouver and Toronto.	There are significantly more single-vehicle collisions (of various types) in Vancouver, Toronto, Moncton and Halifax; and more two-vehicle head-on or sideswipe collisions in Vancouver, Calgary, Toronto, Ottawa and Moncton.
Roadway configuration	There tend to be more collisions at intersections (at intersection of 2+ public roads in Vancouver, Toronto, Montreal and Quebec; at intersection with parking lot access, driveway or lane in Halifax)	There tend to be more non-intersection collisions; these differences are significant for Vancouver, Calgary, Toronto and Ottawa. Collisions at special features (e.g., bridges, ramps) are also over-represented in some of the study areas.
Light condition	There tend to be more collisions in darkness (all study areas) and at dusk or dawn (Vancouver, Toronto, Montreal and Quebec City).	There tend to be more collisions in darkness (all study areas except Calgary) and at dusk or dawn (Toronto, Montreal).
Road classification III	No significant differences.	Crashes on divided roads are over-represented in Toronto.
Road alignment	There tend to be more collisions on curved sections of road (Vancouver, Toronto and Montreal).	There tend to be more collisions on curved sections of road and also on gradients (significant differences observed in all study areas except Calgary).
Traffic control	Collisions at traffic signals are over-represented in all study areas except Calgary and Moncton. Montreal also tends to have more crashes at stop signs.	Crashes involving no traffic control tend to be over-represented in Vancouver, Toronto, Ottawa and Moncton.
Posted speed limit	No clear patterns across study area: 50 km/h roads are over-represented in Montreal; 60 km/h roads are over-represented in Toronto and Ottawa; 90 km/h roads are over-represented in Quebec City.	A clear pattern with over-representation of higher speed roads. Differences are significant for Toronto, Ottawa, Montreal and Moncton.

Table 4-18: Significant differences in vehicle-level attributes during precipitation relative to dry conditions

	Rain days								*Winter precipitation days*							
	Vancouver	Calgary	Toronto	Ottawa	Montreal	Quebec City	Moncton	Halifax	Vancouver	Calgary	Toronto	Ottawa	Montreal	Quebec City	Moncton	Halifax
Vehicle type																
Car or light truck					+	+							+			
Truck													+			
Tractor trailer (with or without trailer)																
Bus, school bus, or minibus																
Work or equipment vehicle (e.g., tow truck, snow plow, construction equipment)													+			
Taxi					+											
Emergency vehicle																
Motorcycle or moped					-	-							-	-		
Bicycle					-	-							-	-		
Other vehicle type																
Vehicle events																
Non-collision events																
Skidded or spun off roadway			+								+	+			+	+
Ran off roadway									+		+				+	
Overturned, rollover, jackknife, or trailer swing	-		-				-								+	
Other non-collision event																
Hit moving objects																
Hit another moving vehicle	+		+	+				+			-				-	-
Hit pedestrian			+	-							-					
Hit bicyclist	-		-	-					-		-	-				
Hit animal																
Hit train/streetcar or other moving object			-					-								
Hit non-moving objects																
Hit parked vehicle																+
Hit building or other object that is not part of road structure											+	+				
Hit object that is part of road structure	+		+						+		+	+			+	

Table 4-18: Significant differences in vehicle-level attributes during precipitation relative to dry conditions

	Rain days								*Winter precipitation days*							
	Vancouver	Calgary	Toronto	Ottawa	Montreal	Quebec City	Moncton	Halifax	Vancouver	Calgary	Toronto	Ottawa	Montreal	Quebec City	Moncton	Halifax
Contributing factors																
Driver/pedestrian condition																
Fatigued or fell asleep	-										-	-				
Inexperience	+															-
Under influence of alcohol	-									-						
Under influence of drugs			-													
Other driver condition	-								-							
Driver action																
Following too closely			-	+					-		-				-	
Distracted or inattentive	-		-						-		-	-			-	-
Driving too fast for conditions	+		+	+					+		+	+			+	
Improper turning or passing	-		-	-							-					
Failing to yield right-of-way										-	-	-				
Disobeying traffic control device or traffic officer											-	-				
Driving on wrong side of road or in wrong direction																-
Backing up unsafely																
Lost control											+	+				
Other driver action	-		-	-						+	-					
Vehicular contributing factor																
Defective brakes																
Defective steering																
Defective lights																
Blown out tire									+							
Unsecured, spilled, or oversized load																
Visibility obstructed (e.g., wiper, defroster, mirror, tinting)	-						+									
Other vehicular contributing factor																
Environmental contributing factor																
Animal or other obstruction in road																
Road surface or other road conditions (e.g., slippery, construction, faulty controls)	+							+	+	-					+	+
View obstructed (e.g., glare, reflection)	-							-	-							
Weather or other acts of God	+								+						+	+
Other environmental contributing factor																

Differences that are statistically significant at the 95% confidence level based on chi-squared analysis are denoted with a '+' or '-' sign; these indicate over-representation (i.e., more collisions during hazardous weather), or under-representation (fewer collisions), respectively.

Table 4-19: Discussion of significant differences in vehicle-level attributes

	Days with rain relative to dry, seasonal conditions	***Days with winter precipitation relative to dry, seasonal conditions***
Vehicle type	Fewer bicycles, motorcycles and mopeds are involved in collisions during the rain, probably reflecting lower exposure. Cars and light trucks are over-represented (Montreal and Quebec City).	Fewer bicycles, motorcycles and mopeds are involved in collisions (Montreal and Quebec City), probably reflecting lower exposure. Cars, light trucks and work equipment are over-represented (Montreal).
Vehicle event(s)	There are more collisions involving skidding (Toronto), and hitting another moving vehicle (Vancouver, Toronto, Ottawa and Halifax). Toronto`s data also suggest that a disproportionate number of rain-related collisions involve pedestrians, while the opposite was found for Ottawa. During rainfall, Vancouver and Toronto also have a disproportionate number of collisions where a vehicle hit an object that is part of the road structure.	There are more collisions involving skidding (Toronto, Ottawa, Moncton and Halifax), running off the road (Vancouver, Toronto and Moncton), and overturning, roll over, jackknife or trailer swing (Moncton). There were also more collisions involving a vehicle hitting non-moving objects (i.e., parked vehicle in Halifax, building in Toronto and Ottawa, and part of road structure in Vancouver, Toronto, Ottawa and Moncton.
Contributing factor(s)	Slippery roads and driving too fast for conditions is over-represented (Vancouver, Toronto, Ottawa and Halifax).	Driving too fast for conditions is over-represented (Vancouver, Toronto, Ottawa, Moncton), as are lost control (Toronto, Ottawa), road surface or other road conditions (Vancouver, Moncton, Halifax), and weather or other acts of God (Vancouver, Moncton, Halifax).

Table 4-20: Significant differences in person-level attributes during precipitation relative to dry conditions

	Rain days								***Winter precipitation days***							
	Vancouver	Calgary	Toronto	Ottawa	Montreal	Quebec City	Moncton	Halifax	Vancouver	Calgary	Toronto	Ottawa	Montreal	Quebec City	Moncton	Halifax
Driver sex																
Male											+					
Female											-					
Driver age																
< 16																
16-19			+													
20-24																
25-34											+					
35-44																
45-54																
55-64											-					
65-74			-								-					
75-84			-								-					
≥ 85			-								-					
Pedestrian action																
Crossing intersection:																
with traffic control, with right-of-way																
with traffic control, without right-of-way																
with no traffic control											-					
Crossing roadway at a crosswalk																
Walking on or along roadway																
On sidewalk, median, or safety zone											+					
Coming from behind parked or moving vehicle or roadside object											+					
Running into roadway																
Getting on or off bus or other vehicle																
Pushing or working on vehicle on road																
Working on roadway (e.g., construction worker)			-													

Differences that are statistically significant at the 95% confidence level based on chi-squared analysis are denoted with a '+' or '-' sign; these indicate over-representation (i.e., more collisions during hazardous weather), or under-representation (fewer collisions), respectively.

Table 4-21: Discussion of significant differences in person-level attributes

	Days with rain relative to dry, seasonal conditions	***Days with winter precipitation relative to dry, seasonal conditions***
Driver sex	No significant differences.	A disproportionate number of males are involved in winter-precipitation crashes in Toronto.
Driver age	A disproportionate number of young (16-19) drivers in Toronto are involved in rainfall crashes in Toronto, whereas there are fewer drivers aged 65+ involved in collisions during rainfall.	A disproportionate number of 25-34 year olds in Toronto are involved in winter-precipitation crashes in Toronto, whereas there are fewer drivers aged 55+ involved in collisions.
Pedestrian action	No significant differences.	Of the pedestrian collisions in Toronto, comparatively more involve pedestrians being on the sidewalk, median or safety zone or a pedestrian coming from behind vehicles or roadside objects.

In summary, in terms of rain-related collision risk – something that is important today and will be of growing importance because of climate change – the data highlight how rainfall at night is particularly problematic, as is driving in the rain on curved sections of roadway or driving too fast for conditions. As well, collisions at traffic signals and crashes involving pedestrians are over-represented during rainfall.

Risks related to winter driving are significantly elevated both relative to dry conditions and in comparison to rain days, but the frequency of winter precipitation days is expected to decrease across southern Canada by mid-century. Hazards related to snow and ice will continue, however, despite the shorter season in most years and regions. Issues related to snowfall and other winter-weather conditions include more single-vehicle collisions (e.g., those involving run-off-road or hitting a roadside object), more collisions on curved sections of roadway and on gradients, and in some cases on bridges, ramps and other special features. Of particular note are the tendencies for higher speed roads and non-daylight conditions to be over-represented in winter-weather collisions.

4.5.1 Weather conditions reported in pedestrian collisions

In order to provide more information on pedestrians, who are a vulnerable road user group, Table 4-22 was prepared based on those records where a vehicle hit a pedestrian. As the table shows, the vast majority of injury collisions involving a pedestrian occur during clear weather conditions. However, in several cities, a disproportionate number of pedestrian collisions take place during inclement weather. For example, rainfall in Vancouver is observed in approximately 15% of all hours, yet rain is reported in more than one-quarter of crashes involving pedestrian injury or death. Similarly in Toronto, precipitation of various forms is observed 12% of the time, but more than 18% of pedestrian collisions occur during these conditions.

Table 4-22: Weather conditions during injury collisions involving pedestrians, 2000-2009

	Vancouver	*Calgary*	*Toronto*	*Ottawa*	*Montreal*	*Quebec City*	*Moncton*	*Halifax*
Total injury collisions [a]	51,280	23,509	134,800	19,401	78,942	20,582	3,174	5,914
Injury collisions involving pedestrians (n=)	7,692	2,920	16,023	2,294	14,984	2,191	231	827
% of all injury collisions involving pedestrians	15.0%	12.4%	11.9%	11.8%	19.0%	10.6%	7.3%	14.0%
Pedestrians involved in injury collisions	8,127	3,099	17,117	2,446	15,790	2,274	239	870
Weather conditions for injury collisions involving pedestrians [b]								
Clear or overcast (no active weather)	69.9%	86.7%	80.0%	81.0%	79.6%	80.1%	76.6%	76.5%
Rain	26.3%	3.7%	15.2%	12.0%	13.8%	11.1%	16.5%	13.5%
Snow	1.4%	3.6%	3.3%	4.9%	4.3%	5.0%	2.6%	1.9%
Freezing rain, sleet, hail	0.1%	0.4%	0.2%	0.7%	0.0%	0.0%	0.9%	0.6%
Visibility limitation (drifting snow, fog, smog, dust, etc.)	0.6%	0.1%	0.5%	0.5%	0.3%	0.9%	0.4%	1.3%
Strong wind	0.1%	0.1%	0.1%	0.3%	0.1%	0.0%	0.0%	0.1%
Weather conditions observed (% time)								
Clear or overcast (no active weather)	81.4%	84.8%	81.1%	79.7%	79.6%	75.1%	78.1%	68.9%
Rain	14.7%	4.4%	6.9%	7.8%	8.3%	8.9%	8.5%	8.6%
Snow	0.9%	8.6%	5.4%	7.3%	7.4%	10.1%	7.8%	8.5%
Freezing rain, sleet, hail	0.0%	0.0%	0.2%	0.2%	0.2%	0.3%	0.3%	0.3%
Visibility limitation (drifting snow, fog, smog, dust, etc.)	3.0%	2.3%	6.4%	5.0%	4.6%	5.6%	5.3%	13.7%
Strong wind	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

[a] Montreal and Quebec City collision counts are for 2000-2009; all other cities 2003-2009.
[b] Weather conditions as recorded on collision reporting form.

In addition, a crude risk estimate for pedestrians involved in collisions can be derived from the counts used to produce Appendix J. During a Toronto rain day, 7.4 pedestrians are injured or killed, compared to 6.4 on matched control days, on average, for a simple risk ratio of 1.16. Similarly, a winter precipitation day sees 7.7 pedestrians involved in injury crashes, with 7.2 on corresponding control days, on average (risk estimate 1.07). These estimates suggest that the risk of pedestrian injury is greater on rainy days than winter precipitation days, but elevated during precipitation—regardless of the type.

5 Conclusion

Until recently, the implications of climate change for road safety have not been seriously considered. The current project represents the most comprehensive assessment of its kind—for any country of the world. The report documents the ways in which climate change may affect road safety in Canada, estimates the magnitude of associated risks and identifies which motor vehicle collision types could be most affected by climate change and where they will take place in the future.

It is widely acknowledged that weather of various types create more hazardous operating environments. Precipitation is the most serious weather-related driving risk in Canada, in large part because it simultaneously affects both road friction and driver visibility, but also because precipitation, in all its various forms – rain, drizzle, hail, snow, freezing precipitation and ice pellets – occurs frequently. As a result, the report focuses mainly on precipitation events, although some attention also is given to other weather hazards including reduced visibility, blowing snow, high winds, extreme heat, and wet, snowy or icy roads when precipitation is not occurring.

Using police reports of road collisions that occurred from 2000-2009, the analysis provides quantitative estimates of the collision risk during precipitation and other types of potentially hazardous weather relative to dry, seasonal conditions. These estimates are based on data for eight urban areas – Vancouver, Calgary, Toronto, Ottawa, Montreal, Quebec City, Moncton and Halifax. Overall, the risk of injury collision is 12% higher on days with rainfall as compared to dry days, and there is a clear progression in risk as the daily accumulation of rainfall increases. During winter precipitation events, the relative risk of injury collision is even higher – 22% above normal. There is also some evidence that other weather conditions including reduced visibility, blowing snow, high winds, extreme heat, and wet, snowy or icy roads lead to higher collision rates, although these events occur less frequently.

However, risk estimates vary from city to city – both overall, and also in terms of differences for rainfall versus winter precipitation days and also according to the amount of precipitation received. This finding underscores the importance of working at the local level, and aggregating up in order to obtain locally calibrated, robust estimates of the implications of weather for road safety.

Accordingly, the risk estimates for individual cities are then combined with projections of regional climate change. The impacts of climate change on road safety are expected to result more from changes in precipitation form (e.g., rain versus snow) and amount (i.e., heavy versus light rainfall), than in total seasonal precipitation or precipitation frequency. In this study we use an ensemble of simulations of the Canadian Regional Climate Model driven by different global circulation models. The simulations are combined with historical data in order to estimate the frequency of both rain days and winter precipitation days in the future.

These simulations of future climate are presented for six (of the eight) study areas. As expected, all of the simulations project higher average temperatures in future decades, and changes in annual total precipitation are also mostly positive. Expected changes in annual precipitation days are more variable.

In fact, for five of the six study areas (not Montreal), the different simulations have different bottom lines, with one model suggesting an increase in precipitation days and another indicating a decrease in precipitation days. This is a reasonable outcome, given that the change in frequency of precipitation is expected to be small. For Montreal, all projections indicate that there will be fewer precipitation days in the future. In addition to overall changes in the number of precipitation days, there are location-specific differences in precipitation form and amount.

The resulting implications of climate change for road safety thus depend on local risk rates, as well as changes in the frequency of precipitation events of different types and intensities. Overall, climate change is expected to have regionally specific effects on road safety in Canadian cities. The net effect, which considers changes in the frequency, form and intensities of precipitation days, varies from a decrease of 30% in weather-attributable injury collisions in Calgary to an increase of 4% in weather-attributable injury collisions in Vancouver. Indeed, some locales (Calgary, Toronto) are expected to have substantially fewer weather-attributable injury collisions by the 2050s because of milder winters and fewer days with winter precipitation. The overall increase in Vancouver, and also summer-time increases in other jurisdictions, is linked with projected increases in moderate-to-heavy rainfalls (i.e., daily accumulations greater than 10 mm). The situation for other weather hazards is less certain, but it would appear that fog, blowing snow, and wet, snowy or ice roads will occur less frequently in the future.

The final part of the analysis identifies those subsets of collisions that are over-represented during inclement weather. This provides a way of identifying issues that are of current concern – given present-day climate – and potentially of concern in the future, given the changing nature of climate in Canada. In terms of rain-related collision risk – something that is important today and will be of growing importance in the future because of climate change – the data highlight how rainfall at night is particularly problematic, as is driving in the rain on curved sections of roadway or driving too fast for conditions. As well, collisions at traffic signals and crashes involving pedestrians are over-represented during rainfall.

Collision rates are significantly elevated during winter precipitation in comparison to both dry conditions and rain days, but the frequency of winter precipitation days is expected to decrease across southern Canada by mid-century. Hazards related to snow and ice will continue, however, despite the shorter season in most years and regions. Issues related to snowfall and other winter-weather conditions include more single-vehicle collisions (e.g., those involving run-off-road or hitting a roadside object), more collisions on curved sections of roadway and on gradients, and in some cases on bridges, ramps and other special features. Of particular note are the tendencies for higher speed roads and non-daylight conditions to be over-represented in winter-weather collisions.

In summary, the report highlights the continued importance of inclement weather for road safety outcomes in Canadian cities. Indeed, increases in the frequency and intensity of rainfall events are expected to mostly offset the safety gains associated with shorter and milder winters across urban regions of Canada. With climate change, increased emphasis should be given to rainfall-related driving hazards, especially to the visibility and friction reductions that accompany heavier rainfalls.

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Climate Change and Road Safety: Projections within Urban Areas

Appendices to Final Report – May 2012

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Appendix A: Collision data availability

Collision records from the National Collision Database (NCDB) were provided by Transport Canada for the variables marked with an 'X' in Table A-1.

For the six cities outside the province of Quebec, NCDB data are available for 2000-2009, with the following exceptions:

- Calgary data available for 2003-2009 only (police detachment/location information missing for 2000-2002)
- Vehicle and person-level variables provided for 2003-2009 only (except element 64: medical treatment required, which is available for all years)
- Information on property-damage-only collisions available for 2001-2009 only (2000 data are for injury collisions only)

For the two Quebec cities, data were provided by Transports Québec (MTQ) for 2000-2009 and were transposed to the NCDB format where possible (i.e., where variables were directly comparable). Table A-1 refers to the transposed version of Quebec variables; Table A-2 contains a list of all variables provided by MTQ.

Note than an 'X' in the table does not necessarily indicate that records are complete for a given variable or city, only that they were provided in some form.

Table A-1: Availability of data elements from the National Collision Database for 8 study cities

Data element number/description	**Vancouver**	**Calgary**	**Toronto**	**Ottawa**	**Montreal**	**Quebec City**	**Moncton**	**Halifax**
Time and location information								
1. Province	X	X	X	X	X	X	X	X
2. Police detachment/region code	X	X	X	X	X	X	X	X
3. Collision case number	X	X	X	X	X	X	X	X
4. Scene attended (by police: yes/no)	X	X						X
5. Year of collision	X	X	X	X	X	X	X	X
6. Month of collision	X	X	X	X	X	X	X	X
7. Day of the month	X	X	X	X	X	X	X	X
8. Day of the week	X	X	X	X	X	X	X	X
9. Hour of collision	X	X	X	X	X	X	X	X
Collision-level variables								
10. Severity of collision (PDO, non-fatal injury, fatal)	X	X	X	X	X	X	X	X
11. Number of persons killed	X	X	X	X	X	X	X	X
12. Number of persons injured	X	X	X	X	X	X	X	X

Table A-1: Availability of data elements from the National Collision Database for 8 study cities

Data element number/description	Vancouver	Calgary	Toronto	Ottawa	Montreal	Quebec City	Moncton	Halifax
13. Number of vehicles involved	X	X	X	X	X	X	X	X
14. Collision configuration (run-off-road, rear-end, turn conflict, etc.)	X	X	X	X	X	X	X	X
15. Hit & run flag (yes/no)	X	X	X	X				X
16. Roadway configuration (intersection, rail crossing, bridge, freeway, etc.)	X	X	X	X	X	X	X	X
17. Weather condition	X	X	X	X	X	X	X	X
18. Light condition	X	X	X	X	X	X	X	X
19. Artificial light condition (artificial illumination available/not available)	X	X	X	X	X	X	X	X
20. Road classification I (urban/rural)	X	X	X	X			X	X
21. Road classification II (freeway, arterial, collector, local)								X
22. Road classification III (# lanes, one-way, divided, etc.)	X	X	X	X			X	X
23. Road surface material	X	X	X	X	X	X	X	X
24. Road surface condition (dry, wet, snowy/icy, etc.)	X	X	X	X	X	X	X	X
25. Road repair condition		X	X	X	X	X	X	X
26. Road alignment (straight/curved, level/gradient)	X	X	X	X	X	X	X	X
27. Traffic control (light, sign, pavement marking, crossing guard, etc.)	X	X	X	X	X	X	X	X
28. Posted speed limit	X		X	X	X	X	X	X
Vehicle-level variables								
29. Vehicle sequence number	X	X	X	X	X	X	X	X
30. Number of occupants in vehicle		X	X	X			X	X
31. Direction of travel	X		X	X			X	X
32. Vehicle license jurisdiction	X	X	X	X			X	X
33. Vehicle identification number								
34. Vehicle model year	X	X	X	X	X	X	X	X
35. Vehicle type					X	X		
36. Vehicle use (taxi, utility, emergency, work, etc.)	X		X	X	X	X		X
37. Emergency use (emergency situation/response mode: yes/no)			X	X				X
38. Trailer type		X	X	X			X	X
39. Use of vehicle headlights								
40. Vehicle speed			X	X				
41. Vehicle manoeuvre	X		X	X	X	X	X	X
42. Vehicle damage severity	X	X	X	X				X
43. First impact location	X	X	X	X			X	X
44. Vehicle event #1	X	X	X	X			X	X
45. Vehicle event #2	X	X	X	X			X	X
46. Vehicle event #3		X	X	X			X	X
47. Contributing factor #1	X	X	X	X			X	X
48. Contributing factor #2	X	X	X	X			X	X

Table A-1: Availability of data elements from the National Collision Database for 8 study cities

Data element number/description	**Vancouver**	**Calgary**	**Toronto**	**Ottawa**	**Montreal**	**Quebec City**	**Moncton**	**Halifax**
49. Contributing factor #3	X	X	X	X			X	X
50. Contributing factor #4		X					X	X
51. Prioritization of contributing factors								
52. Dangerous goods class	X	X					X	X
53. Load status of commercial vehicles			X	X			X	X
Person-level variables								
54. Person sequence number	X	X	X	X	X	X	X	X
55. Person sex	X	X	X	X	X	X	X	X
56. Person age	X	X	X	X	X	X	X	X
57. Years licensed in jurisdiction							X	X
58. License status		X	X	X				X
59. Province of driver's license	X	X	X	X			X	X
60. Blood alcohol concentration			X	X				
61. Person position (seating position inside/outside vehicle, pedestrian)	X	X	X	X	X	X	X	X
62. Occupant ejection from vehicle	X		X	X			X	X
63. Ejection location								
64. Medical treatment required (i.e., injury severity)	X	X	X	X	X	X	X	X
65. Safety device used (seatbelt, booster seat, helmet, etc.)	X	X	X	X	X	X	X	X
66. Proper usage of safety device (yes, no, none fitted)	X		X	X	X	X		
67. Air bag deployment	X	X	X	X			X	X
68. Pedestrian action	X	X	X	X	X	X	X	X

Table A-2: Variables provided by Transports Québec for Montreal and Quebec City

Variable	***Transposed***	***Variable***	***Transposed***
Collision-level variables		*Vehicle-level variables*	
Accident date	Yes	Event number	Yes
Accident hour	Yes	Vehicle ID number	Yes
Event number	Yes	Traffic control/signal	Yes
Accident severity	Yes	Visibility	No
Number of persons severely injured	Yes	Vehicle type	Yes
Number of persons slightly injured	Yes	Vehicle model year	Yes
Number of persons killed	Yes	Vehicle movement	Yes
Number of vehicles involved	Yes	Type/condition of tires	No
Municipal code	No	*Person-level variables*	
Municipality name	No	Event number	Yes
City	Yes	Person ID number	Yes
Authorized speed limit	Yes	Pedestrian action	Yes
Type of accident	Yes	Person age	Yes
Weather condition	Yes	Person sex	Yes
Road surface condition	Yes	Person position	Yes
Light condition	Yes	Person injury severity	Yes
Environment/land use	No	Restraint/safety device used	Yes
Road classification	No		
Road alignment/aspect	Yes		
Roadway configuration	Yes		
Road surface material	Yes		
Road repair condition	Yes		
Accident configuration	Yes		

Appendix B: Study area definitions

Vancouver

The Vancouver study area (Figure B-1) comprises the Vancouver, White Rock and Walnut Grove urban areas as defined by statistics Canada, with a combined 2006 population of 2.05 million spread over almost 1,200 km^2. The area accounts for most of Vancouver census metropolitan area's population (2.12 million), but is substantially smaller in land area (2,877 km^2).

The study area – with almost 150,000 collisions over the 10-year study period – coincides approximately with the following police detachment codes from the NCDB:

401	Vancouver (municipal police)	716	Langley City (RCMP)
407	Delta (municipal police)	717	Langley Township (RCMP)
409	New Westminster (municipal police)	720	North Vancouver City (RCMP)
410	West Vancouver (municipal police)	721	North Vancouver District (RCMP)
412	Port Moody (municipal police)	722	Richmond (RCMP)
704	Burnaby (RCMP)	726	Surrey (RCMP)
710	Coquitlam (RCMP)	727	University (RCMP)
711	Port Coquitlam (RCMP)	729	White Rock (RCMP)
713	Maple Ridge (RCMP)	741	Pitt Meadows (RCMP)

Calgary

The Calgary study area (Figure B-2) coincides with the municipal boundaries of the City of Calgary, home to almost 1 million people (2006) in an area of roughly 727 square kilometres. It is slightly less populated and covers a significantly smaller land area than the Calgary CMA (1.08 million people and 5,107 km^2).

The area is defined by two police service codes: CPS (Calgary Police Service) and K0486 (Calgary International Airport RCMP). The City of Calgary had approximately 285,000 total crashes over the 2003-2009 period.

Toronto

The Toronto study area (Figure B-3) is roughly conterminous with the Toronto urban area defined by Statistics Canada (population 4.75 million, land area 1,749 km^2) – with 360,000 fewer people than the Toronto CMA (5.11 million) over a land area roughly 30% of the size (5,904 square kilometres).

This area, which saw more than 852,000 collisions in the 2000-2009 study period, comprises the following county/municipality codes:

80140	Ajax; Pickering Village	545981	Newmarket
86350	Claremont; Pickering	546056	North York; Willowdale
176082	Oakville	546612	Richmond Hill
361257	Bramalea; Brampton; Chinguacousy Township; Toronto Gore	546834	Scarborough
365753	Mississauga; Port Credit; Streetsville	547390	CF Toronto; CFB Toronto; Metropolitan Toronto
540500	Aurora	547392	Toronto
542746	East York	547511	Vaughan
542975	Etobicoke	547780	York
545382	Markham		

<table>
<tr><td>Ottawa</td><td>The Ottawa study area (Figure B-4) is comprised of the Ottawa and Kanata urban regions defined by Statistics Canada. Its population and land area are approximately 734,000 people and 422 km^2, respectively, compared to 847,000 persons and 3,274 km^2 for the Ontario part of the Ottawa-Gatineau CMA.

The area had slightly more than 121,000 crashes in the study period, and is defined by the following eight county/municipality codes:
<table>
<tr><td>043716</td><td>Goulbourn Township; Richmond; Stittsville</td><td>046162</td><td>Kenmore; Metcalfe; Orleans; Osgoode Township</td></tr>
<tr><td>045360</td><td>Kanata</td><td>046190</td><td>Ottawa</td></tr>
<tr><td>045497</td><td>City View</td><td>046654</td><td>Rockcliffe Park</td></tr>
<tr><td>045947</td><td>Nepean</td><td>047501</td><td>Vanier</td></tr>
</table></td></tr>
<tr><td>Montreal</td><td>The Montreal study area (Figure B-5) covers the Island of Montreal (Statistics Canada's Montreal census division), with a population of 1.85 million in a land area of 499 square kilometres. Comparatively, the Montreal CMA extends onto the mainland, with 3.64 million inhabitants over 4,259 km^2.

Collision data for 438,000 study-period crashes in Montreal were directly provided by Transports Québec.</td></tr>
<tr><td>Quebec City</td><td>The Quebec City study area (Figure B-6) coincides with the boundaries of the City of Quebec (pre-2000 amalgamation/fusion), home to 491,000 people over 454 km^2. It is smaller than the Quebec CMA, which has a population of 716,000 and land area of 3,277 km^2.

Collision data (n=174,000) for Quebec City were directly provided by Transports Québec.</td></tr>
<tr><td>Moncton</td><td>The Moncton study area (Figure B-7) comprises the Moncton urban area defined by Statistics Canada (population 97,000; land area 146 square kilometres). For comparison, the Moncton CMA is home to 126,000 people in an area roughly 16 times the size (2,406 km^2).

The area – which saw approximately 15,000 collisions between 2000 and 2009 – is defined by three municipality codes: 9 (City of Moncton), 15 (City of Dieppe) and 58 (Town of Riverview).</td></tr>
<tr><td>Halifax</td><td>The Halifax study area (Figure B-8) has approximately the same boundaries as the Halifax urban area defined by Statistics Canada, with 283,000 inhabitants and a land area of 263 km^2. It is home to three-quarters of the CMA population (373,000) in an area one-twentieth of the size (5,496 square kilometres).

The area comprises three detachments of the Halifax Regional Police: M4020 (Dartmouth), M4060 (Halifax) and M4253 (Bedford). Roughly 39,000 crashes occurred here during the study period.</td></tr>
</table>

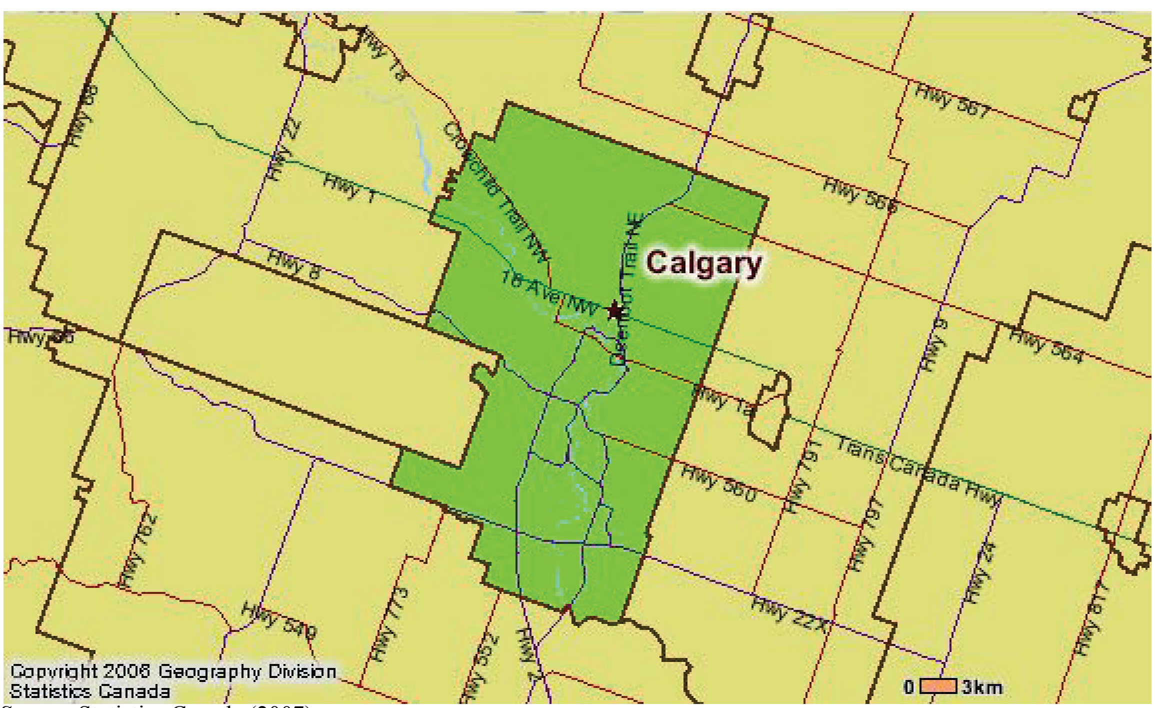
Figure B-1: Vancouver urban area

The Vancouver study area comprises three parts:

1. Vancouver urban area (shaded green area)
2. White Rock urban area (shaded yellow area directly south of Surrey)
3. Walnut Grove urban area (shaded yellow area halfway between Maple Ridge and Langley)

Source: Statistics Canada (2007)

Figure B-2: City of Calgary

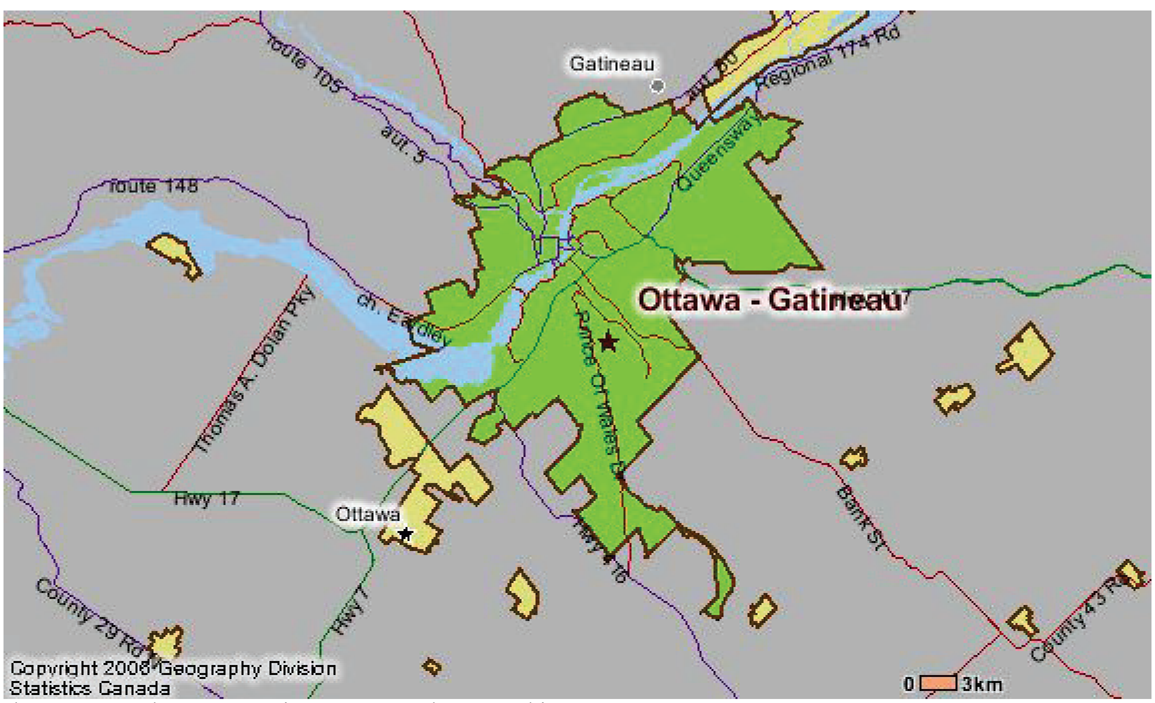


Source: Statistics Canada (2007)

Figure B-3: Toronto urban area

Source: Statistics Canada (2007)

Figure B-4: Ottawa urban area

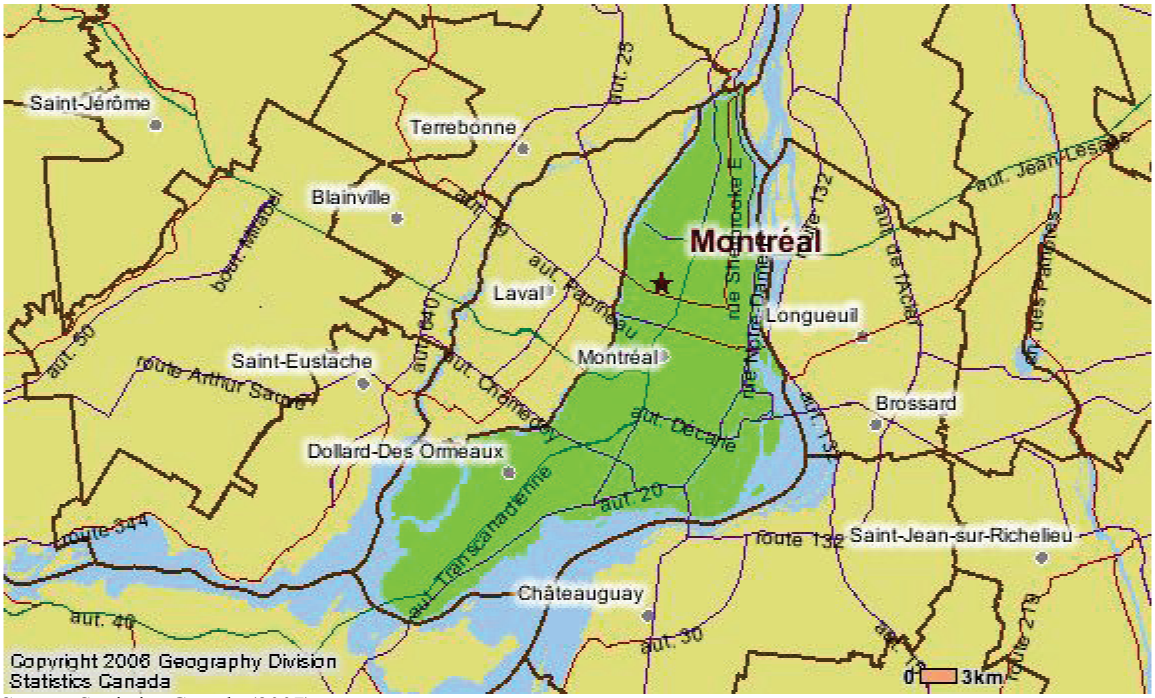


The Ottawa study area comprises two areas shown on this map:

1. Ontario part of the Ottawa-Gatineau urban area (shaded green area south of the Ottawa river, but not on north side)
2. Kanata urban area (smaller 'reverse L-shaped' yellow shaded area to the west of Ottawa)

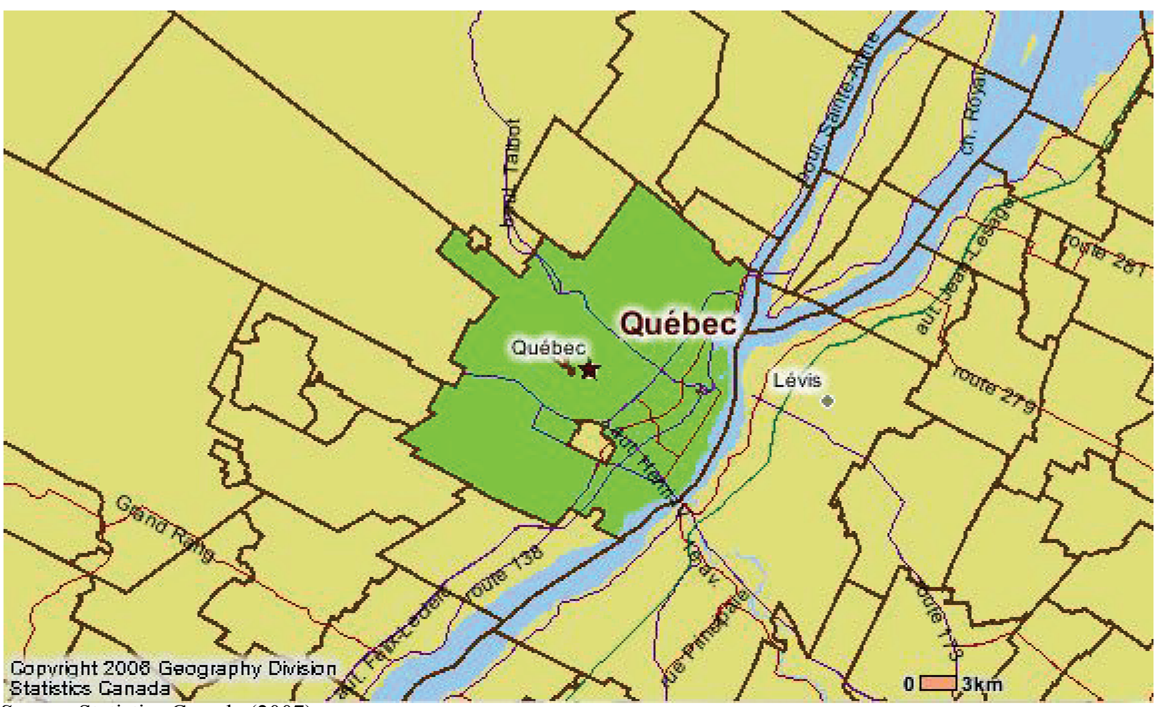
Source: Statistics Canada (2007)

Figure B-5: Island of Montreal



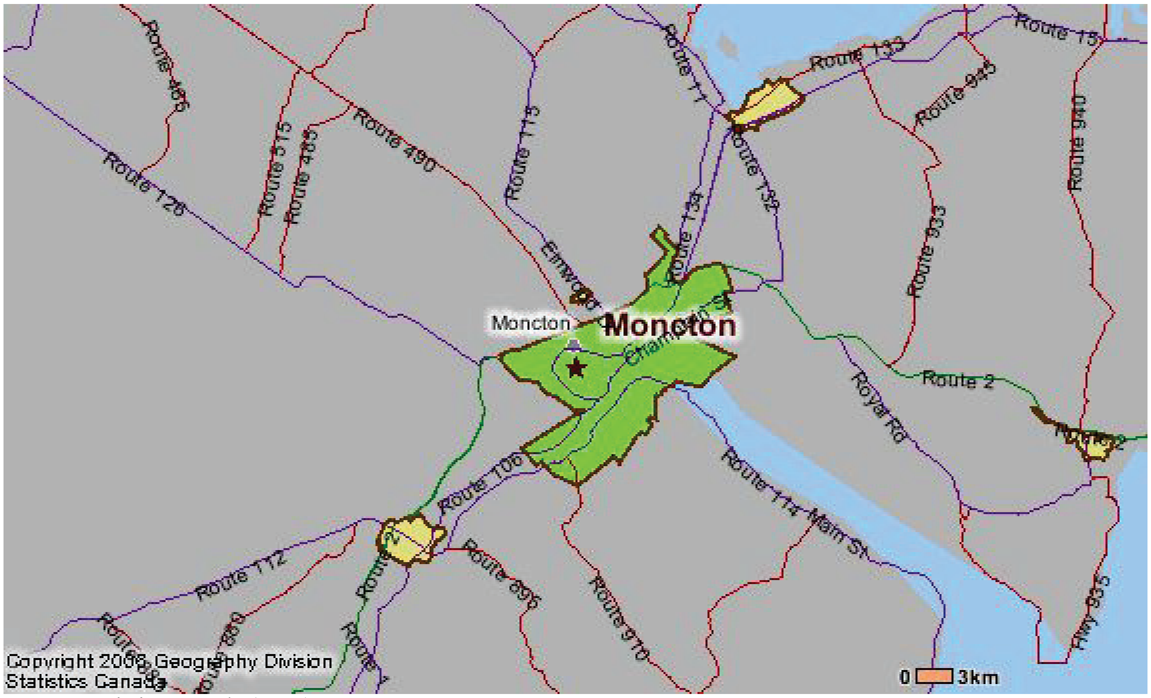
Source: Statistics Canada (2007)

Figure B-6: Old City of Quebec



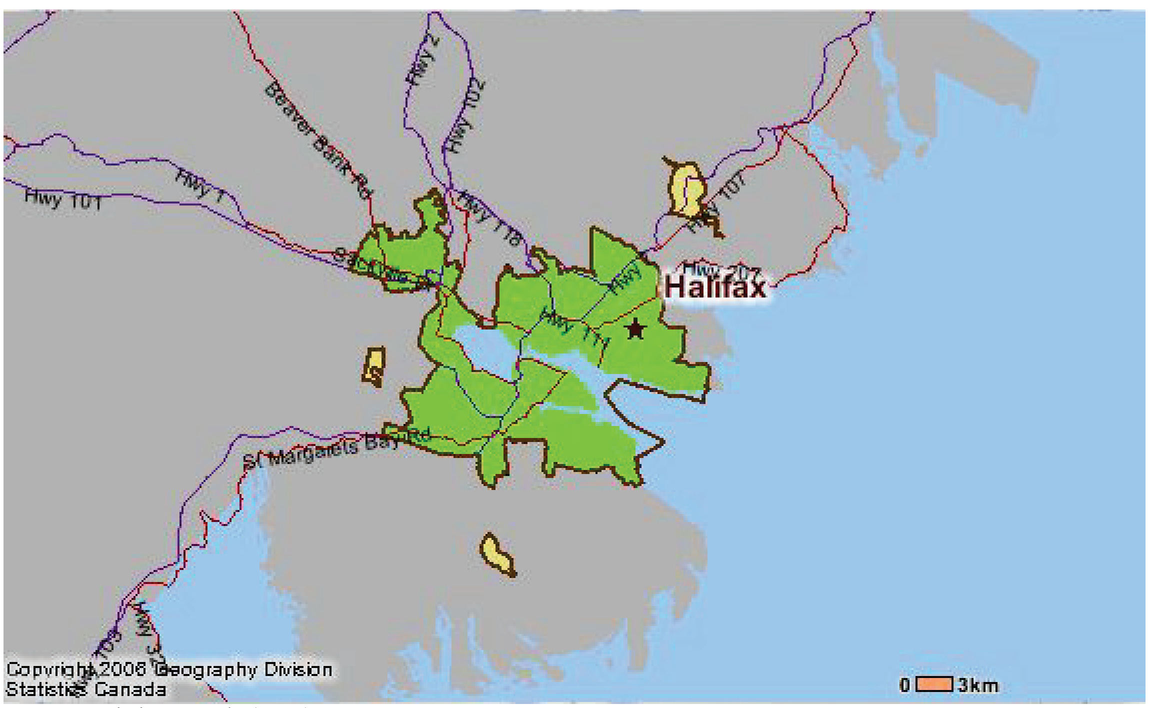
Source: Statistics Canada (2007)

Figure B-7: Moncton urban area



Source: Statistics Canada (2007)

Figure B-8: Halifax urban area



Source: Statistics Canada (2007)

Appendix C: Weather conditions observed (% time) at Canadian cities, 1984-2000

City	*Clear/no active weather*	*Rainfall*	*Snowfall*	*Other frozen precipitation*	*Fog, smog, or mist*	*Dust or 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	82.20	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	0.86	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
Reproduced from: Andrey et al. (2005)								

Appendix D: Relative risk calculation

In order to estimate weather-related collision risk, odds ratios are calculated, as per Johansson et al. (2009). These ratios represent the probability of a collision occurring during one condition (i.e., inclement weather) relative to the odds of a crash during a different condition (i.e., dry, seasonal conditions). Each matched pair produces four counts, as shown in Table D-1.

Table D-1: Collision counts used in calculating odds ratios

Count	*Description*
A	Collisions during the control period
B	Collisions during the event period
C	Estimate of safe outcomes* during the control period
D	Estimate of safe outcomes* during the event
*Safe outcomes represent the number of trips during which no collision occurred; these are large in urban areas, and therefore can be assigned an arbitrarily large value (e.g., one million).	

From these counts, an odds ratio is calculated for each matched pair as follows:

$$Odds\ ratio = \frac{(B/D)}{(A/C)} = \frac{(Collisions\ during\ rainfall\ /\ Safe\ outcomes\ during\ rainfall)}{(Collisions\ on\ dry\ days\ /\ Safe\ outcomes\ on\ dry\ days)}$$

The logarithm of the odds ratio (y_i) is then computed, for which the variance (v_i) is calculated as:

$$y_i = \ln\frac{(B/D)}{(A/C)} \qquad v_i = \frac{1}{A} + \frac{1}{B} + \frac{1}{C} + \frac{1}{D}$$

Estimates of risk can be combined from odds ratios for individual matched pairs using one of two methods: the fixed-effects model and the random-effects model. The fixed-effects model assumes that the variation in risk estimates is random only, while the random-effects model adds a variance component to each matched pair's statistical weight. Using the fixed effects model, the statistical weight (w_i) – which is inversely proportional to the variance – is calculated for each matched pair as:

$$w_i = \frac{1}{v_i}$$

The weighted mean effect ($\bar{y}$) on a set of g matched pairs is then calculated:

$$\bar{y} = \exp\left(\frac{\sum_{i=1}^{g} w_i y_i}{\sum_{i=1}^{g} w_i}\right)$$

An overall relative risk estimate is obtained by taking the antilog of this value. To test the validity of the variation assumption in the fixed-effects model, a Q test is performed as follows (with $g - 1$ degrees of freedom); if the test statistic is statistically significant, a random-effects model is used instead.

$$Q = \sum_{i=1}^{g} w_i y_i^2 - \frac{\left(\sum_{i=1}^{g} w_i y_i\right)^2}{\sum_{i=1}^{g} w_i}$$

In this study, some Q test statistics were found to be statistically significant, so for these a variance component (σ_θ^2) is calculated for use in the random-effects model:

$$\sigma_\theta^2 = \frac{[Q - (g - 1)]}{c}$$

Where c, an estimator, is:

$$c = \sum_{i=1}^{g} w_i - \left[\frac{\sum_{i=1}^{g} w_i^2}{\sum_{i=1}^{g} w_i}\right]$$

In the random-effects model, the variance for each event-control pair becomes:

$$v_i^* = \sigma_\theta^2 + v_i$$

And each pair's statistical weight becomes:

$$w_i^* = \frac{1}{v_i^*}$$

A new weighted mean estimate for the set of matched pairs is calculated as:

$$\bar{y} = \exp\left(\frac{\sum_{i=1}^{g} w_i^* y_i}{\sum_{i=1}^{g} w_i^*}\right)$$

Again, an overall estimate of relative risk is obtained by taking the antilog of this value. The standard error of the risk estimate is calculated as:

$$SE = \frac{1}{\sqrt{\sum_{i=1}^{g} w_i^*}}$$

The standard error is used to calculate 95% confidence intervals for the estimate of effect:

$$95\%\ confidence\ interval = risk\ estimate\ \pm 1.96 \times SE$$

Finally, by anti-logging these values, upper and lower confidence limits for the risk estimate are obtained. The latter two steps can also be illustrated as:

$$95\%\ C.I. = exp\left[\left(\sum_{i=1}^{g} w_i^* y_i \,/\, \sum_{i=1}^{g} w_i^*\right) \pm 1.96 * \left(1/\sqrt{\sum\nolimits_{i=1}^{g} w_i^*}\right)\right]$$

Appendix E: Relative risk sensitivity analysis

In order to arrive at unbiased estimates, care was taken to ensure that the matched events provide a representative set of days on which to base the risk estimates. In the first pass through the data, it was noted that the monthly distribution of matched events did not coincide with the monthly distribution of all event days. Closer investigation indicated that this was because there were few control days during snowy winter seasons, especially in areas where roads remain icy, snowy or wet for an extended period of time, e.g., Ottawa and Quebec City. To ensure that this did not result in seasonal bias in the risk estimates, the analysis was re-run using a less restrictive criterion for road conditions. The initial criterion, as explained in Table E-1, ensured that at least 85% of the collisions that occurred during control periods occurred on dry roads. When the analysis was re-run, the cutoff value was reduced to 50%, which resulted in a seasonal distribution of matched events that more closely aligned with the seasonal distribution of all events. Of importance to the current study is the fact that the relative risk estimates were largely unaffected by the dry-road criterion. As such, the analysis proceeded using the 85% cutoff value – as this represents the purest contrast between inclement weather conditions and good, seasonal conditions. The results of this sensitivity analysis are included in Tables E-2 and E-3 of this appendix.

Table E-1: Criteria used to define events and controls

Event Criteria	• Daily precipitation accumulation of at least 0.4 mm (liquid equivalent) to ensure sufficient moisture to wet roads • Rain or winter precipitation days classified according to daily minimum temperature • Holidays and other special days not included
Control Criteria	• Same day-of-week as the event, either one or two weeks prior or following • Daily precipitation accumulation equal to zero • Zero hourly observations of fog • Average hourly wind speed less than 40 km/h • Dry roads reported at the time of collision for at least 85% of collisions • Holidays and other special days not included

Table E-2: Seasonal distribution of weather events and matched pairs (≥ 1 mm precipitation)[1]

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Year: 100% (n=)*
Vancouver													
% of precipitation days, 1971-2000	11.7%	10.4%	10.5%	8.0%	7.1%	6.1%	3.8%	3.7%	4.9%	8.7%	12.7%	12.5%	4,067
% of precipitation days, 2000-2009	13.5%	8.4%	11.3%	8.2%	7.7%	5.2%	3.2%	3.5%	5.0%	9.4%	12.2%	12.3%	1,371
% of matched pairs													
≥ 85% of control collisions on dry roads	7.8%	9.7%	14.1%	11.2%	10.3%	8.0%	5.3%	5.0%	7.3%	9.3%	9.2%	3.0%	797
≥ 50% of control collisions on dry roads	10.4%	9.5%	12.5%	9.7%	8.8%	6.8%	4.5%	4.2%	6.2%	9.4%	11.5%	6.6%	943
Calgary													
% of precipitation days, 1971-2000	5.8%	4.3%	6.1%	7.7%	12.1%	14.8%	14.0%	11.0%	9.3%	5.3%	4.7%	4.8%	2,076
% of precipitation days, 2003-2009	4.7%	7.1%	6.2%	8.6%	10.5%	15.0%	11.0%	10.7%	8.4%	7.3%	4.9%	5.6%	534
% of matched pairs													
≥ 85% of control collisions on dry roads	3.3%	7.3%	5.7%	9.5%	9.3%	16.3%	11.5%	10.4%	9.5%	7.5%	5.5%	4.2%	453
≥ 50% of control collisions on dry roads	4.1%	7.8%	5.8%	9.3%	9.1%	16.0%	11.2%	10.2%	9.3%	7.3%	5.6%	4.3%	463
Toronto													
% of precipitation days, 1971-2000	8.7%	7.4%	8.4%	8.7%	8.6%	8.6%	7.7%	7.7%	8.1%	8.0%	8.6%	9.4%	3,078
% of precipitation days, 2000-2009	9.1%	7.9%	8.1%	8.7%	8.7%	8.6%	7.8%	6.9%	6.4%	8.8%	8.9%	10.2%	1,068
% of matched pairs													
≥ 85% of control collisions on dry roads	4.0%	7.2%	8.9%	10.3%	9.9%	10.4%	8.9%	8.5%	7.0%	9.5%	10.4%	5.0%	828
≥ 50% of control collisions on dry roads	7.9%	8.5%	9.1%	9.3%	9.0%	9.5%	8.1%	7.7%	6.4%	8.7%	10.0%	5.8%	910

[1] Although relative risk estimates are reported in the present-day risk analysis for all days with measureable precipitation (i.e., at least 0.4 mm), the sensitivity analysis was concerned only with days with ≥ 1 mm of rain or winter precipitation; this is because the latter are the focus of the future climate component of the study.

Table E-2: Seasonal distribution of weather events and matched pairs (≥ 1 mm precipitation)[1]

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Year: 100% (n=)*
Ottawa													
% of precipitation days, 1971-2000	9.8%	7.4%	8.5%	7.7%	8.3%	8.0%	7.7%	7.2%	8.3%	8.2%	9.0%	10.0%	3,583
% of precipitation days, 2000-2009	8.4%	7.6%	7.1%	8.5%	8.6%	8.9%	8.7%	6.8%	6.7%	9.6%	8.9%	10.1%	1,219
% of matched pairs													
≥ 85% of control collisions on dry roads	2.0%	5.4%	8.1%	10.8%	10.3%	10.7%	9.7%	8.3%	9.2%	11.6%	10.8%	3.2%	816
≥ 50% of control collisions on dry roads	5.6%	8.5%	8.2%	9.6%	9.1%	9.4%	8.5%	7.3%	8.1%	10.3%	10.7%	4.7%	928
Montreal													
% of precipitation days, 1971-2000	9.4%	7.3%	8.6%	8.1%	8.2%	7.9%	8.2%	7.9%	7.7%	8.2%	9.2%	9.2%	3,662
% of precipitation days, 2000-2009	8.1%	7.1%	8.3%	8.3%	9.3%	8.0%	9.6%	6.8%	6.3%	8.2%	9.3%	10.7%	1,221
% of matched pairs													
≥ 85% of control collisions on dry roads	1.3%	4.1%	7.6%	10.2%	11.6%	9.6%	11.3%	9.2%	8.6%	9.8%	11.9%	4.7%	850
≥ 50% of control collisions on dry roads	3.8%	6.9%	9.0%	9.4%	10.5%	8.8%	10.2%	8.3%	7.7%	8.8%	10.9%	5.7%	944
Quebec City													
% of precipitation days, 1971-2000	9.4%	7.4%	7.7%	7.6%	8.3%	8.2%	8.1%	8.0%	8.0%	8.2%	9.1%	9.9%	3,450
% of precipitation days, 2000-2009	8.3%	7.5%	7.6%	8.3%	8.0%	8.6%	10.0%	7.9%	6.7%	7.9%	8.7%	10.5%	1,295
% of matched pairs													
≥ 85% of control collisions on dry roads	0.1%	0.4%	5.9%	11.4%	10.9%	11.8%	12.6%	11.8%	10.3%	10.5%	11.1%	3.0%	760
≥ 50% of control collisions on dry roads	1.3%	5.5%	9.2%	10.1%	9.3%	10.0%	10.6%	10.0%	8.6%	9.2%	10.8%	5.4%	904
Moncton													
% of precipitation days, 1971-2000	9.4%	7.6%	9.0%	9.2%	8.5%	7.9%	7.6%	7.0%	7.1%	7.9%	8.9%	10.0%	3,976
% of precipitation days, 2000-2009	8.7%	6.9%	8.0%	9.5%	9.5%	8.6%	8.4%	7.3%	6.2%	8.5%	9.3%	9.1%	1,310
% of matched pairs													
≥ 85% of control collisions on dry roads	3.5%	5.2%	10.6%	10.7%	9.7%	9.8%	9.7%	7.1%	7.2%	9.2%	11.7%	5.5%	887
≥ 50% of control collisions on dry roads	5.5%	7.3%	10.3%	10.1%	9.2%	9.2%	8.9%	6.7%	6.8%	8.7%	10.8%	6.6%	961

Table E-2: Seasonal distribution of weather events and matched pairs (≥ 1 mm precipitation)[1]

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Year: 100% (n=)*
Halifax													
% of precipitation days, 1971-2000	10.8%	8.2%	9.2%	9.1%	8.6%	7.4%	6.8%	6.2%	6.2%	7.5%	9.0%	10.9%	3,862
% of precipitation days, 2000-2009	11.4%	8.3%	9.4%	8.9%	7.6%	7.8%	6.0%	6.9%	5.2%	8.2%	8.9%	11.4%	1,224
% of matched pairs													
≥ 85% of control collisions on dry roads	6.4%	7.6%	11.6%	10.8%	7.1%	8.1%	5.3%	6.7%	6.9%	10.3%	10.9%	8.4%	778
≥ 50% of control collisions on dry roads	8.5%	9.0%	12.1%	10.0%	6.4%	7.3%	4.9%	6.3%	6.3%	9.4%	11.2%	8.7%	860

Table E-3: Effect of control dry road restrictiveness on risk estimates (with 95% confidence intervals in brackets)

	Vancouver	*Calgary*	*Toronto*	*Ottawa*	*Montreal*	*Quebec City*	*Moncton*	*Halifax*
Rain days (minimum temperature ≥ 0.5 °C)								
≥ 85% of control collisions on dry roads	1.23 (1.20-1.27)	0.94 (0.89-0.99)	1.12 (1.10-1.14)	1.10 (1.06-1.14)	1.07 (1.04-1.09)	1.02 (0.97-1.07)	0.95 (0.86-1.05)	1.03 (0.96-1.12)
≥ 50% of control collisions on dry roads	1.23 (1.21-1.26)	0.94 (0.89-0.99)	1.12 (1.09-1.14)	1.09 (1.05-1.14)	1.06 (1.04-1.09)	1.02 (0.98-1.07)	0.93 (0.84-1.02)	1.04 (0.96-1.12)
Winter precipitation days (minimum temperature < 0.5 °C)								
≥ 85% of control collisions on dry roads	1.27 (1.13-1.44)	1.22 (1.13-1.30)	1.26 (1.21-1.31)	1.24 (1.15-1.34)	1.12 (1.07-1.18)	1.11 (1.01-1.21)	0.98 (0.87-1.12)	1.04 (0.95-1.15)
≥ 50% of control collisions on dry roads	1.24 (1.11-1.38)	1.21 (1.13-1.29)	1.19 (1.14-1.23)	1.11 (1.04-1.18)	1.09 (1.05-1.13)	1.14 (1.05-1.23)	0.95 (0.85-1.06)	0.98 (0.90-1.06)

Appendix F: Weather-related driving risks for 6-hour periods

F.1 Weather conditions for analysis

Originally it was planned to conduct the entire study using 6-hours as the temporal unit of analysis. In April 2012, it was advised that the climate scenario data were more robust at the daily level, and so the temporal unit of analysis was changed. The results for 6-hour periods, as presented in this appendix, are from the preliminary analysis completed for the 50% draft report and are included here.

Three precipitation types are examined, and these are further broken down according to precipitation amount[2]. Thus the weather conditions used in the 6-hourly analysis are:

- **Rain** (including hail; 6-hour average temperature ≥ 2 °C)
    - Light accumulation: ≥ 0.4 to < 2.0 mm
    - Moderate accumulation: ≥ 2.0 to < 10.0 mm
    - Heavy accumulation: ≥ 10.0 mm
- **Transition/near-freezing precipitation** (6-hour average temperature ≥ -3 °C to < 2 °C)
- **Snow** (6-hour average temperature < -3 °C)
    - Light accumulation: ≥ 0.4 to < 2.0 cm
    - Moderate to heavy accumulation: ≥ 2.0 cm

F.1.1 Event and control definitions

Precipitation events and matched control periods were defined using the criteria in Table F-1. The proportion of 6-hour periods meeting the event criteria ranged from 22.8% of all periods in Vancouver (i.e., 3,133 rain + 11 snow + 183 transition / 14,612 total 6-hour periods) to 11.6% in Calgary (Table F-2 through Table F-9). This is as would be expected, given the relatively wet climate of Vancouver and the drier climate of Calgary. Indeed, two-thirds of Calgary's 6-hour periods had no active weather, compared to 40% in Halifax. Holidays and other special days (e.g., long weekends, Christmas break) that typically have altered traffic patterns were then removed, for an average loss of 8-11 % of potential events and controls. Counts of matched event-control pairs for each city and precipitation category are provided in Table F-10.

[2] Initially, three subcategories were examined for snowfall; however, 6-hour snowfall accumulation ≥ 10 cm is rarely observed (1 6-hour period in Vancouver, 0 in Calgary, 4 in Toronto, 12 in Ottawa, and 14 in Halifax) so moderate and heavy snowfall were combined into one to allow more robust risk estimates.

Table F-1: Criteria used to define events and controls

Event Criteria	• 6-hour precipitation accumulation of at least 0.4 mm (liquid equivalent) • Precipitation type (rain, transition/near-freezing, snow) classified according to 6-hour average temperature for each period that meets the accumulation criterion • Holidays and other special days not included
Control Criteria	• Same clock time as the event, either one or two weeks before or after the event • 6-hour precipitation accumulation equal to zero • Zero hourly observations of fog • Average hourly wind speed less than 40 km/h • Dry roads reported at the time of collision for at least 85% of collisions during the control period • Holidays and other special days not included

Table F-2: Characteristics of all 6-hour event and control periods, Vancouver, 2000-2009

Precipitation type/amount	*Count of 6-hour periods*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
All rainfall (≥ 0.4 mm)	3,133	3.9	3.3	6.5
Light accumulation (0.4-1.9 mm)	1,529	2.9	0.9	5.9
Moderate accumulation (2.0-9.9 mm)	1,417	4.7	4.5	6.8
Heavy accumulation (≥ 10.0 mm)	191	5.6	13.9	8.0
All snowfall (≥ 0.4 mm)	11	5.0	3.2	3.6
Light accumulation (0.4-1.9 mm)	4	5.0	0.8	4.3
Moderate to heavy accumulation (≥ 2.0 mm)	7	5.0	4.5	3.3
Transition/near-freezing precipitation (≥ 0.4 mm)	183	4.7	3.7	5.1
Controls	7,354			4.8
All 6-hour periods	14,612			5.1

Table F-3: Characteristics of all 6-hour event and control periods, Calgary, 2003-2009

Precipitation type/amount	*Count of 6-hour periods*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
All rainfall (≥ 0.4 mm)	688	3.5	3.4	2.6
Light accumulation (0.4-1.9 mm)	371	3.0	0.9	2.4
Moderate accumulation (2.0-9.9 mm)	264	4.1	4.5	2.7
Heavy accumulation (≥ 10.0 mm)	53	4.9	15.9	3.4
All snowfall (≥ 0.4 mm)	316	5.4	1.1	2.9
Light accumulation (0.4-1.9 mm)	274	5.3	0.8	2.8
Moderate to heavy accumulation (≥ 2.0 mm)	42	5.6	3.2	4.0
Transition/near-freezing precipitation (≥ 0.4 mm)	180	4.8	1.9	2.6
Controls	6,805			2.3
All 6-hour periods	10,228			2.3

Table F-4: Characteristics of all 6-hour event and control periods, Toronto, 2000-2009

Precipitation type/amount	*Count of 6-hour periods*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
All rainfall (≥ 0.4 mm)	1,669	3.4	3.8	18.2
Light accumulation (0.4-1.9 mm)	802	2.7	0.9	16.5
Moderate accumulation (2.0-9.9 mm)	710	4.0	4.6	19.6
Heavy accumulation (≥ 10.0 mm)	157	4.6	15.6	21.0
All snowfall (≥ 0.4 mm)	288	4.9	2.0	19.4
Light accumulation (0.4-1.9 mm)	192	4.6	0.9	18.1
Moderate to heavy accumulation (≥ 2.0 mm)	96	5.5	4.3	22.1
Transition/near-freezing precipitation (≥ 0.4 mm)	349	4.5	2.5	18.8
Controls	8,405			13.5
All 6-hour periods	14,612			14.0

Table F-5: Characteristics of all 6-hour event and control periods, Ottawa, 2000-2009

Precipitation type/amount	*Count of 6-hour periods*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
All rainfall (≥ 0.4 mm)	1,681	3.4	4.1	2.5
Light accumulation (0.4-1.9 mm)	742	2.7	0.9	2.2
Moderate accumulation (2.0-9.9 mm)	766	3.9	4.5	2.7
Heavy accumulation (≥ 10.0 mm)	173	4.7	16.4	2.9
All snowfall (≥ 0.4 mm)	535	4.9	2.1	2.4
Light accumulation (0.4-1.9 mm)	349	4.6	0.9	2.0
Moderate to heavy accumulation (≥ 2.0 mm)	186	5.6	4.5	3.1
Transition/near-freezing precipitation (≥ 0.4 mm)	444	4.8	3.1	2.3
Controls	7,654			1.7
All 6-hour periods	14,612			1.9

Table F-6: Characteristics of all 6-hour event and control periods, Montreal, 2000-2009

Precipitation type/amount	*Count of 6-hour periods*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
All rainfall (≥ 0.4 mm)	1,917	3.2	3.9	6.8
Light accumulation (0.4-1.9 mm)	840	2.1	0.7	6.2
Moderate accumulation (2.0-9.9 mm)	879	3.8	4.2	7.0
Heavy accumulation (≥ 10.0 mm)	198	4.7	15.9	8.4
All snowfall (≥ 0.4 mm)	537	4.7	2.5	5.3
Light accumulation (0.4-1.9 mm)	309	4.1	0.7	5.0
Moderate to heavy accumulation (≥ 2.0 mm)	228	5.5	4.8	5.6
Transition/near-freezing precipitation (≥ 0.4 mm)	467	4.6	3.1	5.5
Controls	7,444			5.3
All 6-hour periods	14,612			5.3

Table F-7: Characteristics of all 6-hour event and control periods, Quebec City, 2000-2009

Precipitation type/amount	*Count of 6-hour periods*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
All rainfall (≥ 0.4 mm)	1,802	3.4	4.3	1.6
Light accumulation (0.4-1.9 mm)	691	2.5	0.8	1.5
Moderate accumulation (2.0-9.9 mm)	883	3.8	4.1	1.7
Heavy accumulation (≥ 10.0 mm)	228	4.7	15.9	2.0
All snowfall (≥ 0.4 mm)	957	3.8	1.6	1.5
Light accumulation (0.4-1.9 mm)	648	3.1	0.7	1.3
Moderate to heavy accumulation (≥ 2.0 mm)	311	5.2	3.5	1.7
Transition/near-freezing precipitation (≥ 0.4 mm)	620	4.2	3.2	1.3
Controls	6,353			1.3
All 6-hour periods	14,612			1.4

Table F-8: Characteristics of all 6-hour event and control periods, Moncton, 2000-2009

Precipitation type/amount	*Count of 6-hour periods*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
All rainfall (≥ 0.4 mm)	1,944	4.0	4.1	0.33
Light accumulation (0.4-1.9 mm)	959	3.2	0.8	0.30
Moderate accumulation (2.0-9.9 mm)	769	4.6	4.6	0.35
Heavy accumulation (≥ 10.0 mm)	216	5.5	16.6	0.39
All snowfall (≥ 0.4 mm)	455	5.0	3.2	0.35
Light accumulation (0.4-1.9 mm)	260	4.6	0.9	0.34
Moderate to heavy accumulation (≥ 2.0 mm)	195	5.5	6.4	0.36
Transition/near-freezing precipitation (≥ 0.4 mm)	665	5.0	3.9	0.32
Controls	8,870			0.28
All 6-hour periods	14,612			0.32

Table F-9: Characteristics of all 6-hour event and control periods, Halifax, 2000-2009

Precipitation type/amount	*Count of 6-hour periods*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
All rainfall (≥ 0.4 mm)	1,696	4.3	6.5	0.73
Light accumulation (0.4-1.9 mm)	566	3.2	0.9	0.70
Moderate accumulation (2.0-9.9 mm)	744	4.5	4.7	0.75
Heavy accumulation (≥ 10.0 mm)	386	5.4	18.3	0.76
All snowfall (≥ 0.4 mm)	367	4.9	2.5	0.71
Light accumulation (0.4-1.9 mm)	223	4.5	0.8	0.69
Moderate to heavy accumulation (≥ 2.0 mm)	144	5.4	5.1	0.74
Transition/near-freezing precipitation (≥ 0.4 mm)	541	4.9	3.7	0.79
Controls	7,747			0.64
All 6-hour periods	14,612			0.67

Table F-10: Count of 6-hourly matched pairs, 2000-2009

Precipitation type/amount	*Vancouver*	*Calgary*	*Toronto*	*Ottawa*	*Montreal*	*Quebec City*	*Moncton*	*Halifax*
All rainfall (≥ 0.4 mm)	2,170	621	1,430	1,452	1,662	1,585	1,674	1,386
Light (0.4-1.9 mm)	1,060	328	679	634	726	603	827	475
Moderate (2.0-9.9 mm)	980	242	611	668	757	782	670	602
Heavy (≥ 10.0 mm)	130	51	140	150	179	200	177	309
All snowfall (≥ 0.4 mm)	1	249	163	258	167	214	350	257
Light (0.4-1.9 mm)	0	217	103	156	102	145	195	164
Moderate to heavy (≥ 2.0 mm)	1	32	60	102	65	69	155	93
Transition/near-freezing precipitation (≥ 0.4 mm)	77	166	230	297	288	351	554	433

F.2 Weather-related collision risk, 2000-2009

Consistent with previous results, there are statistically significant differences in weather-related crash risk between cities (Table F-11 and F-12). Collision rates increase during precipitation; increases are higher for snowfall than those for rainfall. For those events classified as transition/near-freezing, relative risks are similar to or lower than those for snowfall. One reason for this is that this category is dominated by snow flurries as well as mixed rain and snow events. Consistent with previous studies, risk increases as precipitation amount increases. Finally, relative risks tend to be higher for less severe collisions (i.e., property-damage-only), suggesting some degree of driver adaptation, for example in driving speed.

Table F-11: 6-hourly risk estimates (with 95% confidence intervals in brackets) for injury collisions, 2000-2009

Precipitation type/amount	*Vancouver*	*Calgary*	*Toronto*	*Ottawa*	*Montreal*	*Quebec City*	*Moncton*	*Halifax*
All rainfall (≥ 0.4 mm)	1.44 (1.40-1.48)	1.06 (0.98-1.14)	1.30 (1.28-1.33)	1.32 (1.25-1.39)	1.20 (1.16-1.23)	1.12 (1.06-1.19)	1.04 (0.96-1.13)	1.10 (1.02-1.19)
Light (0.4-1.9 mm)	1.31 (1.26-1.36)	1.03 (0.93-1.14)	1.20 (1.17-1.23)	1.19 (1.10-1.29)	1.09 (1.04-1.13)	1.03 (0.93-1.13)	0.99 (0.88-1.12)	1.01 (0.88-1.15)
Moderate (2.0-9.9 mm)	1.54 (1.48-1.60)	1.05 (0.93-1.18)	1.39 (1.35-1.43)	1.39 (1.29-1.50)	1.25 (1.20-1.31)	1.16 (1.06-1.26)	1.04 (0.91-1.19)	1.13 (1.01-1.28)
Heavy (≥ 10.0 mm)	1.81 (1.63-2.00)	1.29 (1.01-1.64)	1.40 (1.33-1.49)	1.48 (1.27-1.73)	1.43 (1.32-1.55)	1.28 (1.09-1.50)	1.28 (0.99-1.65)	1.20 (1.01-1.42)
All snowfall (≥ 0.4 mm)	--	1.38 (1.22-1.56)	1.74 (1.64-1.85)	1.71 (1.49-1.98)	1.22 (1.09-1.35)	1.44 (1.19-1.74)	1.16 (0.96-1.40)	1.11 (0.92-1.35)
Light (0.4-1.9 mm)	--	1.32 (1.15-1.50)	1.61 (1.50-1.74)	1.54 (1.27-1.87)	1.08 (0.94-1.24)	1.23 (0.97-1.55)	1.11 (0.86-1.42)	1.09 (0.85-1.38)
Moderate to heavy (≥ 2.0 mm)	--	1.92 (1.37-2.68)	1.98 (1.80-2.17)	1.95 (1.58-2.41)	1.44 (1.22-1.69)	1.99 (1.43-2.76)	1.24 (0.93-1.64)	1.16 (0.84-1.61)
Transition/near-freezing precipitation (≥ 0.4 mm)	1.71 (1.45-2.02)	1.45 (1.24-1.70)	1.59 (1.52-1.67)	1.34 (1.18-1.51)	1.25 (1.16-1.35)	1.20 (1.05-1.37)	1.10 (0.95-1.28)	1.15 (1.00-1.33)

Table F-12: 6-hourly risk estimates (with 95% confidence intervals in brackets) for property-damage-only collisions, 2000-2009

Precipitation type/amount	*Vancouver*	*Calgary*	*Toronto*	*Ottawa*	*Montreal*	*Quebec City*	*Moncton*	*Halifax*
All rainfall (≥ 0.4 mm)	1.47 (1.43-1.51)	1.08 (1.06-1.11)	1.37 (1.36-1.39)	1.42 (1.38-1.47)	1.17 (1.15-1.19)	1.27 (1.24-1.30)	1.08 (1.00-1.16)	1.05 (0.99-1.10)
Light (0.4-1.9 mm)	1.39 (1.33-1.45)	1.04 (1.01-1.07)	1.25 (1.23-1.27)	1.30 (1.24-1.37)	1.08 (1.06-1.11)	1.13 (1.09-1.18)	1.04 (0.93-1.16)	0.90 (0.82-0.99)
Moderate (2.0-9.9 mm)	1.51 (1.45-1.57)	1.13 (1.09-1.17)	1.49 (1.47-1.51)	1.49 (1.43-1.55)	1.22 (1.19-1.24)	1.32 (1.27-1.36)	1.13 (1.01-1.27)	1.11 (1.02-1.20)
Heavy (≥ 10.0 mm)	1.75 (1.58-1.93)	1.16 (1.08-1.25)	1.50 (1.45-1.55)	1.60 (1.47-1.74)	1.33 (1.27-1.39)	1.49 (1.40-1.60)	1.07 (0.86-1.35)	1.17 (1.04-1.31)
All snowfall (≥ 0.4 mm)	--	1.95 (1.88-2.01)	2.44 (2.36-2.51)	2.13 (1.98-2.29)	1.66 (1.58-1.73)	1.91 (1.78-2.05)	1.55 (1.32-1.81)	1.45 (1.28-1.63)
Light (0.4-1.9 mm)	--	1.88 (1.82-1.95)	2.03 (1.95-2.12)	1.80 (1.63-1.99)	1.37 (1.29-1.45)	1.72 (1.57-1.88)	1.36 (1.10-1.69)	1.42 (1.23-1.65)
Moderate to heavy (≥ 2.0 mm)	--	2.40 (2.20-2.62)	3.17 (3.02-3.33)	2.61 (2.34-2.90)	2.16 (2.01-2.32)	2.31 (2.05-2.61)	1.80 (1.42-2.28)	1.50 (1.21-1.86)
Transition/near-freezing precipitation (≥ 0.4 mm)	2.02 (1.74-2.34)	1.70 (1.62-1.78)	2.02 (1.97-2.07)	1.51 (1.42-1.61)	1.51 (1.46-1.57)	1.47 (1.39-1.55)	1.38 (1.21-1.56)	1.41 (1.29-1.55)

Appendix G: Count of days with precipitation of different forms, based on daily temperature

Table G-1: Count of days with precipitation of different forms, by daily temperature, Vancouver, 2000-2009

Daily maximum temperature (°C)	*Daily minimum temperature (°C)*																											
	< -3		*-3 to -2.5*		*-2.5 to -2*		*-2 to -1.5*		*-1.5 to -1*		*-1 to -0.5*		*-0.5 to 0*		*0 to 0.5*		*0.5 to 1*		*1 to 1.5*		*1.5 to 2*		*2 to 2.5*		*2.5 to 3*		*≥ 3*	
< -3																												
-3 to -2.5																												
-2.5 to -2	1																											
-2 to -1.5																												
-1.5 to -1	2																											
	1																											
-1 to -0.5	2		1																									
-0.5 to 0	2																											
0 to 0.5					1		1																					
0.5 to 1	3					1			1																			
							1																					
1 to 1.5	1	2	1	1	1	1				1																		
1.5 to 2	1	3					1		1		1	1		1														
									1		1																	
2 to 2.5			1		1	1		1				1		1		1												
2.5 to 3	1	1					1			1		1				2		1										
	1			1			1																					
≥ 3	2	1		2	2	3		2	1	1	1	5		8	2	26	2	9		3		5		1				1
	2	3	3	2	5	1	5	3	3	7	2	13	2	12		26		28		38		50		57		58		1406

Legend for each box:

Snow	Rain with snow
Freezing rain	Rain

Blank values indicate zero counts

Table G-2: Count of days with precipitation of different forms, by daily temperature, Calgary, 2000-2009

Daily maximum temperature (°C)		Daily minimum temperature (°C)													
		< -3	*-3 to -2.5*	*-2.5 to -2*	*-2 to -1.5*	*-1.5 to -1*	*-1 to -0.5*	*-0.5 to 0*	*0 to 0.5*	*0.5 to 1*	*1 to 1.5*	*1.5 to 2*	*2 to 2.5*	*2.5 to 3*	*≥ 3*
	< -3	313 26													
	-3 to -2.5	10 2													
	-2.5 to -2	12 5													
	-2 to -1.5	8 6													
	-1.5 to -1	18 2													
	-1 to -0.5	19 5		 1											
	-0.5 to 0	16 3		2											
	0 to 0.5	10 1			 1										
	0.5 to 1	12 1				2	1								
	1 to 1.5	17 2	2	1											
	1.5 to 2	7 3	3	1	1 1	 1	1								
	2 to 2.5	14 7				 1		1	1						
	2.5 to 3	10 2 1		1		1									
	≥ 3	87 19 47 15	8 3 5 4	5 3 1 5	7 6 4 6	7 4 4 7	6 6 1 8	2 11 5 9	6 15 2 12	4 8 1 8	2 5 19	3 1 23	3 16	 1 16	 1 567

Legend for each box:	
Snow	Rain with snow
Freezing rain	Rain
Blank values indicate zero counts	

Table G-3: Count of days with precipitation of different forms, by daily temperature, Toronto, 2000-2009

Legend for each box: Snow (top left), Rain with snow (top right), Freezing rain (bottom left), Rain (bottom right). Blank values indicate zero counts.

Daily maximum temperature (°C) \ Daily minimum temperature (°C)	< -3		-3 to -2.5		-2.5 to -2		-2 to -1.5		-1.5 to -1		-1 to -0.5		-0.5 to 0		0 to 0.5		0.5 to 1		1 to 1.5		1.5 to 2		2 to 2.5		2.5 to 3		≥ 3	
< -3	190	1																										
	7																											
-3 to -2.5	26																											
	3																											
-2.5 to -2	25																											
-2 to -1.5	29																											
	2																											
-1.5 to -1	24																											
	5																											
-1 to -0.5	26																											
	5		1		1																							
-0.5 to 0	36																											
	2																											
0 to 0.5	30	1	1		1						1																	
	3																											
0.5 to 1	21	1					1																					
	4		1				1																					
1 to 1.5	22	2	2		2				1		2	1	1	1														
	4	1									1																	
1.5 to 2	12	6	2				4		2		1																	
		1	1						1			1																
2 to 2.5	8	1	2		3	1	1		2	1			1			1												
	3		1	1	1								1		1													
2.5 to 3	10	5	1		4			4		2	2	3					1											
	2	1	1				1		1					1		2	1											
≥ 3	26	29	3	2	3	5	9	10	4	6	4	9	3	9	3	9	7	9		7		1		3		1		
	14	18	2	8	3	5	4	9	3	8	1	13	4	18	6	20	6	21	1	31	1	28		32		43	1	865

Table G-4: Count of days with precipitation of different forms, by daily temperature, Ottawa, 2000-2009

Daily maximum temperature (°C)	Daily minimum temperature (°C)																											
	< -3		-3 to -2.5		-2.5 to -2		-2 to -1.5		-1.5 to -1		-1 to -0.5		-0.5 to 0		0 to 0.5		0.5 to 1		1 to 1.5		1.5 to 2		2 to 2.5		2.5 to 3		≥ 3	
< -3	315																											
	31																											
-3 to -2.5	19																											
	4																											
-2.5 to -2	16																											
	4																											
-2 to -1.5	21																											
	6																											
-1.5 to -1	31																											
	6																											
-1 to -0.5	28																											
	8		1																									
-0.5 to 0	15																											
	7																											
0 to 0.5	17	1	2		1																							
	12		1																									
0.5 to 1	20		3		1		1	1				1																
	10						1																					
1 to 1.5	21	1			2						1					1												
	4							1			1		1															
1.5 to 2	17	4	2				2					2				1												
	8	1			1				1		1																	
2 to 2.5	11	4		1		1	1	1		1			1			1		1										
	5								1		2				1													
2.5 to 3	10	6	2	1			2	2		2	1	3	1	3		2												
	5	1			1		1			1								2										
≥ 3	31	31	1	4	5	2	3	4	1	3	3	4	2	1	1	12	1	8	1	6		2		2				1
	32	13	5	4	4	7	4	11	2	8	8	12	5	14	3	20	1	25		27	1	27		29		26		882

Legend for each box:	
Snow	Rain with snow
Freezing rain	Rain
Blank values indicate zero counts	

Table G-5: Count of days with precipitation of different forms, by daily temperature, Montreal, 2000-2009

Daily maximum temperature (°C)	*Daily minimum temperature (°C)*																											
	< -3		*-3 to -2.5*		*-2.5 to -2*		*-2 to -1.5*		*-1.5 to -1*		*-1 to -0.5*		*-0.5 to 0*		*0 to 0.5*		*0.5 to 1*		*1 to 1.5*		*1.5 to 2*		*2 to 2.5*		*2.5 to 3*		*≥ 3*	
< -3	297																											
	21																											
-3 to -2.5	24																											
-2.5 to -2	29																											
	3																											
-2 to -1.5	30																											
	3																											
-1.5 to -1	21				1																							
	7																											
-1 to -0.5	19																											
	5																											
-0.5 to 0	27		1				1																					
	5																											
0 to 0.5	19		1						1																			
	4				1		1																					
0.5 to 1	22		2				3		1																			
	6												1															
1 to 1.5	24	2	2								1		1															
	5								2																			
1.5 to 2	15	1	2		3		1		2	1		1	1		1		1											
	3	1							2																			
2 to 2.5	12	5	2		1	1	1	1	1		1					2												
	6				1						1		1															
2.5 to 3	8	4	1	2	1	1	1	1			1			3	1	3												
	2	1					1													1								
≥ 3	18	32	5	1	6	5	3	7	7	6	5	6	2	6	4	14	2	6	1	6		2		1		2		
	24	21	1		4	6	4	10	2	7	3	13	1	18	3	10	3	28		23	1	29	1	23	1	30		933

Legend for each box:	
Snow	Rain with snow
Freezing rain	Rain
Blank values indicate zero counts	

Table G-6: Count of days with precipitation of different forms, by daily temperature, Quebec City, 2000-2009

Daily maximum temperature (°C)	Daily minimum temperature (°C)																											
	< -3		-3 to -2.5		-2.5 to -2		-2 to -1.5		-1.5 to -1		-1 to -0.5		-0.5 to 0		0 to 0.5		0.5 to 1		1 to 1.5		1.5 to 2		2 to 2.5		2.5 to 3		≥ 3	
< -3	419																											
	40																											
-3 to -2.5	29																											
	7																											
-2.5 to -2	31																											
	5																											
-2 to -1.5	25																											
	9																											
-1.5 to -1	26		1																									
	3				1																							
-1 to -0.5	23																											
	5																											
-0.5 to 0	27																											
	10		1																									
0 to 0.5	19		3						1		1																	
	8				1																							
0.5 to 1	16		1		1				2					1														
	8	1	1		1		1		1																			
1 to 1.5	16	5	2		2		1	1	2				1	1														
	6	1			1		3			1	1																	
1.5 to 2	10	6	1	1	1		1		1	1	2	1	1	2		3												
	2	1							1																			
2 to 2.5	10	2	1			2		1	1			2		1		1		1										
	3						1							1	1													
2.5 to 3	6	4			1		3			1			1	1		1						1						
	9	2				1			1	1			1					1										
≥ 3	16	24	3	1	4	4	7	2		6	6	7	3	6	1	14		14	1	7	1	3				1		1
	15	17	2	5	1	8	5	4	7	12	6	11	2	16	3	15	2	28	2	23	1	24		20		34	2	909

Legend for each box:	
Snow	Rain with snow
Freezing rain	Rain
Blank values indicate zero counts	

Table G-7: Count of days with precipitation of different forms, by daily temperature, Moncton, 2000-2009

		Daily minimum temperature (°C)																											
		< -3		-3 to -2.5		-2.5 to -2		-2 to -1.5		-1.5 to -1		-1 to -0.5		-0.5 to 0		0 to 0.5		0.5 to 1		1 to 1.5		1.5 to 2		2 to 2.5		2.5 to 3		≥ 3	
Daily maximum temperature (°C)	< -3	255																											
		12																											
	-3 to -2.5	18																											
		2																											
	-2.5 to -2	25																											
		5																											
	-2 to -1.5	32																											
		5																											
	-1.5 to -1	28		2																									
		7		1																									
	-1 to -0.5	35				1																							
		12																											
	-0.5 to 0	30																											
		12				1				1																			
	0 to 0.5	29	1	1		1						1																	
		5		2		2		1		1																			
	0.5 to 1	15	4	1	1				1	1																			
		11				2		2		1		3																	
	1 to 1.5	16	3	1	1					3	1		1																
		4				1		3		1		1																	
	1.5 to 2	19	2	1			1		1		1	1			1		1												
		4				1				1				2															
	2 to 2.5	8	6	1		1				1			1				1												
		3	2					2	1			1				1				1									
	2.5 to 3	8	4	1		2		1	1	1	1						1		1		1								
		2	1	1		1		1				1		2															
	≥ 3	33	46	2	5	7	5	4	7	4	7	6	4	2	7	1	10		4		2	1	2						1
		47	41	3	8	9	8	6	10	11	19	11	17	5	21	2	37	1	25	3	29	1	31	1	31		21		899

Legend for each box:	
Snow	Rain with snow
Freezing rain	Rain
Blank values indicate zero counts	

Table G-8: Count of days with precipitation of different forms, by daily temperature, Halifax, 2000-2009

Daily maximum temperature (°C)	Daily minimum temperature (°C)																											
	< -3		-3 to -2.5		-2.5 to -2		-2 to -1.5		-1.5 to -1		-1 to -0.5		-0.5 to 0		0 to 0.5		0.5 to 1		1 to 1.5		1.5 to 2		2 to 2.5		2.5 to 3		≥ 3	
< -3	245																											
	5																											
-3 to -2.5	26																											
	1																											
-2.5 to -2	30																											
	7																											
-2 to -1.5	37																											
	5																											
-1.5 to -1	29																											
	3																											
-1 to -0.5	24	1			1																							
	7		1		1																							
-0.5 to 0	33		1		1																							
	8		1																									
0 to 0.5	30	1		1																								
	17				1		3		1																			
0.5 to 1	23	6			3							1																
	11		1				1				1																	
1 to 1.5	19	5			2		1		1							1												
	9		1						3		1		2															
1.5 to 2	12	6	1					1	1			1		1														
	6	1			2		1				1		1		1													
2 to 2.5	12	3	2	1	1			1		1				1		2												
	3				1						1																	
2.5 to 3	10	9				1			1		1			2	1	1												
	5		1		3				2																			
≥ 3	42	56	5	9	12	2	6	6	5	6	3	6	4	10	2	10		7		5	1	3	1	2				
	54	33	4	7	7	7	7	17	7	13	10	19	15	21	3	28	2	38	1	22		32		31		36	1	942

Legend for each box:

Snow	Rain with snow
Freezing rain	Rain

Blank values indicate zero counts

Appendix H: Characteristics of event and control days

Table H-1: Days meeting the criteria for events and controls, Vancouver, 2000-2009

Precipitation type/amount	*Count of days*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
Rain event days (minimum temperature ≥ 0.5 °C)				
All amounts (≥ 0.4 mm)	1,419	9.1	7.2	22.6
0.4 to 0.9 mm	174	3.5	0.6	18.9
1.0 to 1.9 mm	214	5.6	1.4	19.9
2.0 to 4.9 mm	345	7.2	3.2	21.3
5.0 to 9.9 mm	324	10.1	7.0	23.5
10.0 to 19.9 mm	267	13.5	13.6	25.8
≥ 20.0 mm	95	17.8	30.0	27.9
Winter precipitation event days (minimum temperature < 0.5 °C)				
All amounts (≥ 0.4 mm)	151	9.4	6.3	20.5
0.4 to 0.9 mm	25	3.9	0.6	18.5
1.0 to 1.9 mm	22	4.9	1.4	20.1
2.0 to 4.9 mm	41	8.9	3.5	21.4
5.0 to 9.9 mm	33	10.4	6.9	20.8
10.0 to 19.9 mm	19	15.8	13.3	21.0
≥ 20.0 mm	11	18.4	25.8	21.1
Control days	1,491			18.8
All days	3,653			20.3

Table H-2: Days meeting the criteria for events and controls, Calgary, 2003-2009

Precipitation type/amount	*Count of days*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
Rain event days (minimum temperature ≥ 0.5 °C)				
All amounts (≥ 0.4 mm)	363	8.0	6.2	9.3
0.4 to 0.9 mm	67	4.3	0.6	8.8
1.0 to 1.9 mm	68	5.4	1.3	9.7
2.0 to 4.9 mm	103	7.2	3.2	9.2
5.0 to 9.9 mm	62	10.0	7.2	8.9
10.0 to 19.9 mm	39	13.1	15.1	10.1
≥ 20.0 mm	24	16.4	32.1	10.5
Winter precipitation event days (minimum temperature < 0.5 °C)				
All amounts (≥ 0.4 mm)	353	12.5	2.4	10.0
0.4 to 0.9 mm	115	10.4	0.6	8.9
1.0 to 1.9 mm	97	12.2	1.3	9.9
2.0 to 4.9 mm	99	13.8	3.0	10.7
5.0 to 9.9 mm	34	15.1	7.0	11.7
10.0 to 19.9 mm	8	17.6	13.7	10.4
≥ 20.0 mm	0	--	--	--
Control days	1,383			9.0
All days	2,557			9.2

Table H-3: Days meeting the criteria for events and controls, Toronto, 2000-2009

Precipitation type/amount	*Count of days*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
Rain event days (minimum temperature ≥ 0.5 °C)				
All amounts (≥ 0.4 mm)	839	6.7	7.0	61.9
0.4 to 0.9 mm	133	3.0	0.6	55.0
1.0 to 1.9 mm	128	4.9	1.4	57.4
2.0 to 4.9 mm	216	5.9	3.1	61.9
5.0 to 9.9 mm	164	7.5	7.0	62.6
10.0 to 19.9 mm	121	9.4	13.5	66.6
≥ 20.0 mm	77	12.6	27.5	72.1
Winter precipitation event days (minimum temperature < 0.5 °C)				
All amounts (≥ 0.4 mm)	499	9.5	4.1	59.8
0.4 to 0.9 mm	137	6.3	0.6	55.0
1.0 to 1.9 mm	89	7.6	1.4	54.6
2.0 to 4.9 mm	135	10.3	3.1	60.8
5.0 to 9.9 mm	78	11.4	6.8	65.7
10.0 to 19.9 mm	54	14.9	13.9	69.1
≥ 20.0 mm	6	19.3	27.2	65.3
Control days	1,652			52.9
All days	3,653			56.2

Table H-4: Days meeting the criteria for events and controls, Ottawa, 2000-2009

Precipitation type/amount	***Count of days***	***Average hours of precipitation***	***Average precipitation amount (mm)***	***Average injury collision count***
Rain event days (minimum temperature ≥ 0.5 °C)				
All amounts (≥ 0.4 mm)	862	6.9	7.6	8.2
0.4 to 0.9 mm	136	3.1	0.6	7.0
1.0 to 1.9 mm	114	4.3	1.3	7.4
2.0 to 4.9 mm	229	5.7	3.2	7.8
5.0 to 9.9 mm	169	7.9	7.3	8.9
10.0 to 19.9 mm	143	10.3	13.9	9.2
≥ 20.0 mm	71	13.2	32.8	9.5
Winter precipitation event days (minimum temperature < 0.5 °C)				
All amounts (≥ 0.4 mm)	626	10.9	4.9	8.0
0.4 to 0.9 mm	133	6.9	0.6	7.5
1.0 to 1.9 mm	115	8.4	1.3	7.6
2.0 to 4.9 mm	176	11.0	3.1	7.6
5.0 to 9.9 mm	118	14.0	7.1	9.2
10.0 to 19.9 mm	62	15.4	14.0	8.8
≥ 20.0 mm	22	18.3	25.5	8.3
Control days	1,388			6.9
All days	3,653			7.5

Table H-5: Days meeting the criteria for events and controls, Montreal, 2000-2009

Precipitation type/amount	***Count of days***	***Average hours of precipitation***	***Average precipitation amount (mm)***	***Average injury collision count***
Rain event days (minimum temperature ≥ 0.5 °C)				
All amounts (≥ 0.4 mm)	894	6.9	7.5	23.2
0.4 to 0.9 mm	140	3.2	0.5	21.6
1.0 to 1.9 mm	139	3.4	1.3	21.1
2.0 to 4.9 mm	213	5.6	3.2	22.1
5.0 to 9.9 mm	186	8.3	7.0	23.6
10.0 to 19.9 mm	141	10.4	14.4	25.0
≥ 20.0 mm	75	13.7	32.2	28.5
Winter precipitation event days (minimum temperature < 0.5 °C)				
All amounts (≥ 0.4 mm)	617	11.1	5.8	19.6
0.4 to 0.9 mm	150	7.5	0.6	19.8
1.0 to 1.9 mm	105	9.0	1.4	18.9
2.0 to 4.9 mm	154	11.2	3.1	19.1
5.0 to 9.9 mm	93	13.3	7.0	20.2
10.0 to 19.9 mm	79	14.5	14.1	20.0
≥ 20.0 mm	36	18.6	29.9	21.3
Control days	1,421			21.2
All days	3,653			21.3

Table H-6: Days meeting the criteria for events and controls, Quebec City, 2000-2009

Precipitation type/amount	*Count of days*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
Rain event days (minimum temperature ≥ 0.5 °C)				
All amounts (≥ 0.4 mm)	870	7.9	8.4	5.8
0.4 to 0.9 mm	139	4.1	0.6	5.0
1.0 to 1.9 mm	124	5.0	1.4	5.7
2.0 to 4.9 mm	184	6.2	3.3	5.6
5.0 to 9.9 mm	174	8.9	7.2	5.8
10.0 to 19.9 mm	161	11.5	14.2	6.1
≥ 20.0 mm	88	13.0	32.7	6.7
Winter precipitation event days (minimum temperature < 0.5 °C)				
All amounts (≥ 0.4 mm)	748	11.8	5.1	5.0
0.4 to 0.9 mm	184	7.1	0.6	4.9
1.0 to 1.9 mm	133	9.8	1.4	4.4
2.0 to 4.9 mm	193	13.4	3.3	4.8
5.0 to 9.9 mm	121	14.1	7.1	5.9
10.0 to 19.9 mm	91	16.0	13.8	5.7
≥ 20.0 mm	26	16.8	30.7	5.0
Control days	1,157			5.4
All days	3,653			5.4

Table H-7: Days meeting the criteria for events and controls, Moncton, 2000-2009

Precipitation type/amount	*Count of days*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
Rain event days (minimum temperature ≥ 0.5 °C)				
All amounts (≥ 0.4 mm)	880	8.4	7.8	1.2
0.4 to 0.9 mm	161	3.7	0.6	1.2
1.0 to 1.9 mm	128	5.5	1.4	1.1
2.0 to 4.9 mm	191	7.6	3.2	1.2
5.0 to 9.9 mm	192	9.5	7.1	1.3
10.0 to 19.9 mm	128	12.6	14.3	1.1
≥ 20.0 mm	80	15.4	35.1	1.5
Winter precipitation event days (minimum temperature < 0.5 °C)				
All amounts (≥ 0.4 mm)	745	11.5	7.0	1.2
0.4 to 0.9 mm	154	7.1	0.6	1.2
1.0 to 1.9 mm	124	9.3	1.4	1.2
2.0 to 4.9 mm	167	11.0	3.2	1.2
5.0 to 9.9 mm	130	12.7	6.9	1.3
10.0 to 19.9 mm	104	15.0	14.0	1.4
≥ 20.0 mm	66	19.1	31.1	0.9
Control days	1,247			1.3
All days	3,653			1.3

Table H-8: Days meeting the criteria for events and controls, Halifax, 2000-2009

Precipitation type/amount	*Count of days*	*Average hours of precipitation*	*Average precipitation amount (mm)*	*Average injury collision count*
Rain event days (minimum temperature ≥ 0.5 °C)				
All amounts (≥ 0.4 mm)	733	9.9	12.0	2.6
0.4 to 0.9 mm	82	4.8	0.6	2.3
1.0 to 1.9 mm	90	6.4	1.4	2.6
2.0 to 4.9 mm	136	7.4	3.2	2.5
5.0 to 9.9 mm	135	9.9	7.2	2.5
10.0 to 19.9 mm	154	11.9	14.2	3.0
≥ 20.0 mm	136	15.4	37.1	2.8
Winter precipitation event days (minimum temperature < 0.5 °C)				
All amounts (≥ 0.4 mm)	676	12.2	7.9	2.8
0.4 to 0.9 mm	103	8.8	0.6	2.8
1.0 to 1.9 mm	119	10.7	1.3	2.4
2.0 to 4.9 mm	146	11.7	3.2	2.9
5.0 to 9.9 mm	118	13.2	7.3	3.0
10.0 to 19.9 mm	120	13.6	13.7	3.0
≥ 20.0 mm	70	16.9	30.7	2.5
Control days	1,142			2.6
All days	3,653			2.7

Appendix I: Climate futures

It is noted that data for future simulation number 6 are almost entirely missing for the month of March in all years and for all cities; future changes would therefore be substantially under-estimated in any annual projections based on these data. Accordingly, values for simulation number 6 are not shown below.

Table I-1: Projections of climate change, 1971-2000 to 2041-2070

Simulation reference #	*Δ annual mean temperature (°C)*	*Δ annual total precipitation (mm)*	*Δ annual total precipitation (%)*	*Δ annual precipitation days ≥ 1 mm*
Vancouver				
1	+2.4	+161.0	+13.4%	+0.0
2	+2.0	+115.2	+9.6%	-1.1
3	+2.4	+112.2	+9.4%	-1.5
4	+2.4	+166.2	+13.9%	+0.0
5	+2.4	+110.2	+9.2%	-1.4
6				
7	+2.1	+105.5	+8.8%	+0.1
8	+2.0	+136.6	+11.4%	+0.0
9	+1.7	+38.4	+3.2%	-1.7
Calgary				
1	+2.4	+16.5	+4.0%	+1.6
2	+2.1	+36.1	+8.8%	+0.5
3	+2.3	+55.1	+13.4%	+0.6
4	+2.3	+34.4	+8.4%	+1.3
5	+2.4	+16.7	+4.0%	-0.8
6				
7	+2.0	+59.1	+14.3%	+3.1
8	+1.9	+62.5	+15.2%	+2.0
9	+1.9	-6.9	-1.7%	-1.9
Toronto				
1	+3.6	+65.5	+8.3%	+0.3
2	+3.1	+60.7	+7.7%	-0.8
3	+3.7	+88.4	+11.1%	+0.3
4	+3.7	+61.9	+7.8%	-0.7
5	+3.3	+48.7	+6.1%	-3.7
6				
7	+2.5	+73.3	+9.2%	-3.1
8	+2.6	+59.4	+7.5%	-1.4
9	+2.9	+58.7	+7.4%	-1.1

Table I-1: Projections of climate change, 1971-2000 to 2041-2070

Simulation reference #	*∆ annual mean temperature (°C)*	*∆ annual total precipitation (mm)*	*∆ annual total precipitation (%)*	*∆ annual precipitation days ≥ 1 mm*
Montreal				
1	+3.3	+77.1	+7.9%	-4.1
2	+2.9	+137.1	+14.0%	-3.6
3	+3.4	+98.6	+10.0%	-4.0
4	+3.4	+92.8	+9.5%	-3.9
5	+3.1	+50.0	+5.1%	-5.9
6				
7	+2.3	+104.3	+10.6%	-5.2
8	+2.5	+98.9	+10.1%	-6.8
9	+2.6	+80.8	+8.2%	-4.4
Quebec City				
1	+3.2	+126.3	+12.5%	+2.6
2	+2.8	+115.6	+11.4%	+0.1
3	+3.1	+128.2	+12.6%	+1.5
4	+3.1	+163.1	+16.1%	+2.7
5	+2.8	+97.4	+9.6%	-0.5
6				
7	+2.2	+131.9	+13.0%	+0.1
8	+2.4	+150.1	+14.8%	-0.3
9	+2.4	+121.2	+12.0%	+0.6
Halifax				
1	+3.1	+183.9	+12.7%	-1.5
2	+2.7	+121.2	+8.4%	+1.3
3	+3.0	+103.1	+7.1%	-0.5
4	+3.0	+170.3	+11.8%	+0.2
5	+2.7	+33.0	+2.3%	-2.9
6				
7	+2.3	+147.7	+10.2%	-1.0
8	+2.4	+71.3	+4.9%	-2.5
9	+2.3	+20.8	+1.4%	-3.6

Table I-2: Average annual days with precipitation, 1971-2000 and 2041-2070

Simulation reference # (1 through 9)	*Rain days by precipitation amount (mm)*					*Winter precipitation days by precipitation amount (mm)*					*All precipitation days (sum)*
	1.0 - 1.9	*2.0 - 4.9*	*5.0 - 9.9*	*10.0 - 19.9*	*≥ 20.0*	*1.0 - 1.9*	*2.0 - 4.9*	*5.0 - 9.9*	*10.0 - 19.9*	*≥ 20.0*	
Vancouver											
1971-2000 normals	17.3	34.5	31.7	27.0	12.4	2.4	4.1	3.0	2.3	0.9	135.5
Change in annual # days, 2041-2070, relative to 1971-2000 normals											
1	-1.0	+0.0	+3.5	+2.3	+4.8	-1.7	-3.1	-2.2	-1.8	-0.6	+0.0
2	-0.3	+0.3	+1.6	+3.2	+2.6	-1.5	-2.7	-2.0	-1.6	-0.5	-1.0
3	+0.6	-1.0	+1.8	+3.4	+3.5	-1.7	-3.2	-2.3	-1.9	-0.7	-1.5
4	-0.2	+0.4	-0.2	+4.5	+4.5	-1.7	-2.7	-2.2	-1.6	-0.7	+0.1
5	+0.0	+0.9	+1.0	+3.1	+3.6	-1.9	-3.0	-2.3	-2.0	-0.7	-1.4
6											
7	+2.5	-1.0	+3.2	+2.6	+2.7	-1.7	-3.0	-2.5	-1.9	-0.7	+0.2
8	+0.4	-1.4	+3.5	+3.3	+3.3	-1.7	-2.9	-2.1	-1.8	-0.5	+0.0
9	+0.8	+0.1	+3.1	+1.6	+1.2	-1.7	-2.6	-2.1	-1.6	-0.6	-1.7
Calgary											
1971-2000 normals	8.8	13.2	9.7	6.5	2.7	11.5	11.5	3.7	1.4	0.2	69.2
Change in annual # days, 2041-2070, relative to 1971-2000 normals											
1	+0.3	+1.3	+0.6	+0.8	+0.0	-0.3	+0.3	-1.0	-0.5	-0.1	+1.6
2	-0.3	+1.8	+0.6	+1.0	+0.5	-2.3	+0.4	-0.7	-0.3	-0.1	+0.5
3	+1.0	+0.5	+0.5	+1.1	+0.9	-1.2	-1.1	-0.6	-0.4	-0.0	+0.6
4	+1.1	+1.4	+0.3	+0.9	+0.2	-1.8	-0.8	+0.3	-0.2	-0.1	+1.3
5	-0.4	+1.1	+1.4	+0.5	+0.2	-1.1	-1.0	-0.9	-0.6	-0.1	-0.8
6											
7	+1.3	+0.6	+0.8	+1.2	+1.4	+0.0	-0.9	-1.0	-0.3	+0.0	+3.1
8	-0.2	+1.3	+1.0	+1.1	+1.2	-0.8	-0.6	-0.4	-0.3	-0.1	+2.0
9	+1.5	+0.6	+1.8	-0.1	-0.5	-3.0	-0.8	-0.8	-0.3	-0.1	-1.9
Toronto											
1971-2000 normals	11.4	19.6	15.8	12.6	6.5	9.6	12.8	8.6	4.4	1.2	102.6
Change in annual # days, 2041-2070, relative to 1971-2000 normals											
1	+2.9	+3.0	+5.0	+3.7	+1.0	-3.2	-5.9	-4.0	-1.7	-0.5	+0.3
2	+2.4	+1.9	+2.8	+1.6	+1.7	-3.8	-3.8	-3.0	-0.3	-0.2	-0.8
3	+3.1	+4.2	+2.5	+4.1	+2.4	-4.4	-5.2	-4.4	-1.6	-0.4	+0.3
4	+2.8	+2.8	+4.1	+3.8	+1.3	-4.3	-5.5	-4.2	-1.0	-0.5	-0.7
5	+1.8	+2.6	+2.7	+2.5	+1.3	-4.7	-4.7	-3.6	-1.2	-0.4	-3.7
6											
7	+1.0	+1.7	+2.7	+2.0	+1.8	-3.4	-4.4	-2.8	-1.5	-0.2	-3.1
8	+1.4	+2.7	+2.9	+3.3	+1.6	-4.1	-3.8	-3.4	-1.2	-0.6	-1.4
9	+2.2	+2.5	+2.6	+3.7	+1.5	-3.4	-5.0	-3.7	-1.1	-0.4	-1.1

Table I-2: Average annual days with precipitation, 1971-2000 and 2041-2070

Simulation reference # (1 through 9)	*Rain days by precipitation amount (mm)*					*Winter precipitation days by precipitation amount (mm)*					*All precipitation days (sum)*
	1.0 - 1.9	*2.0 - 4.9*	*5.0 - 9.9*	*10.0 - 19.9*	*≥ 20.0*	*1.0 - 1.9*	*2.0 - 4.9*	*5.0 - 9.9*	*10.0 - 19.9*	*≥ 20.0*	
Montreal											
1971-2000 normals	12.8	21.3	17.0	14.1	7.4	12.0	15.8	10.7	7.9	3.1	122.0
Change in annual # days, 2041-2070, relative to 1971-2000 normals											
1	+0.6	+1.7	+3.7	+2.0	+1.5	-3.7	-5.4	-3.0	-1.2	-0.3	-4.1
2	-0.1	+1.7	+1.0	+1.7	+3.2	-2.4	-4.5	-3.8	-1.6	+1.2	-3.6
3	+0.8	+2.8	+0.9	+2.2	+2.9	-3.0	-4.6	-4.4	-1.7	+0.1	-4.0
4	+1.9	+2.8	+1.4	+2.1	+2.5	-3.4	-5.9	-3.5	-2.2	+0.4	-3.9
5	+1.8	+1.5	+1.4	+2.4	+1.3	-3.8	-5.7	-3.2	-1.7	+0.1	-5.9
6											
7	-1.6	+0.3	+0.4	+1.2	+3.0	-3.5	-2.6	-2.1	-0.8	+0.5	-5.2
8	-0.3	-0.1	+1.5	+1.6	+3.0	-2.8	-4.2	-3.1	-2.3	-0.2	-6.8
9	+0.6	+1.8	-0.3	+1.0	+3.5	-2.3	-2.9	-3.5	-2.0	-0.4	-4.4
Quebec City											
1971-2000 normals	8.6	16.2	14.8	13.1	8.9	11.2	18.3	11.7	8.9	3.3	115.0
Change in annual # days, 2041-2070, relative to 1971-2000 normals											
1	+1.3	+3.3	+2.4	+3.7	+2.4	-2.5	-3.6	-3.0	-1.6	+0.1	+2.6
2	+1.1	+2.3	+2.6	+1.6	+2.3	-2.5	-5.1	-1.4	-1.5	+0.8	+0.1
3	+2.4	+2.5	+1.7	+2.1	+2.7	-1.2	-4.7	-2.7	-2.0	+0.6	+1.5
4	+1.4	+2.6	+2.8	+3.7	+3.2	-2.3	-4.5	-2.7	-2.2	+0.7	+2.7
5	+1.6	+2.2	+1.9	+1.8	+1.6	-2.1	-4.5	-2.0	-1.5	+0.5	-0.5
6											
7	+0.6	+1.8	+1.5	+3.3	+2.4	-3.1	-3.0	-2.8	-1.2	+0.6	+0.1
8	+0.7	+2.1	+2.9	+3.7	+3.1	-3.6	-4.4	-2.4	-2.3	-0.1	-0.3
9	+1.0	+0.0	+3.1	+1.9	+2.9	-0.9	-5.5	-0.7	-1.0	-0.1	+0.6
Halifax											
1971-2000 normals	9.6	17.0	15.0	14.5	12.9	11.8	15.6	12.2	11.4	8.7	128.7
Change in annual # days, 2041-2070, relative to 1971-2000 normals											
1	+3.0	+4.9	+4.1	+4.0	+5.5	-5.3	-5.1	-5.6	-5.0	-2.1	-1.5
2	+3.7	+3.1	+3.5	+5.1	+4.3	-2.4	-4.1	-6.2	-4.5	-1.2	+1.3
3	+3.5	+4.2	+3.7	+5.0	+4.2	-4.0	-4.8	-5.3	-4.0	-3.1	-0.5
4	+1.4	+4.2	+3.3	+5.6	+4.2	-4.3	-4.5	-4.3	-4.3	-1.2	+0.2
5	+2.3	+3.6	+3.9	+4.1	+3.2	-3.2	-5.0	-4.8	-4.2	-2.7	-2.9
6											
7	+2.2	+1.2	+3.1	+3.6	+5.4	-2.6	-3.9	-4.4	-4.1	-1.6	-1.0
8	+2.0	+3.9	+2.6	+2.4	+3.3	-2.8	-3.8	-4.4	-4.0	-1.7	-2.5
9	+1.4	+2.5	+2.6	+3.0	+3.2	-1.5	-4.3	-4.3	-4.0	-2.1	-3.6

Table I-3: Average annual change in injury collisions associated with future climate

Simulation reference #	*# injury collisions on rain days by precipitation amount (mm)*					*# injury collisions on winter precipitation days by precipitation amount (mm)*					*Sum of injury collisions on days with*		
	1.0 - 1.9	*2.0 - 4.9*	*5.0 - 9.9*	*10.0 - 19.9*	*≥ 20.0*	*1.0 - 1.9*	*2.0 - 4.9*	*5.0 - 9.9*	*10.0 - 19.9*	*≥ 20.0*	*Rain*	*Winter precipitation*	*All days*
Vancouver													
1	-1.3	+0.0	+19.5	+17.9	+48.0	-3.0	-17.3	-9.3	-19.4	-6.8	+84.2	-55.8	+28.4
2	-0.4	+0.9	+9.2	+25.6	+26.2	-2.7	-15.2	-8.6	-17.2	-5.8	+61.4	-49.5	+11.9
3	+0.7	-3.4	+10.0	+27.1	+35.6	-3.0	-17.6	-9.8	-20.8	-7.2	+70.0	-58.5	+11.5
4	-0.3	+1.5	-1.1	+35.3	+45.7	-3.1	-15.0	-9.4	-17.2	-7.2	+81.0	-52.0	+29.0
5	+0.0	+3.0	+5.4	+24.5	+35.9	-3.3	-16.7	-9.7	-21.5	-7.9	+68.9	-59.2	+9.7
6													
7	+3.2	-3.3	+17.9	+20.6	+27.2	-3.1	-16.9	-10.7	-20.1	-7.6	+65.5	-58.3	+7.2
8	+0.5	-4.7	+19.5	+25.8	+33.2	-3.0	-16.3	-8.7	-19.0	-5.4	+74.3	-52.5	+21.8
9	+1.0	+0.2	+17.7	+12.6	+12.4	-3.0	-14.7	-8.7	-16.9	-6.1	+44.0	-49.3	-5.4
Calgary													
1	-0.4	-0.5	-0.2	-0.0	+0.0	-0.6	+0.9	-2.5	-2.6	-0.4	-1.1	-5.2	-6.3
2	+0.3	-0.6	-0.2	-0.0	+0.4	-5.0	+1.0	-1.7	-1.8	-0.5	-0.1	-7.9	-8.0
3	-1.3	-0.2	-0.2	-0.0	+0.9	-2.7	-2.8	-1.5	-2.3	-0.2	-0.8	-9.5	-10.2
4	-1.5	-0.5	-0.1	-0.0	+0.2	-3.8	-2.0	+0.6	-1.1	-0.7	-1.8	-6.9	-8.7
5	+0.5	-0.4	-0.4	-0.0	+0.2	-2.3	-2.6	-2.1	-3.0	-0.5	-0.2	-10.6	-10.8
6													
7	-1.6	-0.2	-0.3	-0.0	+1.3	+0.0	-2.4	-2.3	-1.8	+0.0	-0.9	-6.5	-7.4
8	+0.3	-0.5	-0.3	-0.0	+1.1	-1.8	-1.6	-1.0	-1.8	-0.5	+0.5	-6.8	-6.2
9	-1.9	-0.2	-0.6	+0.0	-0.5	-6.5	-2.1	-1.9	-1.6	-0.5	-3.2	-12.7	-15.9
Toronto													
1	+8.0	+19.6	+40.7	+36.7	+15.5	-21.1	-96.4	-64.5	-45.4	-11.6	+120.6	-238.9	-118.3
2	+6.6	+12.1	+22.7	+15.5	+25.6	-24.6	-61.5	-49.3	-8.7	-3.6	+82.5	-147.8	-65.3
3	+8.6	+27.4	+20.8	+40.7	+36.6	-28.7	-85.0	-72.1	-41.9	-9.4	+134.0	-237.1	-103.0
4	+7.7	+18.3	+33.9	+38.0	+19.1	-28.1	-89.3	-68.3	-27.0	-11.6	+117.0	-224.3	-107.4
5	+5.0	+16.6	+21.9	+25.1	+19.6	-30.9	-76.8	-59.0	-30.5	-8.0	+88.1	-205.3	-117.1
6													
7	+2.7	+11.2	+22.1	+19.8	+26.6	-22.0	-71.3	-45.0	-40.1	-5.1	+82.4	-183.5	-101.1
8	+3.9	+17.7	+23.5	+32.4	+23.6	-26.8	-62.6	-55.8	-32.3	-13.8	+101.0	-191.3	-90.2
9	+6.1	+16.2	+21.0	+37.0	+22.6	-22.0	-81.2	-60.1	-29.7	-9.4	+102.9	-202.4	-99.5

Table I-3: Average annual change in injury collisions associated with future climate

Simulation reference #	*# injury collisions on rain days by precipitation amount (mm)*					*# injury collisions on winter precipitation days by precipitation amount (mm)*					*Sum of injury collisions on days with*		
	1.0 - 1.9	*2.0 - 4.9*	*5.0 - 9.9*	*10.0 - 19.9*	*≥ 20.0*	*1.0 - 1.9*	*2.0 - 4.9*	*5.0 - 9.9*	*10.0 - 19.9*	*≥ 20.0*	*Rain*	*Winter precipitation*	*All days*
Montreal													
1	-0.4	+0.5	+8.3	+6.1	+8.7	-7.2	-7.2	-7.8	-4.4	-2.1	+23.1	-28.6	-5.5
2	+0.1	+0.5	+2.1	+5.4	+18.1	-4.7	-6.0	-9.8	-5.8	+7.7	+26.2	-18.6	+7.6
3	-0.5	+0.8	+2.1	+6.9	+16.2	-5.7	-6.1	-11.5	-6.1	+0.8	+25.5	-28.7	-3.2
4	-1.3	+0.8	+3.1	+6.5	+14.0	-6.6	-7.8	-9.2	-7.8	+2.7	+23.1	-28.7	-5.6
5	-1.2	+0.4	+3.1	+7.4	+7.5	-7.3	-7.6	-8.3	-6.0	+0.4	+17.2	-28.8	-11.6
6													
7	+1.1	+0.1	+0.9	+3.8	+17.2	-6.8	-3.5	-5.5	-2.9	+3.3	+23.1	-15.3	+7.8
8	+0.2	-0.0	+3.3	+5.0	+17.2	-5.4	-5.5	-8.0	-8.2	-1.3	+25.6	-28.4	-2.8
9	-0.4	+0.5	-0.6	+3.0	+20.0	-4.4	-3.8	-9.0	-7.3	-2.5	+22.5	-27.0	-4.5
Quebec City													
1	-0.3	+0.0	+0.1	+2.8	+2.0	-0.2	-0.2	-4.0	-1.8	+0.1	+4.6	-6.0	-1.4
2	-0.3	+0.0	+0.1	+1.2	+1.9	-0.2	-0.3	-1.8	-1.7	+0.9	+2.9	-3.2	-0.2
3	-0.6	+0.0	+0.0	+1.6	+2.3	-0.1	-0.3	-3.5	-2.2	+0.7	+3.3	-5.4	-2.1
4	-0.4	+0.0	+0.1	+2.8	+2.7	-0.1	-0.3	-3.5	-2.4	+0.8	+5.3	-5.6	-0.3
5	-0.4	+0.0	+0.0	+1.4	+1.4	-0.1	-0.3	-2.7	-1.7	+0.6	+2.4	-4.2	-1.8
6													
7	-0.1	+0.0	+0.0	+2.6	+2.0	-0.2	-0.2	-3.7	-1.4	+0.6	+4.5	-4.9	-0.3
8	-0.2	+0.0	+0.1	+2.9	+2.6	-0.2	-0.3	-3.1	-2.6	-0.1	+5.4	-6.3	-0.9
9	-0.2	+0.0	+0.1	+1.5	+2.5	-0.1	-0.4	-0.9	-1.1	-0.1	+3.8	-2.6	+1.2
Halifax													
1	+0.0	+0.2	-1.1	+1.1	+2.4	-0.2	+0.9	-3.1	-1.1	-0.0	+2.6	-3.5	-0.9
2	+0.0	+0.1	-1.0	+1.4	+1.8	-0.1	+0.7	-3.4	-1.0	-0.0	+2.5	-3.8	-1.4
3	+0.0	+0.2	-1.0	+1.4	+1.8	-0.1	+0.8	-2.9	-0.9	-0.0	+2.4	-3.2	-0.8
4	+0.0	+0.2	-0.9	+1.6	+1.8	-0.1	+0.8	-2.4	-1.0	-0.0	+2.7	-2.7	-0.0
5	+0.0	+0.2	-1.1	+1.1	+1.4	-0.1	+0.9	-2.7	-0.9	-0.0	+1.6	-2.9	-1.2
6													
7	+0.0	+0.1	-0.9	+1.0	+2.3	-0.1	+0.7	-2.4	-0.9	-0.0	+2.5	-2.8	-0.2
8	+0.0	+0.2	-0.7	+0.7	+1.4	-0.1	+0.7	-2.5	-0.9	-0.0	+1.6	-2.8	-1.2
9	+0.0	+0.1	-0.7	+0.8	+1.4	-0.0	+0.8	-2.4	-0.9	-0.0	+1.6	-2.6	-1.0

Appendix J: Injury collision attributes during precipitation versus dry, seasonal conditions

This appendix provides the frequency data behind the collision attribute analysis for event and control days presented in Section 4.5 of the main report.

Note that a dash ('--') in the following tables indicates that a jurisdiction either:

1. did not consistently report data for a given variable;
2. did not use or did not consistently use specific options or codes for a variable; or
3. provided data that were not easily made compatible with that for other jurisdictions. The latter issue occurred with Montreal and Quebec City records, wherein translation and conversion between the provincial and national collision databases made some categories incompatible, so results for the two cities were not provided for certain variables.

J.1 Collision-level attributes

Table J-1: Collision configuration

	Vancouver				*Calgary*			
	Rain days	*Controls for rain days*	*Winter precipitation days*	*Controls for winter days*	*Rain days*	*Controls for rain days*	*Winter precipitation days*	*Controls for winter days*
Injury collisions with available information (n=)	*17,134*	*9,548*	*827*	*550*	*2,788*	*2,269*	*2,671*	*1,889*
Single vehicle								
Hit object or parked vehicle	5.1%	5.3%	6.0%	4.9%	3.4%	2.9%	2.1%	3.0%
Ran off road	9.1%	8.5%	16.7%	8.9%	3.0%	3.8%	3.5%	3.9%
Other non-collision	0.2%	0.2%	0.4%	0.5%	20.1%	19.5%	23.3%	23.6%
Two vehicles, same direction								
Rear-end	24.8%	25.2%	19.8%	24.0%	40.5%	40.0%	37.7%	37.4%
Sideswipe	0.1%	0.1%	0.1%	0.0%	3.0%	3.3%	3.9%	2.6%
Passing or turning conflict	1.7%	2.3%	2.1%	2.4%	1.6%	1.8%	1.4%	1.3%
Two vehicles, different direction								
Head-on or approaching sideswipe	6.1%	5.4%	8.8%	4.2%	1.7%	1.2%	3.6%	1.9%
Left turn across opposing traffic	22.4%	21.6%	16.2%	23.6%	10.4%	11.8%	8.8%	11.8%
Right turn or turning conflict	11.1%	11.9%	12.9%	12.2%	--	--	--	--
Two vehicles - other configuration	19.4%	19.5%	16.9%	19.3%	16.1%	15.6%	15.7%	14.6%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-1: Collision configuration

	Toronto				***Ottawa***			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*44,727*	*30,939*	*18,610*	*10,519*	*5,788*	*3,969*	*2,372*	*1,356*
Single vehicle								
Hit object or parked vehicle	6.8%	6.8%	9.7%	7.8%	5.4%	6.4%	10.2%	9.3%
Ran off road	--	--	--	--	--	--	--	--
Other non-collision	15.4%	14.8%	18.2%	15.4%	17.1%	18.1%	20.8%	18.2%
Two vehicles, same direction								
Rear-end	37.2%	36.6%	32.1%	36.4%	37.0%	30.2%	29.8%	32.2%
Sideswipe	7.4%	7.6%	9.3%	6.8%	5.4%	7.0%	5.5%	5.1%
Passing or turning conflict	--	--	--	--	--	--	--	--
Two vehicles, different direction								
Head-on or approaching sideswipe	1.7%	1.4%	3.9%	1.5%	1.9%	1.5%	4.8%	1.2%
Left turn across opposing traffic	7.2%	7.0%	7.3%	7.6%	5.4%	6.4%	5.4%	6.9%
Right turn or turning conflict	3.9%	4.3%	4.3%	4.5%	3.4%	4.4%	4.5%	4.6%
Two vehicles - other configuration	20.4%	21.5%	15.1%	19.9%	24.3%	25.9%	19.1%	22.5%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-1: Collision configuration

	Moncton				*Halifax*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*840*	*683*	*520*	*366*	*1,273*	*997*	*888*	*576*
Single vehicle								
Hit object or parked vehicle	7.1%	8.6%	9.6%	7.7%	18.3%	19.9%	19.0%	17.5%
Ran off road	7.4%	7.0%	15.8%	8.5%	3.4%	3.5%	5.4%	2.6%
Other non-collision	1.2%	2.5%	1.5%	0.3%	2.5%	2.1%	2.4%	1.0%
Two vehicles, same direction								
Rear-end	36.4%	41.1%	29.8%	39.1%	38.4%	39.3%	36.6%	41.1%
Sideswipe	1.2%	0.3%	1.5%	0.0%	1.6%	2.6%	1.1%	2.6%
Passing or turning conflict	2.5%	3.5%	2.5%	1.9%	5.7%	6.8%	5.5%	5.7%
Two vehicles, different direction								
Head-on or approaching sideswipe	1.3%	2.0%	2.9%	1.6%	2.8%	1.9%	4.8%	1.9%
Left turn across opposing traffic	12.6%	10.4%	11.3%	12.3%	8.7%	5.8%	5.7%	8.9%
Right turn or turning conflict	9.6%	7.9%	7.3%	8.7%	5.9%	5.4%	5.0%	3.8%
Two vehicles - other configuration	20.6%	16.5%	17.7%	19.9%	12.6%	12.6%	14.4%	14.8%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-2: Roadway configuration

	Vancouver				*Calgary*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*19,044*	*10,732*	*895*	*614*	*2,508*	*2,149*	*2,332*	*1,667*
Non-intersection	31.0%	31.8%	38.2%	30.1%	40.3%	41.1%	44.0%	40.4%
Intersection of 2+ public roads	60.9%	58.9%	55.0%	62.1%	59.1%	58.3%	55.4%	59.1%
Intersection with parking lot access, driveway, or lane	4.7%	6.0%	3.9%	5.0%	0.1%	0.0%	0.1%	0.0%
Railway crossing	0.1%	0.2%	0.0%	0.0%	0.4%	0.4%	0.3%	0.4%
Bridge, overpass, or viaduct	1.5%	1.4%	1.7%	1.1%	0.0%	0.1%	0.0%	0.1%
Ramp	1.0%	0.8%	0.3%	0.7%	0.1%	0.0%	0.1%	0.1%
Other configuration (e.g., tunnel, traffic circle)	0.8%	1.0%	0.9%	1.0%	--	--	--	--
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-2: Roadway configuration

	Toronto				*Ottawa*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*44,822*	*31,020*	*18,650*	*10,536*	*5,798*	*3,974*	*2,371*	*1,356*
Non-intersection	32.2%	33.1%	39.4%	32.0%	23.8%	24.8%	30.6%	21.2%
Intersection of 2+ public roads	57.9%	56.6%	51.3%	57.9%	66.9%	65.1%	61.3%	69.6%
Intersection with parking lot access, driveway or lane	9.1%	9.7%	8.0%	9.4%	8.4%	9.0%	6.7%	8.4%
Railway crossing	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%
Bridge, overpass or viaduct	0.2%	0.2%	0.6%	0.3%	0.6%	0.6%	0.8%	0.4%
Ramp	0.3%	0.3%	0.5%	0.3%	0.1%	0.2%	0.3%	0.1%
Other configuration (e.g., tunnel, traffic circle)	0.2%	0.1%	0.2%	0.1%	0.2%	0.1%	0.0%	0.0%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*
	Montreal				***Quebec City***			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*17,005*	*12,026*	*5,089*	*3,143*	*3,699*	*2,556*	*1,023*	*711*
Non-intersection	31.2%	32.5%	31.9%	33.1%	36.4%	38.2%	42.0%	39.0%
Intersection of 2+ public roads	60.9%	59.4%	59.5%	59.7%	55.4%	52.6%	48.8%	53.4%
Intersection with parking lot access, driveway or lane	--	--	--	--	--	--	--	--
Railway crossing	0.1%	0.1%	0.1%	0.0%	--	--	--	--
Bridge, overpass or viaduct	--	--	--	--	--	--	--	--
Ramp	--	--	--	--	--	--	--	--
Other configuration (e.g., tunnel, traffic circle)	7.8%	8.0%	8.5%	7.2%	8.3%	9.2%	9.2%	7.6%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-2: Roadway configuration

	Moncton				*Halifax*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	--	--	--	--	*1,078*	*846*	*761*	*490*
Non-intersection	--	--	--	--	28.1%	32.5%	32.2%	29.0%
Intersection of 2+ public roads	--	--	--	--	62.9%	59.8%	59.7%	60.8%
Intersection with parking lot access, driveway or lane	--	--	--	--	5.0%	2.7%	2.9%	5.3%
Railway crossing	--	--	--	--	0.0%	0.1%	0.0%	0.2%
Bridge, overpass or viaduct	--	--	--	--	0.3%	0.8%	0.3%	0.6%
Ramp	--	--	--	--	0.6%	0.7%	0.9%	0.2%
Other configuration	--	--	--	--	3.2%	3.3%	4.1%	3.9%
Sum	--	--	--	--	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-3: Light condition

	Vancouver				*Calgary*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*18,726*	*10,766*	*859*	*597*	*2,925*	*2,411*	*2,702*	*1,902*
Daylight	64.2%	73.9%	52.9%	63.3%	79.2%	83.2%	63.1%	64.0%
Dawn or dusk	6.9%	5.5%	8.4%	7.5%	--	--	--	--
Darkness	28.9%	20.6%	38.8%	29.1%	20.8%	16.8%	36.9%	36.0%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*
	Toronto				*Ottawa*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*42,371*	*29,709*	*16,734*	*9,706*	*5,681*	*3,901*	*2,252*	*1,319*
Daylight	76.4%	81.7%	63.5%	72.4%	78.6%	83.1%	65.9%	74.7%
Dawn or dusk	4.2%	3.4%	5.6%	4.5%	4.1%	3.7%	5.7%	4.8%
Darkness	19.4%	14.9%	30.8%	23.1%	17.2%	13.2%	28.4%	20.5%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-3: Light condition

	Montreal				*Quebec City*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*17,826*	*12,674*	*5,351*	*3,319*	*4,024*	*2,784*	*1,108*	*777*
Daylight	67.0%	76.4%	52.0%	65.2%	72.6%	79.1%	56.6%	69.9%
Dawn or dusk	5.8%	2.8%	7.3%	4.2%	4.5%	2.0%	5.9%	4.0%
Darkness	27.3%	20.8%	40.7%	30.6%	22.9%	18.8%	37.5%	26.1%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*
	Moncton				***Halifax***			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*834*	*678*	*513*	*359*	*1,378*	*1,093*	*963*	*624*
Daylight	77.0%	80.7%	62.2%	70.2%	76.1%	84.3%	66.4%	77.7%
Dawn or dusk	3.5%	3.7%	4.3%	5.3%	6.1%	4.7%	8.7%	7.2%
Darkness	19.5%	15.6%	33.5%	24.5%	17.8%	11.1%	24.9%	15.1%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-4: Road classification III

	Toronto			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*31,293*	*22,046*	*12,115*	*7,115*
One-way	3.2%	3.2%	2.6%	3.1%
Undivided, two-way	66.6%	66.5%	60.1%	66.3%
Divided	30.2%	30.3%	37.3%	30.6%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-5: Road alignment

	Vancouver				*Calgary*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*19,025*	*10,776*	*899*	*599*	*2,365*	*1,985*	*2,169*	*1,569*
Straight and level	63.4%	66.0%	59.0%	65.3%	82.1%	81.5%	78.1%	79.3%
Straight with gradient	24.3%	23.7%	26.6%	23.5%	7.1%	6.5%	7.4%	6.7%
Curved and level	4.9%	4.5%	5.6%	4.8%	6.1%	5.9%	6.6%	7.3%
Curved with gradient	6.6%	4.9%	7.9%	5.2%	2.6%	3.3%	4.2%	3.8%
Top of hill/gradient	0.7%	0.7%	0.7%	0.7%	1.2%	1.7%	2.2%	2.2%
Bottom of hill/gradient	0.2%	0.1%	0.3%	0.5%	1.0%	1.1%	1.4%	0.8%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*
	Toronto				***Ottawa***			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*44,802*	*31,008*	*18,635*	*10,534*	*5,792*	*3,973*	*2,373*	*1,355*
Straight and level	86.9%	87.9%	83.5%	87.4%	86.7%	86.6%	82.1%	87.7%
Straight with gradient	7.8%	7.6%	9.3%	7.8%	6.8%	6.6%	8.4%	6.1%
Curved and level	3.4%	2.9%	4.6%	3.1%	5.3%	5.1%	7.3%	4.9%
Curved with gradient	1.9%	1.6%	2.6%	1.7%	1.2%	1.8%	2.2%	1.3%
Top of hill/gradient	--	--	--	--	--	--	--	--
Bottom of hill/gradient	--	--	--	--	--	--	--	--
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*
	Montreal				***Quebec City***			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*17,426*	*12,330*	*5,205*	*3,222*	*3,806*	*2,631*	*1,052*	*734*
Straight and level	86.3%	87.6%	84.7%	87.9%	71.7%	73.6%	69.4%	75.5%
Straight with gradient	7.5%	7.3%	7.8%	7.0%	15.4%	14.3%	12.7%	13.9%
Curved and level	4.0%	3.5%	4.9%	3.6%	8.0%	7.9%	11.0%	6.7%
Curved with gradient	2.2%	1.7%	2.5%	1.6%	4.9%	4.2%	6.8%	4.0%
Top of hill/gradient	--	--	--	--	--	--	--	--
Bottom of hill/gradient	--	--	--	--	--	--	--	--
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-5: Road alignment

	Moncton				Halifax			
	Rain days	*Controls for rain days*	*Winter precipitation days*	*Controls for winter days*	*Rain days*	*Controls for rain days*	*Winter precipitation days*	*Controls for winter days*
Injury collisions with available information (n=)	*838*	*684*	*523*	*365*	*1,404*	*1,093*	*996*	*625*
Straight and level	80.1%	80.7%	74.4%	84.9%	65.7%	66.1%	61.6%	67.2%
Straight with gradient	11.1%	11.1%	13.4%	9.0%	20.7%	20.9%	20.8%	19.4%
Curved and level	5.6%	5.0%	7.5%	3.6%	6.0%	5.8%	4.5%	5.9%
Curved with gradient	2.5%	2.6%	3.6%	1.9%	5.3%	4.2%	8.7%	3.8%
Top of hill/gradient	0.4%	0.4%	0.4%	0.0%	1.1%	2.1%	1.4%	1.6%
Bottom of hill/gradient	0.4%	0.1%	0.8%	0.5%	1.3%	1.0%	2.9%	2.1%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-6: Traffic control

	Vancouver				Calgary			
	Rain days	*Controls for rain days*	*Winter precipitation days*	*Controls for winter days*	*Rain days*	*Controls for rain days*	*Winter precipitation days*	*Controls for winter days*
Injury collisions with available information (n=)	*18,325*	*10,344*	*869*	*581*	*2,821*	*2,388*	*2,642*	*1,871*
Traffic signal	36.2%	34.4%	32.1%	38.9%	36.3%	36.6%	36.9%	37.5%
Stop sign	16.1%	16.0%	15.2%	16.7%	8.2%	7.5%	7.3%	6.6%
Yield sign	1.5%	1.3%	1.0%	1.2%	3.9%	3.8%	3.3%	4.0%
Pedestrian crosswalk or school crossing	--	--	--	--	3.6%	4.5%	2.8%	4.0%
Police officer, crossing guard, or flagman	0.4%	0.6%	0.1%	0.5%	--	--	--	--
Other control	0.2%	0.3%	0.3%	0.0%	--	--	--	--
No control present	45.6%	47.4%	51.2%	42.7%	48.1%	47.7%	49.6%	47.9%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-6: Traffic control

	Toronto				*Ottawa*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*44,729*	*30,955*	*18,617*	*10,514*	*5,776*	*3,967*	*2,374*	*1,351*
Traffic signal	41.3%	40.0%	36.2%	41.8%	47.7%	45.5%	41.5%	49.4%
Stop sign	9.1%	9.2%	8.2%	8.8%	10.4%	10.7%	10.2%	11.2%
Yield sign	0.4%	0.4%	0.4%	0.4%	1.7%	1.9%	2.1%	1.9%
Pedestrian crosswalk or school crossing	1.1%	1.1%	1.0%	0.9%	0.3%	0.3%	0.5%	0.6%
Police officer, crossing guard, or flagman	0.9%	0.8%	0.7%	0.6%	0.8%	0.8%	0.8%	1.3%
Other control	0.0%	0.1%	0.0%	0.1%	0.0%	0.1%	0.2%	0.1%
No control present	47.1%	48.4%	53.5%	47.3%	38.9%	40.7%	44.7%	35.5%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-6: Traffic control

	Montreal [a]				**Quebec City [a]**			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collision-involved vehicles with available information (n=)	*31,530*	*22,372*	*9,129*	*5,752*	*6,708*	*4,580*	*1,840*	*1,336*
Traffic signal	41.7%	39.0%	41.4%	41.1%	33.4%	29.3%	32.1%	29.7%
Stop sign	9.0%	8.5%	8.5%	8.7%	9.7%	9.4%	7.7%	10.8%
Yield sign	0.5%	0.5%	0.5%	0.5%	1.2%	1.2%	1.3%	1.2%
Pedestrian crosswalk or school crossing	0.2%	0.2%	0.2%	0.2%	0.3%	0.6%	0.1%	0.1%
Police officer, crossing guard, or flagman	0.1%	0.1%	0.1%	0.2%	0.3%	0.2%	0.2%	0.4%
Other control	0.3%	0.4%	0.4%	0.2%	0.2%	0.3%	0.3%	0.4%
No control present	48.3%	51.3%	49.1%	49.2%	54.9%	59.0%	58.3%	57.4%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*
[a] In Montreal and Quebec City, traffic control is a vehicle-level variable, so n= the number of injury collision-involved vehicles rather than the number of injury collisions; in all other cities n= injury collisions.								
	Moncton				***Halifax***			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*842*	*688*	*523*	*366*	*1,084*	*861*	*770*	*467*
Traffic signal	27.1%	25.4%	23.7%	30.3%	33.7%	29.2%	32.6%	33.4%
Stop sign	10.0%	7.4%	9.4%	7.1%	6.7%	8.4%	7.8%	6.0%
Yield sign	5.1%	4.2%	4.4%	4.9%	4.9%	5.5%	5.2%	6.2%
Pedestrian crosswalk or school crossing	4.5%	5.5%	3.6%	5.2%	7.7%	8.4%	7.9%	9.0%
Police officer, crossing guard, or flagman	0.2%	0.6%	0.6%	0.8%	0.1%	0.3%	0.1%	0.0%
Other control	0.6%	1.2%	0.6%	0.8%	1.5%	1.9%	0.5%	0.6%
No control present	52.5%	55.7%	57.7%	50.8%	45.4%	46.5%	45.8%	44.8%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-7: Posted speed limit

	Vancouver				*Calgary*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*18,023*	*10,136*	*860*	*573*	--	--	--	--
40 km/h or less	4.0%	4.0%	2.4%	3.0%	--	--	--	--
50 km/h	74.9%	76.0%	73.8%	76.6%	--	--	--	--
60 km/h	15.0%	14.4%	16.7%	14.1%	--	--	--	--
70 km/h	2.7%	2.6%	2.7%	3.3%	--	--	--	--
80 km/h	2.9%	2.5%	3.6%	2.4%	--	--	--	--
90 km/h	0.4%	0.4%	0.5%	0.3%	--	--	--	--
100 or 110 km/h	0.1%	0.2%	0.2%	0.2%	--	--	--	--
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	--	--	--	--
	Toronto				***Ottawa***			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*44,837*	*31,030*	*18,657*	*10,540*	*5,800*	*3,977*	*2,375*	*1,357*
40 km/h or less	7.0%	7.4%	6.1%	6.8%	6.4%	7.1%	6.7%	7.3%
50 km/h	40.6%	40.3%	39.3%	41.1%	41.1%	42.3%	38.6%	44.0%
60 km/h	33.0%	32.3%	30.2%	33.2%	35.1%	32.6%	31.6%	31.5%
70 km/h	3.8%	3.7%	3.7%	3.4%	2.4%	2.2%	2.9%	1.9%
80 km/h	2.4%	2.3%	2.8%	2.0%	12.5%	11.8%	15.2%	11.1%
90 km/h	1.7%	1.6%	1.7%	1.7%	0.1%	0.5%	0.2%	0.4%
100 or 110 km/h	11.5%	12.5%	16.2%	11.9%	2.4%	3.4%	4.8%	3.8%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-7: Posted speed limit

	Montreal				*Quebec City*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*15,948*	*11,261*	*4,800*	*2,970*	*3,104*	*2,133*	*862*	*611*
40 km/h or less	6.4%	7.2%	5.7%	6.3%	2.6%	3.2%	2.7%	3.8%
50 km/h	80.4%	78.7%	77.6%	78.5%	74.2%	74.7%	67.5%	74.0%
60 km/h	0.8%	0.6%	0.6%	0.8%	0.9%	0.7%	1.2%	0.7%
70 km/h	9.0%	9.4%	10.4%	10.0%	5.9%	5.6%	8.1%	5.6%
80 km/h	0.3%	0.3%	0.1%	0.3%	0.7%	0.7%	0.6%	0.2%
90 km/h	--	--	--	--	4.7%	3.5%	5.1%	3.4%
100 or 110 km/h	3.1%	3.7%	5.6%	4.1%	10.9%	11.6%	14.8%	12.4%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*
	Moncton				*Halifax*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collisions with available information (n=)	*807*	*653*	*499*	*352*	*904*	*734*	*637*	*406*
40 km/h or less	0.2%	0.2%	0.0%	0.6%	1.1%	1.9%	0.6%	0.7%
50 km/h	87.7%	87.6%	82.2%	88.4%	84.5%	83.2%	81.5%	86.2%
60 km/h	4.1%	5.2%	4.6%	4.5%	4.5%	4.0%	5.3%	3.9%
70 km/h	4.0%	4.7%	3.8%	3.7%	1.3%	3.4%	3.5%	3.4%
80 km/h	0.5%	0.2%	0.0%	0.9%	5.1%	4.4%	4.1%	2.7%
90 km/h	--	--	--	--	0.6%	0.5%	0.6%	0.2%
100 or 110 km/h	3.3%	2.1%	9.4%	2.0%	2.9%	2.6%	4.4%	2.7%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

J.2 Vehicle-level attributes

Table J-8: Vehicle type

	Montreal				***Quebec City***			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collision-involved vehicles with available information (n=)	*33,879*	*24,155*	*9,855*	*6,225*	*7,502*	*5,121*	*2,047*	*1,473*
Car or light truck	84.0%	80.9%	88.8%	87.5%	84.2%	77.0%	91.2%	89.5%
Truck	2.1%	2.1%	2.4%	1.9%	1.3%	1.2%	2.0%	1.2%
Tractor trailer (with or without trailer)	1.4%	1.3%	1.9%	1.8%	0.8%	0.8%	0.8%	0.7%
Bus, school bus, or minibus	1.8%	2.0%	2.2%	1.9%	0.9%	1.0%	1.2%	0.7%
Work or equipment vehicle (e.g., tow truck, snow plow, construction equipment)	0.4%	0.4%	0.7%	0.4%	0.3%	0.3%	1.2%	0.6%
Taxi	1.5%	1.3%	1.7%	1.5%	0.5%	0.3%	0.4%	0.2%
Emergency vehicle	0.5%	0.5%	0.6%	0.5%	0.5%	0.5%	0.5%	0.4%
Motorcycle or moped	2.0%	3.5%	0.2%	1.1%	5.7%	9.6%	0.8%	2.4%
Bicycle	6.3%	8.0%	1.5%	3.3%	5.5%	9.2%	1.9%	4.1%
Other vehicle type	0.0%	0.1%	0.0%	0.0%	0.1%	0.1%	0.0%	0.2%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-9: Vehicle events

	Vancouver				*Calgary*			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collision-involved vehicles with available information (n=)	*23,786*	*13,781*	*912*	*747*	--	--	--	--
Non-collision events								
Skidded or spun off roadway	--	--	--	--	--	--	--	--
Ran off roadway	1.9%	1.7%	3.9%	2.0%	--	--	--	--
Overturned, rollover, jackknife, or trailer swing	0.7%	1.0%	1.2%	0.7%	--	--	--	--
Other non-collision event	0.1%	0.0%	0.0%	0.0%	--	--	--	--
Hit moving objects								
Hit another moving vehicle	80.7%	78.6%	76.9%	79.0%	--	--	--	--
Hit pedestrian	7.9%	7.8%	8.8%	9.8%	--	--	--	--
Hit bicyclist	5.4%	8.0%	2.9%	6.7%	--	--	--	--
Hit animal	0.1%	0.1%	0.0%	0.1%	--	--	--	--
Hit train/streetcar or other moving object	0.1%	0.1%	0.0%	0.3%	--	--	--	--
Hit non-moving objects								
Hit parked vehicle	--	--	--	--	--	--	--	--
Hit building or other object that is not part of road structure	0.8%	0.8%	1.0%	0.8%	--	--	--	--
Hit object that is part of road structure	9.3%	8.1%	13.6%	7.8%	--	--	--	--

Table J-9: Vehicle events

	Toronto				***Ottawa***			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collision-involved vehicles with available information (n=)	*57,825*	*41,552*	*20,965*	*12,902*	*8,381*	*5,503*	*2,819*	*1,655*
Non-collision events								
Skidded or spun off roadway	2.7%	2.1%	6.5%	2.0%	3.7%	3.2%	7.0%	2.8%
Ran off roadway	1.8%	1.7%	2.5%	1.8%	3.3%	3.7%	4.8%	3.7%
Overturned, rollover, jackknife, or trailer swing	0.9%	1.1%	1.1%	1.0%	1.4%	1.8%	2.0%	1.7%
Other non-collision event	1.8%	1.9%	1.6%	1.5%	1.0%	1.2%	0.8%	0.9%
Hit moving objects								
Hit another moving vehicle	84.9%	84.3%	83.5%	85.3%	83.6%	79.3%	83.5%	82.0%
Hit pedestrian	6.1%	5.7%	6.6%	7.5%	5.4%	6.3%	7.1%	8.2%
Hit bicyclist	2.8%	3.8%	0.9%	1.7%	4.6%	7.1%	0.8%	2.8%
Hit animal	0.1%	0.1%	0.1%	0.0%	0.3%	0.4%	0.3%	0.5%
Hit train/streetcar or other moving object	0.2%	0.2%	0.2%	0.2%	0.1%	0.2%	0.2%	0.0%
Hit non-moving objects								
Hit parked vehicle	0.8%	0.8%	0.9%	0.8%	1.0%	1.0%	0.9%	1.1%
Hit building or other object that is not part of road structure	1.4%	1.5%	1.9%	1.6%	1.4%	1.6%	2.3%	1.2%
Hit object that is part of road structure	6.4%	5.8%	10.1%	5.8%	6.5%	6.5%	9.1%	6.6%

Table J-9: Vehicle events

	Moncton				*Halifax*			
	Rain days	*Controls for rain days*	*Winter precipitation days*	*Controls for winter days*	*Rain days*	*Controls for rain days*	*Winter precipitation days*	*Controls for winter days*
Injury collision-involved vehicles with available information (n=)	*1,129*	*893*	*630*	*488*	*1,231*	*951*	*846*	*536*
Non-collision events								
Skidded or spun off roadway	6.6%	4.6%	12.2%	4.7%	4.4%	3.8%	8.0%	5.2%
Ran off roadway	5.8%	5.5%	12.1%	5.1%	2.9%	3.5%	4.0%	4.1%
Overturned, rollover, jackknife, or trailer swing	1.3%	2.8%	4.1%	1.8%	1.2%	1.7%	1.1%	0.6%
Other non-collision event	0.0%	0.0%	0.2%	0.0%	1.1%	1.4%	1.4%	2.6%
Hit moving objects								
Hit another moving vehicle	89.3%	87.0%	84.3%	90.4%	79.4%	75.6%	73.5%	80.8%
Hit pedestrian	2.9%	3.9%	5.4%	5.3%	9.1%	9.7%	11.1%	9.0%
Hit bicyclist	3.7%	4.1%	0.8%	1.4%	2.7%	2.9%	1.1%	1.9%
Hit animal	0.1%	0.1%	0.2%	0.0%	0.1%	0.1%	0.1%	0.0%
Hit train/streetcar or other moving object	--	--	--	--	0.5%	1.4%	0.5%	0.4%
Hit non-moving objects								
Hit parked vehicle	0.0%	0.0%	0.2%	0.0%	1.4%	1.1%	2.1%	0.6%
Hit building or other object that is not part of road structure	0.4%	0.6%	2.2%	1.2%	3.3%	2.7%	4.1%	3.4%
Hit object that is part of road structure	5.7%	3.9%	7.6%	2.3%	8.6%	9.5%	10.5%	8.8%

Table J-10: Contributing factors

	Vancouver				*Calgary*			
	Rain days	*Controls for rain days*	*Winter precipitation days*	*Controls for winter days*	*Rain days*	*Controls for rain days*	*Winter precipitation days*	*Controls for winter days*
Injury collision-involved vehicles with available information (n=)	*12,676*	*6,942*	*534*	*377*	*2,493*	*2,057*	*2,089*	*1,660*
Driver/pedestrian condition								
Fatigued or fell asleep	1.4%	2.2%	0.9%	2.1%	0.9%	0.5%	0.5%	0.5%
Inexperience	2.1%	1.7%	0.7%	0.5%	--	--	--	--
Under influence of alcohol	8.5%	9.9%	9.7%	9.0%	9.1%	8.4%	8.6%	10.8%
Under influence of drugs	1.1%	1.1%	1.1%	1.6%	0.7%	0.4%	0.4%	0.8%
Other driver condition	15.5%	18.8%	13.7%	23.1%	1.6%	2.0%	1.2%	1.8%
Driver action								
Following too closely	10.8%	10.7%	6.9%	10.9%	27.5%	27.0%	26.1%	26.0%

Table J-10: Contributing factors

Distracted or inattentive	36.1%	40.6%	31.5%	47.5%	--	--	--	--
Driving too fast for conditions	14.1%	10.3%	18.5%	9.8%	1.9%	1.9%	2.6%	2.5%
Improper turning or passing	9.1%	11.2%	7.5%	10.9%	16.2%	16.7%	15.1%	15.6%
Failing to yield right-of-way	22.8%	23.6%	19.1%	18.8%	6.1%	7.4%	6.8%	8.7%
Disobeying traffic control device or traffic officer	10.4%	11.2%	7.7%	10.6%	15.6%	15.3%	15.7%	16.0%
Driving on wrong side of road or in wrong direction	2.0%	2.2%	1.9%	2.1%	2.2%	1.6%	2.7%	1.8%
Backing up unsafely	1.1%	1.3%	0.6%	1.9%	2.6%	1.8%	2.1%	3.0%
Lost control	--	--	--	--	--	--	--	--
Other driver action	0.3%	0.7%	0.2%	0.0%	21.6%	23.3%	24.9%	21.5%
Vehicular contributing factor								
Defective brakes	0.5%	0.6%	0.7%	0.0%	0.6%	0.5%	0.2%	0.4%
Defective steering	0.1%	0.1%	0.0%	0.0%	--	--	--	--
Defective lights	0.2%	0.2%	0.2%	0.3%	0.1%	0.0%	0.0%	0.1%
Blown out tire	0.3%	0.3%	1.7%	0.0%	--	--	--	--
Unsecured, spilled, or oversized load	0.1%	0.1%	0.2%	0.0%	0.0%	0.1%	0.0%	0.1%
Visibility obstructed (e.g., wiper, defroster, mirror, tinting)	0.1%	0.3%	0.0%	0.0%	--	--	--	--
Other vehicular contributing factor	0.4%	0.3%	0.2%	0.0%	0.7%	0.5%	0.3%	0.4%
Environmental contributing factor								
Animal or other obstruction in road	1.2%	1.1%	1.5%	1.6%	--	--	--	--
Road surface or other road conditions (e.g., slippery, construction, faulty controls)	11.5%	1.1%	28.3%	1.6%	4.5%	3.9%	1.4%	3.2%
View obstructed (e.g., glare, reflection)	2.5%	5.2%	1.1%	7.4%	--	--	--	--
Weather or other acts of God	15.7%	0.3%	17.4%	0.3%	--	--	--	--
Other environmental contributing factor	3.0%	3.5%	3.7%	2.9%	--	--	--	--
	Toronto				***Ottawa***			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***	***Rain days***	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collision-involved vehicles with available information (n=)	*27,842*	*19,872*	*10,387*	*6,193*	*4,003*	*2,666*	*1,339*	*813*
Driver/pedestrian condition								
Fatigued or fell asleep	0.8%	0.9%	0.5%	0.9%	0.6%	1.1%	0.4%	1.2%
Inexperience	--	--	--	--	--	--	--	--

Table J-10: Contributing factors

Under influence of alcohol	3.8%	3.6%	3.3%	3.4%	3.7%	4.3%	3.4%	4.8%
Under influence of drugs	0.2%	0.2%	0.2%	0.1%	0.2%	0.2%	0.3%	0.1%
Other driver condition	1.4%	1.6%	1.2%	1.3%	1.8%	1.7%	1.0%	1.8%
Driver action								
Following too closely	22.9%	24.2%	17.6%	24.6%	19.1%	16.8%	15.4%	18.0%
Distracted or inattentive	25.2%	26.0%	20.6%	25.0%	24.7%	25.4%	19.6%	25.3%
Driving too fast for conditions	9.1%	5.4%	18.6%	5.4%	8.3%	4.2%	11.7%	4.4%
Improper turning or passing	16.0%	17.1%	13.2%	16.5%	15.2%	17.9%	13.5%	16.0%
Failing to yield right-of-way	21.3%	21.4%	17.5%	22.9%	18.5%	19.1%	17.8%	22.3%
Disobeying traffic control device or traffic officer	8.8%	9.1%	7.1%	10.2%	10.6%	11.8%	10.2%	14.1%
Driving on wrong side of road or in wrong direction	0.2%	0.2%	0.2%	0.2%	0.5%	0.7%	0.2%	0.0%
Backing up unsafely	--	--	--	--	--	--	--	--
Lost control	9.2%	8.7%	15.4%	7.4%	14.0%	13.0%	20.9%	12.1%
Other driver action	10.4%	11.9%	8.9%	10.9%	10.9%	13.5%	8.3%	10.6%
Vehicular contributing factor								
Defective brakes	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%
Defective steering	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Defective lights	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Blown out tire	0.1%	0.1%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%
Unsecured, spilled, or oversized load	--	--	--	--	--	--	--	--
Visibility obstructed (e.g., wiper, defroster, mirror, tinting)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other vehicular contributing factor	0.9%	1.0%	0.8%	0.9%	0.7%	0.5%	0.9%	0.5%
Environmental contributing factor								
Animal or other obstruction in road	--	--	--	--	--	--	--	--
Road surface or other road conditions (e.g., slippery, construction, faulty controls)	--	--	--	--	--	--	--	--
View obstructed (e.g., glare, reflection)	--	--	--	--	--	--	--	--
Weather or other acts of God	--	--	--	--	--	--	--	--
Other environmental contributing factor	--	--	--	--	--	--	--	--

Table J-10: Contributing factors

	Moncton				*Halifax*			
	Rain days	*Controls for rain days*	*Winter precipitation days*	*Controls for winter days*	*Rain days*	*Controls for rain days*	*Winter precipitation days*	*Controls for winter days*
Injury collision-involved vehicles with available information (n=)	*634*	*495*	*372*	*270*	*565*	*447*	*426*	*262*
Driver/pedestrian condition								
Fatigued or fell asleep	0.6%	1.4%	0.5%	0.7%	1.2%	1.6%	1.4%	1.1%
Inexperience	4.9%	6.9%	3.2%	5.2%	4.6%	4.5%	1.2%	5.3%
Under influence of alcohol	4.9%	3.8%	5.1%	3.0%	3.5%	4.3%	4.7%	4.2%
Under influence of drugs	0.6%	0.6%	0.3%	0.7%	0.7%	0.4%	0.5%	0.0%
Other driver condition	0.6%	1.8%	0.8%	1.1%	1.4%	3.1%	1.2%	1.1%
Driver action								
Following too closely	9.9%	10.9%	5.9%	10.4%	6.0%	7.4%	5.6%	8.4%
Distracted or inattentive	67.0%	67.9%	51.6%	68.1%	61.9%	64.4%	51.4%	61.8%
Driving too fast for conditions	5.4%	3.0%	14.2%	1.9%	7.3%	7.4%	8.9%	6.1%
Improper turning or passing	2.2%	3.8%	2.4%	3.3%	3.5%	5.6%	5.2%	5.7%
Failing to yield right-of-way	28.2%	25.3%	25.0%	29.6%	20.7%	19.5%	16.2%	16.4%
Disobeying traffic control device or traffic officer	8.2%	6.3%	8.9%	13.7%	5.7%	4.5%	4.9%	6.9%
Driving on wrong side of road or in wrong direction	2.1%	1.8%	0.8%	0.7%	2.1%	1.8%	1.4%	4.2%
Backing up unsafely	0.5%	0.0%	0.5%	0.0%	1.2%	1.1%	1.4%	1.5%
Lost control	--	--	--	--	--	--	--	--
Other driver action	2.4%	1.8%	1.3%	1.1%	0.2%	0.2%	0.0%	0.0%
Vehicular contributing factor								
Defective brakes	0.6%	1.2%	0.5%	0.4%	1.9%	2.5%	1.4%	1.5%
Defective steering	--	--	--	--	0.2%	0.2%	0.9%	0.4%
Defective lights	0.0%	0.4%	0.3%	0.0%	0.2%	0.0%	0.2%	0.4%
Blown out tire	0.5%	0.2%	0.3%	0.4%	0.4%	0.4%	0.2%	0.8%
Unsecured, spilled, or oversized load	--	--	--	--	0.4%	0.2%	0.0%	0.0%
Visibility obstructed (e.g., wiper, defroster, mirror, tinting)	1.3%	0.0%	1.9%	0.7%	3.4%	3.8%	3.3%	3.8%
Other vehicular contributing factor	0.2%	0.0%	0.3%	0.4%	0.4%	0.4%	0.7%	0.0%
Environmental contributing factor								
Animal or other obstruction in road	0.8%	1.2%	1.6%	1.1%	1.6%	1.8%	1.2%	1.5%

Table J-10: Contributing factors

Road surface or other road conditions (e.g., slippery, construction, faulty controls)	3.2%	1.4%	23.7%	2.2%	5.5%	0.9%	15.7%	1.5%
View obstructed (e.g., glare, reflection)	4.4%	4.6%	5.4%	7.0%	0.7%	4.7%	5.4%	5.7%
Weather or other acts of God	0.0%	0.0%	1.6%	0.0%	0.2%	0.0%	1.9%	0.0%
Other environmental contributing factor	1.7%	3.0%	1.9%	2.6%	4.8%	2.7%	3.3%	3.1%

J.3 Person-level attributes

Table J-11: Driver sex

	Toronto			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collision-involved drivers with available information (n=)	*56,350*	*40,175*	*20,696*	*12,652*
Male	66.6%	66.1%	67.0%	65.5%
Female	33.4%	33.9%	33.0%	34.5%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-12: Driver age

	Toronto			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collision-involved drivers with available information (n=)	*54,374*	*38,669*	*19,991*	*12,220*
< 16	0.1%	0.1%	0.1%	0.1%
16-19	4.8%	4.5%	4.2%	4.3%
20-24	11.3%	11.1%	10.8%	10.2%
25-34	22.7%	22.4%	23.6%	22.1%
35-44	24.5%	24.3%	25.4%	24.5%
45-54	19.4%	19.4%	20.2%	20.0%
55-64	10.7%	10.7%	10.2%	11.3%
65-74	4.3%	4.6%	3.6%	4.8%
75-84	1.9%	2.3%	1.7%	2.3%
≥ 85	0.3%	0.4%	0.2%	0.5%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*

Table J-13: Pedestrian action

	Toronto			
	Rain days	***Controls for rain days***	***Winter precipitation days***	***Controls for winter days***
Injury collision-involved pedestrians with available information (n=)	*3,351*	*2,214*	*1,315*	*927*
Crossing intersection:				
with traffic control, with right-of-way	48.4%	45.9%	47.1%	49.4%
with traffic control, without right-of-way	17.7%	16.6%	17.1%	16.6%
with no traffic control	7.5%	7.1%	6.3%	9.1%
Crossing roadway at a crosswalk	6.1%	6.2%	7.0%	6.7%
Walking on or along roadway	2.4%	2.9%	3.6%	2.6%
On sidewalk, median, or safety zone	6.7%	7.7%	7.5%	5.2%
Coming from behind parked or moving vehicle or roadside object	1.6%	2.1%	3.0%	1.1%
Running into roadway	7.1%	7.8%	5.0%	6.8%
Getting on or off bus or other vehicle	1.3%	1.7%	1.7%	1.7%
Pushing or working on vehicle on road	0.2%	0.2%	0.5%	0.2%
Working on roadway (e.g., construction worker)	1.0%	1.7%	1.3%	0.6%
Sum	*100.0%*	*100.0%*	*100.0%*	*100.0%*