

Implementing Climate Change Adaptation

in Prince George, BC

Volume 5: Transportation Infrastructure



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Acknowledgement of Sponsors

The preparation of the eight volumes of *Implementing Climate Change Adaptation in Prince George, BC* the production of educational videos, participation of the project team during the City of Prince George *myPG* process and the organization of several workshops and meetings with local government, provincial government, academics/researchers and stakeholders was made possible by funding from Natural Resources Canada's (NRCan) Regional Adaptation Collaboration (RAC) Program.



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Executive Summary:

Implementing Climate Change Adaptation in Prince George, BC Volume 5: Transportation Infrastructure

Transportation infrastructure is a broad topic, referring to roads, paths, railways, and airport facilities. Most of these structures are made to last for a long time, but they are designed for a specific range of conditions and are thus vulnerable to changes in the climate. The City of Prince George is already dealing with the effects of climate change on transportation infrastructure and is considering how to plan, design, construct, and maintain roads and other structures to account for both expected and unexpected changes. Transportation was selected as one of the top three impacts in Prince George in the local climate change adaptation strategy, and it has been identified as a high priority for future action. Transportation also closely relates to many other important adaptation priorities, such as flooding and emergency response. Roads can be designed to also act as dykes to mitigate flooding, and it is crucial to have a functioning transportation network to effectively respond to emergencies. Therefore the local adaptation researchers, supported through the federally funded Regional Adaptation Collaborative (RAC) program, focused largely on transportation for the Prince George case study.

The Prince George transportation network includes local roads, regional roads, provincial highways, private roads and logging roads. One of the main climate-related concerns that affect pavement and other road materials in northern regions is freeze-thaw cycles. With warmer winter temperatures, more winter freeze-thaw cycles are occurring in northern regions. These can lead to the rapid deterioration of roads and other surfaces as water within the structures expands and contracts. Unusual weather events, freezing rain, and rain-on-snow events are also generally increasing with climate change. These types of weather events present a significant maintenance challenge and also affect road safety.

Because transportation is such a large topic, the Prince George adaptation research team established a local steering committee. This group, consisting of senior staff responsible for managing and operating different aspects of the local transportation network, advised on future research and action so that it would be most relevant for Prince George. Contact was also made with a group of world-renowned transportation experts from the University of Waterloo to provide assistance and information. Based on feedback from the groups, a list of 23 potential areas of focus for future research was drafted. The list included topics related to road design, vehicle loads, pavement maintenance, salt use, road placement, safety, traffic patterns and sustainability. The steering committee ranked which focus areas they thought were most important for the city. Based on the results of this exercise, two main topics were determined. These were:

- 1. Winter road maintenance and safety and climate change**
- 2. Road design and climate change**

These topics were explored in detail over the course of a two-day workshop in Prince George in the spring of 2011. University of Waterloo experts, the adaptation research team and the steering committee were present to discuss different aspects of climate change and transportation. Researchers from the University of Northern BC, consultants, and representatives from different levels of government also participated in the event. The workshop included an information session – which was open to the public - where the Waterloo team shared information regarding climate change and transportation, and a focus group where City staff explained current conditions in Prince George and discussed the focus areas with researchers. The workshop was very successful in bringing interested parties together, raising awareness, and outlining how to continue local efforts. City staff

gained valuable information about new ideas and technologies, and outside parties learned about the local conditions and challenges and also the innovative work ongoing in Prince George to deal with the climate. Information about how each topic is being pursued locally is discussed below.

1. Winter road maintenance and safety and climate change

For this topic it was decided that a graduate student from the University of Waterloo would conduct a research project for Prince George. The results will be used to maximize road safety and road maintenance efficiency. The project is already underway and is focused on addressing the following points:

- How weather triggers snow and ice control operations locally, how climate variability explains these different types of weather, and how climate change may affect how snow and ice control operations are conducted
- How weather affects collision rates locally and to what extent collision rates rise during winter-weather events
- Estimating how collision rates are expected to change as a function of climate change over the next 50 years

2. Road design and climate change

Future plans regarding how to better design roads in a changing climate are still being discussed and developed. A great deal of local interest was generated, in particular related to alternative forms of pavement and concrete for roads and parking lots. Ideas were explored in the workshop, and are still being discussed by participants, related to:

- Permeable concrete (which allows water to flow through it rather than trap it at the surface)
- Ready-mix concrete (mixing concrete at lower temperatures to save energy and improve quality)
- Rubberized asphalt (using recycled rubber in asphalt to reuse waste and change asphalt characteristics)

A major challenge is that most of these designs have never been tested in northern climates. Exploration on these topics continues, and local staff are hopeful that pilot projects will occur in the summer of 2012. These projects represent an opportunity for local government, provincial government, local consultants, local contractors, and experts and students from the University of Waterloo and the University of Northern British Columbia to work and learn together.

Prince George has the opportunity to become a national leader in transportation adaptation, save taxpayer money, and increase safety. This can be done by improving road maintenance for better safety and designing transportation infrastructure that will perform well in future climates. There are many more opportunities for future work related to the focus topics, as well as other aspects of transportation infrastructure. The results of ongoing and future efforts should be used to improve transportation infrastructure in Prince George and other northern communities. Other potential areas of exploration include:

- Studying climate projections and determining if there is another community currently experiencing the conditions that Prince George is expected to encounter in the future
- Performing freeze-thaw projections and incorporating these into infrastructure design standards

- Exploring how climate change affects pedestrians and cyclists
- Working with forestry companies and other industries to examine road closures and road restrictions
- Making efforts to combine climate change mitigation and adaptation considerations in infrastructure planning

Background

Natural Resources Canada established the Regional Adaptation Collaborative (RAC) program in 2008 to assist communities and regions across the country as they adapt to climate change. Adaptation refers to actions that respond to or prepare for changes in the climate that are either expected or already occurring. Actions can be taken to become more prepared for unexpected events, to minimize the negative impacts of events already occurring or expected, or to maximize any positive benefits that may arise. Adaptation is different than climate change mitigation, which refers to actions that reduce the amount of greenhouse gases (GHGs) in the atmosphere.

Prince George has become a leader in community adaptation, and has been pursuing this topic for over five years in partnership with many organizations. The City was selected to be one of four community case studies to participate as part of the British Columbia (BC) RAC program (NRCan, 2011). The RAC funding allows for Prince George to build upon its climate change adaptation efforts to incorporate adaptation into local plans and begin implementing actions to address priorities within city administration. The City of Prince George has worked closely with the University of Northern BC (UNBC) and the Fraser Basin Council on this project, along with many other collaborators.

Although the focus of the Prince George RAC project is on adaptation, actions that address both adaptation and mitigation are encouraged whenever possible. Both adaptation and mitigation will be necessary for communities to prepare for and respond to climate change. Adaptation is needed to respond to the changes that are occurring in the climate, and mitigation is required to prevent further changes that may severely impact natural and human systems in the future.

The adaptation work conducted in Prince George under the RAC program is documented in this written case study, consisting of eight volumes. Each volume discusses an impact priority or a specific project from the many and varied community initiatives that RAC team members have contributed to in Prince George. Where applicable, the case study draws direct links to Prince George's adaptation priorities, as identified in the strategy document, *Adapting to climate change in Prince George: an overview of adaptation priorities* (Picketts et al., 2009a), which was received by City Council in November 2009.

The Volumes of *Implementing Climate Change Adaptation in Prince George BC* are:

Volume 1: The *myPG* Integrated Community Sustainability Plan

Volume 2: The Official Community Plan

Volume 3: Forests

Volume 4: Flooding

Volume 5: Transportation Infrastructure

Volume 6: Natural Areas and Ecosystems

Volume 7: Precipitation and Freeze-Thaw

Volume 8: Ongoing and Future Initiatives

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Introduction

Transportation infrastructure is a very broad topic. Communities must manage the planning, design, construction and maintenance of roads, paths, rail lines, airports, parking areas and other structures designed for the movement of goods and people (Natural Resources Canada, 2007). Prince George has been dealing with the realities of climate change for many years, and alterations in temperature and precipitation have had an effect on how the city's infrastructure is managed. Changes such as increased winter freeze-thaw cycles, warmer winter temperatures, and changing amounts of snow can have both positive and negative impacts on roads and other structures. This volume explores how Prince George is adapting its transportation infrastructure to climate change by providing background information about climate change and transportation in the city and explaining how the City is moving forward with the knowledge that climate change is impacting its transportation infrastructure.

Climate Change in Prince George

In 2002, the City's Transportation Manager conducted an analysis of typical winters in Prince George to improve the approach to budgeting for snow removal and disposal. As part of this analysis, historical local weather data for 1956 to 2001 were obtained from Environment Canada and a chart was prepared plotting average winter minimum temperatures, maximum temperatures, and snowfall. The chart, which is updated to 2004 and presented as Figure 1, shows a decrease in snowfall (black) and a clear warming trend with minimum temperatures (blue) rising twice as fast as maximums (red).

Although this investigation was conducted to inform snow maintenance budgeting, the chart raised a great deal of awareness about climate change amongst City staff and administration and helped to explain many of the changes that were occurring in Prince George. Rising minimum winter temperatures supported the anecdotal experiences of locals that winters were becoming less cold, and that periods of extreme cold (colder than -40°C) were becoming less frequent or even non-existent. Warming winters relate very closely to the current mountain pine beetle (MPB) epidemic in Northern BC, and many experts attribute the unprecedented spread of the beetle to a lack of consistent cold winter temperatures. The changes illustrated in Figure 1 also appear to relate to impacts on local transportation infrastructure. It is expected that warmer minimum winter temperatures in Prince George have led to more incidences of winter freeze-thaw cycles,¹ which stress roads by enlarging surface cracks that will develop into potholes (Mills et al., 2007). Precipitation falling as rain represents a greater maintenance challenge in winter, particularly when rain-on-snow or freezing rain conditions occur.

¹ Detailed freeze-thaw analyses are being completed and are overviewed in Volume 7.

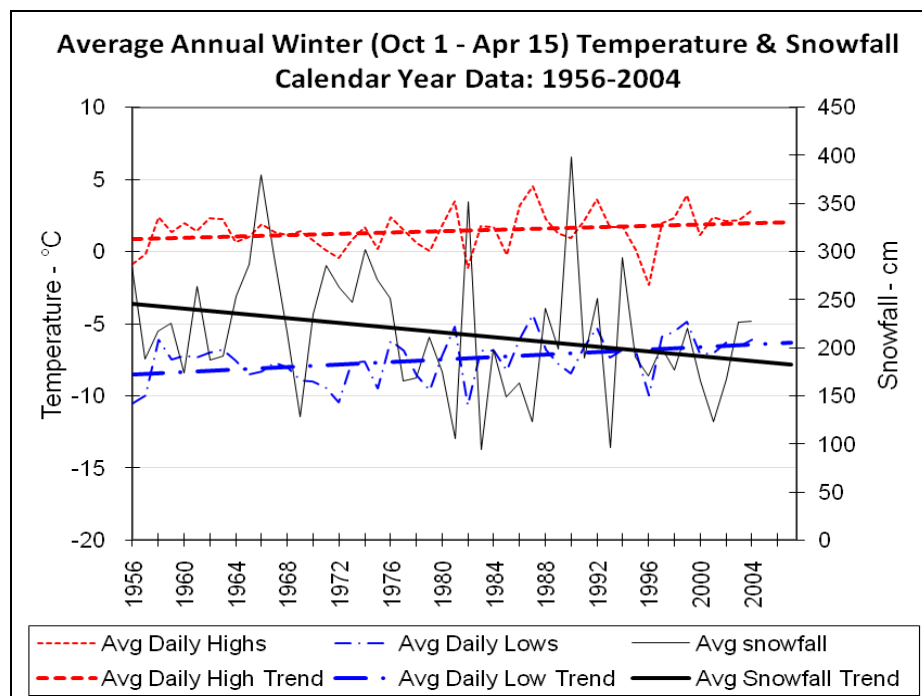


Figure 1. Snow analysis chart illustrating changing temperature and snowfall trends in Prince George.
(Adapted from: F. Blues, City of Prince George, 2004)

When the City began to study climate change adaptation in 2007, one of the first projects was to investigate, in partnership with PCIC, past climate trends and future projections for the region.² The analysis of past conditions verifies the City's earlier analysis and clearly illustrates the trends in the region. The trends for change in temperature and precipitation since 1918 are shown in Figure 2. By analyzing the outputs of many Global Climate Models (complex mathematical simulations of the climate that project temperature and precipitation changes), the assessment finds that, "*annual temperatures in the region are projected to increase an average of 1.6°C to 2.5°C by the middle of the 21st Century. Precipitation is projected to increase by 3% to 10% primarily in winter with possible decreases in summer.*" (Picketts et al., 2009b, p. iii) These changes illustrate that impacts to transportation infrastructure are likely to continue to intensify, and that the City needs to rethink how it designs, builds, and maintains its roads.

² See full report at:

http://pacificclimate.org/sites/default/files/publications/Werner.ClimateChangePrinceGeorge_Aug2009.pdf.

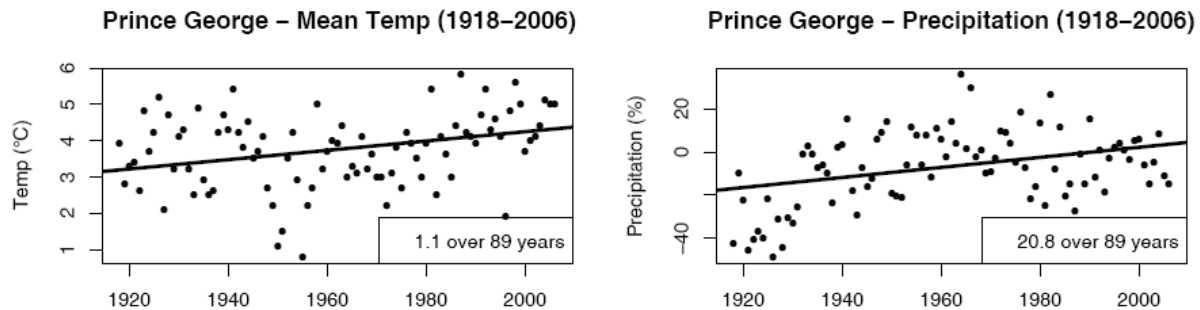


Figure 2. Past trends for Prince George from 1918-2006. Graphs illustrate changes in annual: (a) mean temperature; and (b) precipitation. (Source: Picketts et al. 2009b).

Local impact priorities were identified through a staff workshop and surveys of the public, then outlined in the strategy document *Adapting to Climate Change in Prince George* (Picketts et al., 2009a). Not surprisingly, transportation was ranked highly—the third priority identified overall (after forest impacts and flooding). Transportation infrastructure relates in some way to all of the other priorities identified in the strategy, and is closely linked with several important impacts. Some climate-related impacts that have close ties to transportation are as follows:

- **Flooding:** flooding damages transportation infrastructure; roads can be designed as dikes to prevent floods.
- **Severe weather – emergency response:** functioning transportation networks are crucial for effectively responding to extreme events.
- **Slope stability:** road construction above or below steep slopes or escarpments can cause slope failure, potentially affecting nearby transportation infrastructure.
- **Storm-water:** storm-water management infrastructure is often placed beside or under roads and ineffective management can impact transportation infrastructure.

Although not the focus of this report, transportation has close links to climate mitigation as vehicles are a major source of emissions. Therefore, transportation projects that can address both adaptation and mitigation together are especially encouraged.

Climate Change and Transportation Infrastructure

The natural environment is one of the main factors affecting how roads and other transportation infrastructure are designed and how they perform over time. All types of infrastructure are vulnerable to weather events and climate change, so municipalities and other levels of government must plan to address impacts on both new and existing structures (National Research Council, 2008). Figure 3 illustrates how weather interacts with road structure, construction, maintenance, and traffic patterns to determine how such infrastructure deteriorates.

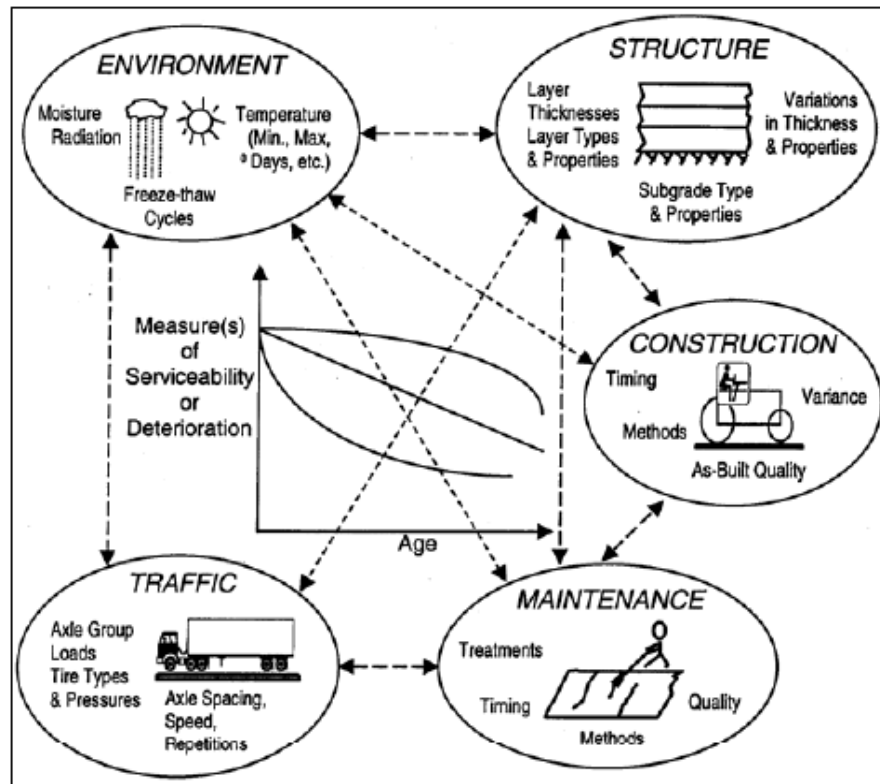


Figure 3. Illustration of different factors affecting road quality. (Source: Haas, 2004)

The US National Research Council (NRC) (2008) worked with many partners to perform a detailed summary outlining the consequences of climate change on the infrastructure and operations of US transportation. The report found that the two major potential impacts of climate change on transportation in America are:

1. Flooding
2. Increases in types of weather and climate extremes (explained further on page 9)

The NRC report focuses on flooding in coastal regions, but it is very relevant to Prince George. Flooding events can damage infrastructure, and also temporarily render roads unusable at times when they are most needed to respond to emergencies.

As Figure 4 illustrates, river flooding has had a big impact on the city in recent years, affecting roads, trails, and railways. An ice jam flood in Prince George during the winter of 2007-2008 demonstrated the impact flooding can have on transportation. During the 1-in-90-year event, ice and water flooded an industrial road and the surrounding area for more than three weeks. Access was cut off to three lumber and wood product industries, a petroleum storage depot, several industry-related businesses, and a few residences. Some industries were forced to suspend operations for several days and some businesses were forced to relocate their operations to hotels or other locations for two to three weeks. A major concern was the threat to the Canadian National Railway (CNR) rail yard and its mainline tracks that connect to the Port of Prince Rupert. Rail cars had to be moved away from the threat as flood waters rose to within centimeters of the rails. Fortunately, the railway mainline was not closed.

Following the ice jam event, the City realized the importance of ensuring that access is maintained within the floodplain for the industries located there and for deploying temporary flood protection measures during a flood event (such as installing sandbags, sand gabions, or pumps). In 2009 the road was widened and raised to the 1-in-200-year flood level. To further protect the industrial area and CNR rail yard and mainline, federal and provincial funding was announced in January 2012 to construct a \$11.5 million, 3.3-kilometre dike project along the industrial road that was flooded in 2007-2008. The City has also restored the walking trails on and around Cottonwood Island. The effects of climate change on flooding in Prince George, and how the City is preparing for flooding, is discussed in detail in Volume 4.



Figure 4. Recent flooding events in Prince George, such as the ice jam flood on the Nechako River in 2008, have affected road and trail transportation infrastructure.

(Photo: courtesy of City of Prince George)

Weather and climate extremes include very hot weather, extreme precipitation events, droughts, storm surges, sea level rise, and other impacts of climate change. Some of these events, such as extreme hot weather and sea level rise, are not as relevant to Prince George because of its colder climate and inland location. In northern areas, cold winter temperatures have a bigger impact on transportation infrastructure than hot summer conditions (Natural Resources Canada, 2007). In the report, *The Road Well Travelled: Implications of Climate Change for Pavement Infrastructure in Southern Canada*, Mills et al. (2007) present the results of an in-depth study on pavement infrastructure and climate change for the Canadian provinces. Many sites across Canada were analyzed to investigate how road infrastructure is expected to be affected by climate change (using projections from global climate models).

Although Prince George was not one of the sites analyzed, northern cities including Thunder Bay, Ontario and Edmonton, Alberta were investigated and these have a similar climate and geography to Prince George. Three main types of impacts from climate change were determined to contribute the most to pavement deterioration in Canada: thermal cracking, frost heave, and thaw weakening and rutting. An overview of these deterioration processes is highlighted in Table 1.

Table 1. Explanation of pavement degradation processes in Canada affected by climate change and predicted impacts in Canada and Prince George. (Adapted from Mills et al., 2007).

Climate-related deterioration process	Explanation of process	Predictions for Canada (based on analysis of all sites)	Predictions for northern cities
<i>Thermal cracking</i>	At very cold temperatures pavement cracks and deteriorates	Less problematic due to warmer temperatures	Less problematic due to warmer conditions
<i>Frost heave and thaw weakening</i>	Pavement rises when water in the base structure freezes, and lowers when it thaws	Structures freeze later and thaw earlier, leading to shorter freeze season lengths	More problematic with increase in winter freeze-thaw cycles
<i>Rutting</i>	During excessive heat pavement gets distorted in wheel paths	Greater potential related to higher pavement temperatures	More problematic, but not a major concern

It is especially important to carefully plan transportation infrastructure to address climate change impacts as many of the structures have long lives. The life spans of infrastructure assets range from about 15 years for an arterial road to 75 years or more for bridges and storm sewer systems. It is far cheaper and more efficient to design structures appropriate to conditions, as retrofits and repairs are costly and often not possible.



Figure 5. Confederation Bridge, which links Prince Edward Island to the mainland, was designed to account for 1 m of sea level rise. (Photo: from: www.concretethinker.com)

Climate Impacts on Prince George's Transportation Infrastructure

Climate change has the potential for significant impact on the 630 km of roads within the City of Prince George, as well as on sidewalks, the airport, railways, parking lots and the many local trails and paths. Because of Prince George's remote location it is also heavily dependent on one major highway from the south for the transportation of necessary goods such as food.

Resource roads that are constructed for forestry operations and mining activities in the region surrounding Prince George form a large network of secondary roads that contribute to the area's economy. These roads feed into city roads at various locations. The different types of roads (including highways, arterial roads, collector roads, resource roads, and local roads) have different surface types and road base designs for their intended purposes. When considering the impacts of climate change, these differences may affect how the City, the BC Ministry of Transportation and Infrastructure, the BC

Ministry of Forests, Lands and Natural Resource Operations, and private resource road owners will adapt.

One scenario is that milder winters may lead to safety concerns as icy roads become more prevalent. Another scenario is that earlier break-up in the spring could reduce the log hauling season, which could lead to more trucks on roads during the shortened winter season. Because some of these roads are outside of the City's jurisdiction, a collaborative effort to collect and share information about adapting to these climate change impacts would be an objective for the Province of BC and private owners (who are both stakeholders in the regional road network).

It is expected that climate change will affect the number of freeze-thaw cycles and that longer periods above freezing will increase during Prince George winters. A historical trend analysis of freeze-thaw cycles is currently underway by McElhanney Consulting Services Ltd. in conjunction with the firm Kerr Wood Leidal. Early results suggest that freeze-thaw cycles are actually decreasing when the entire year is considered, as there are fewer days in October and April where the temperatures are dropping below freezing. However, during the winter months the number of hours above freezing is increasing.³

The increase in mild conditions and freeze-thaw cycles in winter will allow snow and ice-melt water to enter cracks in the roads. This water expands and contracts as it freezes and melts and the change in volume leads to larger voids which in turn fill with water and then freeze and thaw; the cycle repeats, leading to large cracks and potholes if not dealt with (Galbraith et al., 2005). An increase in these winter events is suspected as a major cause of the increasing pothole problem in Prince George, and the large numbers of these events in the north is a main reason why roads do not last nearly as long here as in more southerly regions. The City of Prince George reports an increase in potholes and pavement surface deterioration in recent years. Some of the surface distresses are due to age of the roads as the life span of an asphalt pavement surface on arterial and collector roads in Prince George is typically 12 to 15 years. The freeze-thaw action appears to be causing an increase in widening of pavement cracks, potholes, and surface failure.

³ Refer to Volume 7 for a detailed overview of these reports



Figure 6. Potholes are a common issue on Prince George roads.
(Photo: courtesy of City of Prince George)

Some of the main impacts of climate change on roads in Prince George, outlined by Dyer (2006), include:

- frequent freezing and thawing results in more ice on roads and can cause safety issues
- frequent freezing and thawing results in more rapid road surface and structure deterioration
- temperature changes lead to an increase in maintenance costs (more salt, pre-wetting, anti-icing, etc.)
- greater amounts of salt required for maintenance will increase the toxicity of runoff
- more snow disposal sites may potentially be required if snowfall increases

There are many other factors that can influence the planning and design of transportation infrastructure in Prince George. As noted previously, there are strong links to climate change mitigation, and the City is promoting active transportation to encourage local health and reduce greenhouse gas emissions. The cost of petroleum correlates with the price of asphalt, so increasing fuel costs can affect the types of road materials used. Salt and gravel used on roads in winter is another related issue, and reducing the use of these products can lessen impacts to local air quality and watersheds and also reduce costs for the City.

Existing Practices and Initiatives

There are already several initiatives ongoing in Prince George related to climate change and transportation infrastructure. Although most of them do not explicitly mention climate change as a motivating factor, they are making Prince George more prepared for and resilient to a broader range of conditions.⁴ Examples of local projects already underway are as follows:

Snow and Ice Control: Prince George has a highly organized snow and ice control program and is a member of the Winter Cities Association, which is aimed at making winter cities more livable through better design and management. Local snow and ice control measures include pre-wetting surfaces with salt or abrasive material to combat ice on roads. The City also uses only coarse crushed gravel (with no fine material less than 1 mm in diameter) on roads to minimize impacts to local air quality and aquatic ecosystems.

Salt Management: Prince George carefully manages the application of salt on roads to minimize environmental damage, save money, and appropriately address the road conditions (Amec 2006).

Raising Roads in Flood Prone Areas: In response to the 2007-2008 ice jam flooding event, River Road was permanently raised to help contain flood waters and to allow for vehicle travel during high water levels.



Figure 7. Quality winter road maintenance is a high priority for Prince George residents.
(Photo: courtesy of City of Prince George)

⁴ General information about transportation in Prince George is available at <http://princegeorge.ca/cityservices/transportation/Pages/Default.aspx>

Advancing Local Adaptation Actions

As previously noted, climate change impacts on transportation was listed as a high priority for continued action under the RAC program. This section overviews the steps taken locally to prioritize and create adaptation planning for Prince George. The major activities undertaken or underway are as follows:

1. **Establishing a Steering Group:** getting local government transportation administrators, outside stakeholders, and climate experts together to advise further actions
2. **Partnering with local transportation authorities and experts:** working with specialists in transportation and climate change
3. **Deciding on priorities:** determining focus for ongoing work
4. **Exploring research priorities:** in-depth examination of the priorities
5. **Ongoing actions:** ongoing and proposed actions for priorities

Each step is described in more detail below:

1. Establishing an Adaptation Team

As transportation is a very broad and complex topic, the group examining adaptation in Prince George (adaptation team) sought local expertise to help determine the focus for ongoing study. As a result, the transportation steering group (steering group) was formed, which included the initial adaptation team and key senior City staff managing the transportation network. The group's initial role was to ensure that the projects selected were of most use and relevance to the local staff and that the results would provide the greatest benefit for the community. As investigations progress, the committee's role is to oversee the projects and to provide their expert (local) advice. It will be up to local stakeholders to implement measures and oversee continuing projects with the City. A brief description of the members involved in the group, as well as their roles and their areas of expertise, is outlined in Table 2.

Table 2. Members of transportation steering group.

	Representative	Areas of focus/expertise
City of Prince George	Manager of Transportation Division	Oversees transportation operations, engineering, capital plan
	Transportation Engineering Supervisor	Road design, construction projects, traffic lights, street lighting
	Transportation Engineer/Planner	Transportation planning, traffic engineering, development review, traffic impact assessment, collisions, dangerous goods, active transportation
	Chief Engineer, Planning and Development	Infrastructure planning, development servicing, flood mitigation/management, watershed drainage planning, climate change adaptation
	Asset Manager	Asset Management, winter road maintenance, fleet, water, sanitary, street operations, traffic planning
External	Climate Change Adaptation Researcher (UNBC)	Climate change adaptation, community engagement
	Climate Change Project Assistant (Fraser Basin Council)	Project reporting, documentation, meeting and workshop coordinator
	Transportation management expert	Transportation engineering, road construction, capital road program, traffic lights, asphalt
	BC Ministry of Transportation and Infrastructure Representative	District Ministry representative on climate change adaptation (later addition to committee)
	Engineering Consultant	Geotechnical engineering, transportation engineering (later addition to committee)

2. Partnering with transportation experts

At an early stage in the project, contact was made with three authors of the aforementioned report, *The Road Well Travelled: Implications of Climate Change for Pavement Infrastructure in Southern Canada*. These authors are:

- Brian Mills (Environment Canada researcher, based out of the University of Waterloo)
- Susan Tighe (University of Waterloo professor)
- Jean Andrey (University of Waterloo professor)

These experts were approachable and responsive, and indicated that they would be interested in helping the City Prince George as it explores climate change and transportation. They agreed to advise the adaptation team and steering group and to become involved in the project if a suitable opportunity arose within their areas of expertise. They have become valuable contributors and ongoing decision making includes their input. Mr. Mills, Dr. Tighe, and Dr. Andrey are internationally recognized transportation experts with extensive experience working with communities regarding climate change and transportation infrastructure. Their biographies, as well as Linday Matthews' biography (a graduate student working with Dr. Andrey), are included as Appendix A.

3. Deciding on priorities

There were numerous potential projects to pursue, but the steering committee needed to narrow these down to the priorities that were most relevant for Prince George. The adaptation team created a list of potential topics that could be pursued further by reviewing literature and by communicating with the steering group and the Waterloo experts. The complete list had 23 topics related to climate change and transportation that the City could explore. Members of the steering group who worked for the City were asked to rank the topics in terms of priority on a scale of 0 to 5, which was defined as follows:

- **0-1:** not Important or of low importance, not likely to be used/implemented by the City
- **2-3:** of moderate importance and may be used by City, or is important but not likely to be used
- **4-5:** of moderate-high to high importance, quite likely to be used and implemented by the City

The list, organized by topic, is included as Table 3. The eight top-ranked impacts are **featured in bold** and discussed further afterward. The full chart disseminated to the steering committee for ranking, complete with an explanation of each option, is included as Appendix B.

Table 3. Potential topics on climate change adaptation and transportation ranked by steering group.

INFRASTRUCTURE:
1. Road design: pavement performance and climate change 2. Road design: road structures and climate change 3. Climate change and road drainage systems 4. Climate change and large vehicle loads in the City 5. Examining climate change and vehicle load restrictions on secondary roads 6. Climate change and structures 7. Assessing infrastructure vulnerability to climate change
OPERATIONAL PRACTICES:
8. Road maintenance: Pavement treatments/rehabilitation and climate change 9. Climate change and salt use: impacts on infrastructure 10. Climate change and salt use: general 11. Road maintenance: Road condition analysis and climate change 12. Climate change and winter road maintenance 13. Climate change and road information 14. Exploring wind and transportation and traffic control 15. Climate record research for Prince George
EXTREME EVENT RESPONSE/SAFETY:
16. Extreme events: Climate change, freezing rain events, and transportation 17. Extreme events and road placement 18. Extreme events: Transportation as a key factor in emergency response 19. Climate change and road safety
MISCELLANEOUS:
20. Financing adaptation 21. Climate change and sustainability 22. Climate change and traffic patterns 23. Climate change and other forms of transportation

The steering group had to further narrow down this list of eight top priorities into a couple of areas of focus. Some of the top priorities were not considered for ongoing work because they were deemed beyond the scope for this project. These were:

- **Climate change and sustainability:** a very important issue, but the group decided it was more relevant to the *myPG* sustainability plan and other ongoing local initiatives.

- **Climate change and road drainage systems:** a very important issue, but the group decided it was better pursued as part of a storm-water adaptation project.
- **Financing adaptation:** a vital part of adaptation, but it is not in line with the steering group's expertise.

By analyzing the remaining priorities, the adaptation team combined the top topics into two broader areas of focus. The definitions of the focus areas, the topics from Table 3 that they encompass, and the key questions they explore are overviewed below in Table 4 and in detail in Appendix C. It is important to note that these areas were influenced by the available expertise of the Waterloo group.

Table 4. Description of transportation adaptation focus areas.

Area of focus:	A. Winter road maintenance and safety and climate change	B. Road design and climate change
Topics incorporated:	• Extreme events: climate change, freezing rain events and transportation • Climate change and salt use: impacts on infrastructure • Climate change and salt use: general • (Other priority incorporated: Climate change and road safety)	• Road design: pavement performance and climate change • Road design: road structures and climate change • Road maintenance: pavement treatments/rehabilitation strategies and climate change
Key questions explored:	• What are the implications of climate change for winter road maintenance in Prince George? • How will climate change affect road safety in Prince George and how can the City prepare for this?	• How will climate change affect pavement infrastructure in Prince George? • How can Prince George prepare for and respond to climate change in road design and maintenance? • Is there a region currently experiencing conditions Prince George can expect in the future, and can the City learn from it?
Further information:	• See Appendix C	• See Appendix C

4. Exploring priorities

The steering group and Waterloo experts agreed that a 2-day workshop would be a timely and important next step. Such an event could provide City administration and external stakeholders

information about transportation and climate change, raise awareness of other work being conducted, prioritize areas to investigate, and determine how next to proceed.

The Waterloo experts gave their time 'in-kind' for the visit, and RAC funds and the City of Prince George paid for the travel, the venue, and other associated workshop costs. Over the course of the workshop many activities were scheduled, including:

- An information session
- A tour of the City
- A day-long focus group session
- Meetings between stakeholders

Each of these events is discussed in more detail below.

Information session: The information session was held for half of day 1 and was designed to provide a venue for the Waterloo Team to share their knowledge and experiences with Prince George stakeholders. The event was open to the public as well. The steering group was in attendance as well as several other Prince George staff members and representatives from local consultant groups, the Ministry of Transportation and Infrastructure, and local non-governmental organizations. Several UNBC professors, researchers, and students attended the session also.

Afterward was a brief, facilitated discussion about moving forward and project next steps, and the parties had informal discussions over lunch.



Figure 8. Participants listen to a presentation at the information session.

City Tour: After the information session, senior staff took the Waterloo experts on a tour of the city. Some of the city's most damaged roads were examined, as well as newly paved roads, snow storage facilities, and weather data stations.

Focus Groups: The next day a focus group was held with the Waterloo experts, the steering committee (including new members who just joined), a UNBC climate change expert, and representatives from local consultancies. This day was designed to be an informal yet productive meeting that would help to define how future work should progress. The day started with a debriefing of what participants had learned the previous day. Following this, there was time dedicated to the two previously defined focus areas. The sessions were a lively exchange of information and a wide breadth of topics was talked about throughout the day. Some questions discussed by participants in the two sessions are included in Figures 9 and Figure 10.

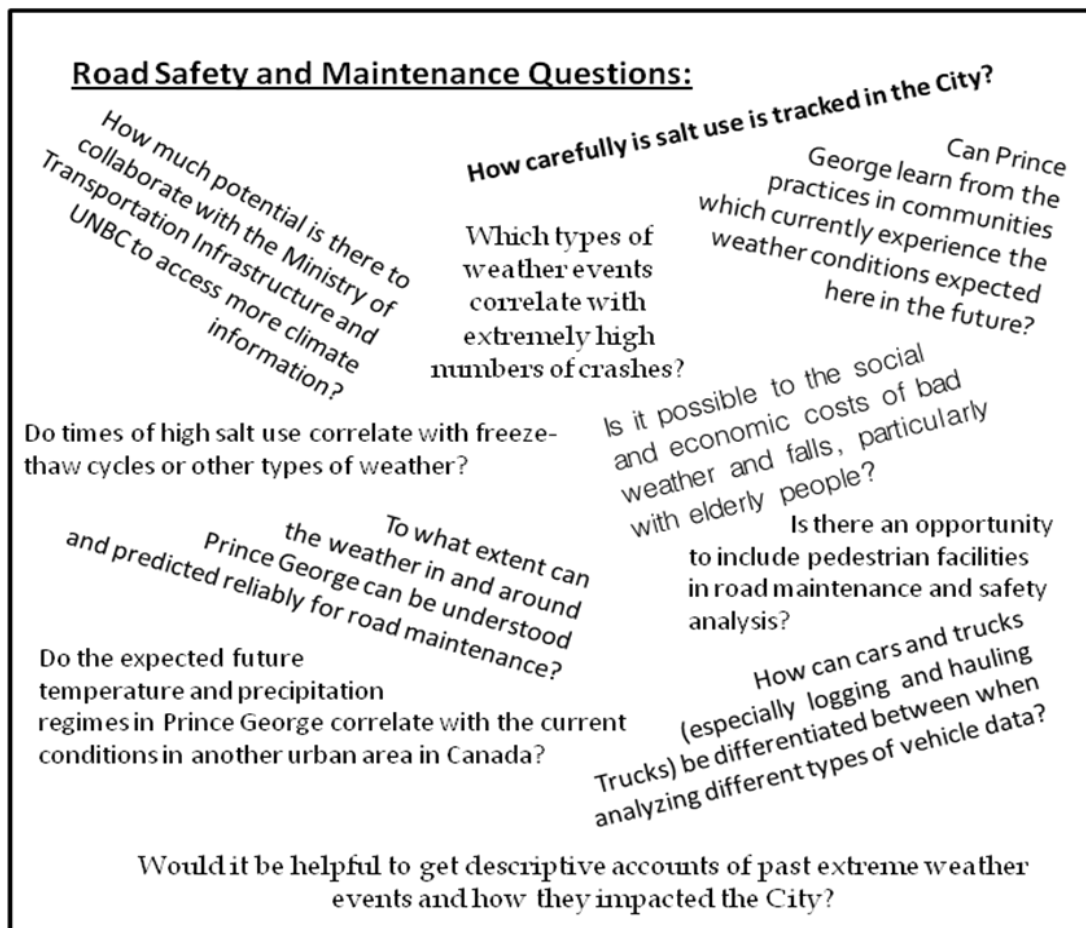


Figure 9. Key questions posed regarding road safety and maintenance during the focus group.

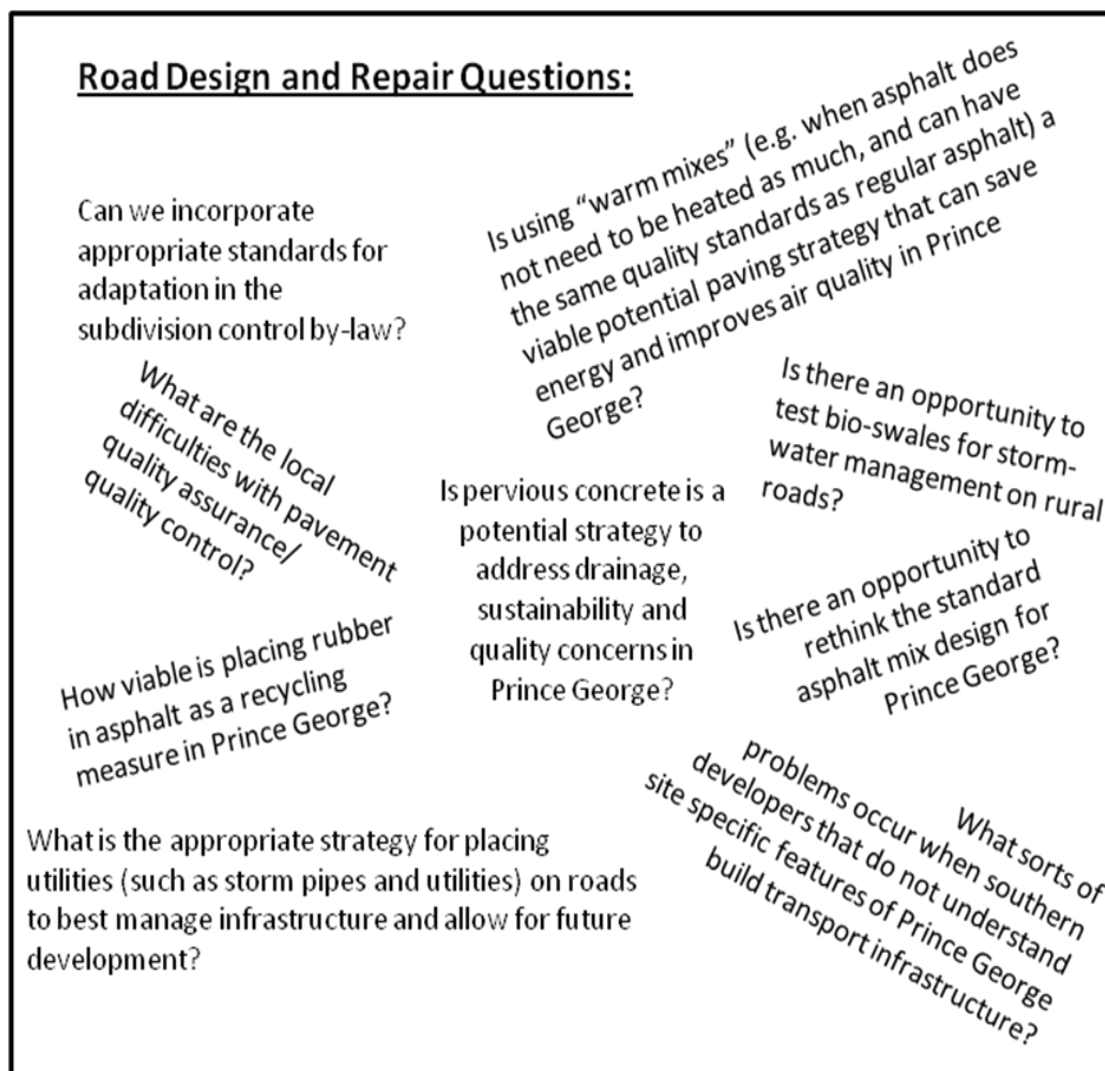


Figure 10. Key questions posed regarding road design and repair during the focus group.

Meetings: Between the events the Waterloo experts met with City and UNBC experts to discuss the Prince George case study, information requirements, possible data sharing agreements, and to take the opportunity to meet in person.

Workshop Outcomes:

- The information session, tour, focus group, and meetings were very successful in bringing people together who had local knowledge, academic knowledge, and a concern about climate impacts in Prince George.

- All of the participants in the different sessions indicated an appreciation for being included in the process, and also that they were willing to participate in ongoing projects in some capacity with the City.
- The University of Waterloo experts were impressed with the information records that Prince George was keeping as well as the level of knowledge, awareness, and action that already exists within the City.
- The Prince George participants appreciated the level of expertise, knowledge, and willingness to help displayed by the Waterloo experts.
- A key conclusion of the event was that there is too much information within the City of Prince George that is locked up in individual senior staff members. It is important that the City document this individual knowledge. If this does not happen then a great deal of valuable expertise may be lost when senior staff members retire or change jobs.



Figure 11. City staff and Waterloo experts discuss transportation strategies for Prince George.

Table 5. Overview of key outcomes from the workshop.

Outcome Topic	Description
Follow-up Opportunities	
Load restrictions	Quantifying the damage of loads is crucial: City needs to know what the costs/damages are and support an enforcement strategy.
Alternative pavements	Lots of interest in alternative treatments from City and great potential for projects, such as pervious concrete. Large amount of consultant interest, and potential partnerships available.
Storm-water management	Continue to encourage on-site disposal of storm-water. Considerable interest in whether these ideas work in Prince George's climate.
Updating Rainfall Intensity Duration Frequency (IDF) curves	With changing IDF curves and other engineering challenges, engineers need to be confident that this is based on good science; complexity of engineering important.
Spring snowmelt	High-intensity storms in summer are what our standards are built to now: should it be snowmelt in spring instead? Important due to combination in spring of snowmelt, increased precipitation, and weak subsoil.
Knowledge/Information Exchange	
Data-sharing agreement	Potential to set up the agreement to share costs and data collection. Includes weather stations from City of Prince George, MoT and UNBC.
Community Awareness and Involvement	
New designs and projects	Business may be interested in technologies (e.g. the technology of pervious concrete) because it could save them money and liability. There is a need to get associations involved: groups will often build for same cost. General disconnect between IDEAS and INDUSTRY – industry reluctant to make changes.
Encouraging adaptation locally	There is an opportunity for the City to consider incentive programs: if there is a good solution then can find a way to get partners together to share risk. Prince George is small enough that businesses might be willing to try new things: get key people who have money and that will get the good contractors.
Relating work with <i>myPG</i> plan	With <i>myPG</i> there is a big connection with sustainability and climate change action.

5. Ongoing Actions

Over the weeks leading to and following the workshop there was a lot of discussion between the groups of stakeholders. During the preparation for the workshop, an opportunity arose for Jean Andrey (from the University of Waterloo) to supervise graduate student Lindsay Matthews to conduct research on Prince George. This opportunity was seized upon, and the outcomes of the workshop were used to help direct Ms. Matthews' project.

A. Winter road maintenance and road safety and climate change

Following the workshop, Lindsay Matthews and Jean Andrey (with assistance from Brian Mills) created a proposal, "The Implications of Climate Variability and Change for Snow and Ice Control and Road Safety in Prince George, British Columbia" for the City steering group in August 2011. The project is intended to assist Prince George to anticipate some of the implications of climate change for snow and ice control and road safety and also to help the City respond effectively to these changes. The project uses available motor vehicle crash data correlated with snow and ice control measures used by the City. The project has six interrelated objectives, outlined below in Table 6. The steering group and the local adaptation researchers provided feedback regarding the proposal, and the Waterloo Team has been working away at the objectives—collecting and analyzing data. The first deliverables from this project were submitted in January 2012 and the project will continue into 2013.

B. Road design and climate change

Although there was no formal project set up to explore road design and climate change, there was a great deal of enthusiasm from consultants, the City, the Waterloo team and other local stakeholders. Susan Tighe was able to send a large amount of relevant information regarding alternative forms of pavement and concrete to the Prince George stakeholders. She also was able to put Prince George staff members in touch with many external organizations, such as the BC Ready Mix Association, tire recycling and pavement experts, the Ontario Rubberized Asphalt Association, and the Cement Association of Canada. Members of the steering group conversed with representatives from these different organizations and shared information about testing new products in Prince George. Most of these types of road construction have not been tested in cold climates or regions where freeze-thaw cycles are predominant (such as Prince George.)

Exploration of these topics continued through the summer of 2011. The steering group, Waterloo experts, consultants, and Ministry of Transportation and Infrastructure representatives continued to be engaged in the discussions. As of spring 2012, the City of Prince George is examining opportunities to develop a project and/or partner with multiple stakeholders to further advance an initiative focused on road design and climate change. Many ideas are being considered, such as:

- Incorporating pervious pavement or recycled asphalt at a test section within one or more appropriate City-managed projects
- Partnering with a consulting firm engaged in research and development to find a project for the City to participate in with another client
- Partnering with an appropriate developer or “green” project
- Exploring opportunities with the Ministry of Transportation and Infrastructure
- Working with UNBC faculty and students to perform monitoring and maintenance on test sections, and for educational opportunities

Table 6 .Major objectives of winter road maintenance and road safety and climate change project.
(Adapted from: Lindsay Matthews’ and Jean Andrey’s research proposal)

Theme	Objective And Outcomes
Snow and ice control: current operations	1. Document how weather triggers snow and ice control operations in Prince George, including key changes that have occurred in equipment, materials, and practices over the past two decades. Associated with this will be an exploration of the extent to which milder winters explains the trend toward increased salt use over time.
	2. Using the above information, explore how climate variability ⁵ explains the occurrence of different types of weather days. The outcome will be a simple tool that can be used to anticipate how snow and ice control needs may vary, based on forecasts of variability cycles.
Snow and ice control: climate change	3. Using the above information and projections of future climate, estimate the ways in which snow and ice control needs may change in the next half-century. The outcomes will help determine cost-effective ways of delivering high-quality service under changed conditions.
Road safety: current conditions	4. Using collision data from various sources, characterize the severity, locations, and road-vehicle-driver attributes of weather-related collisions in Prince George. Based on this: road types, vehicle type or types responsible for many collisions will be identified.
	5. Using collision data from various sources and common techniques, estimate the extent to which collision rates are elevated during winter weather events of different types. The analysis can potentially show how different snow and ice control operations affect collision rates.
Road Safety: climate change	6. Using the above risk estimates in conjunction with projections of future climate, estimate the extent to which collision rates will change over the next half-century—as a function of climate change.

⁵ Climate variability refers to changes in weather over months to years. This is different than climate change, which refers to long- term shifts. For more information on this topic and cycles of variability that affect Prince George refer to Picketts et al. (2009b).

Recommendations

The project initiated under the RAC funding related to winter road maintenance and road safety and climate change is well underway. Hopefully there will be an opportunity to proceed with a pilot project using pervious concrete within the Prince George. This initiative could test the effectiveness of pervious concrete in a northern climate, monitor the environmental benefits, record the maintenance considerations, and determine the local industry's capacity to construct the product. A brief overview of actions that the City should continue with, and embark upon, is as follows:

Research Opportunities

- Continue to work with Waterloo experts on the winter road maintenance and road safety and climate change research, and utilize the results to help improve local road planning, design and maintenance.
- Embark on a test project with the Waterloo experts and researchers from UNBC to test new and innovative types of road design and construction that helps the city adapt to climate change. Partner with UNBC, local consultants, the Ministry of Transportation and Infrastructure and other interested parties to share costs, knowledge, and best practices.
- Investigate projected future climatic conditions for Prince George and determine if there is a community in Canada which currently experiences the conditions expected locally. If so, initiate communication with this local government to learn from their experiences and practices.
- Encourage climate assessments for all new infrastructure projects, especially for bridges and other structures that are expected to have long operational lives.
- Engage with climate change modelling experts (such as PCIC) to obtain state-of-the-art freeze-thaw projections to help inform these strategies.
- Study how climate change affects pedestrians, and how to adapt active transportation infrastructure to occurring and expected changes.

Knowledge/Information Exchange

- Initiate and maintain an open dialogue with forestry companies and trucking organizations to better understand spring and fall road closures on public and private roads.
- Partner with UNBC researchers and provincial governments, Government of Canada, other municipalities, and other organizations to better share climate information, and also to share best practices and learn from each other.

- Engage with City staff involved with the Annual Provisional Financial Plan, Asset Management Performance Measures, and the ICSP (*myPG*) process to ensure that adapting transportation infrastructure to climate change is incorporated into these documents.
- Collaborate with the BC Ministry of Transportation and Infrastructure to incorporate climate change adaptation strategies into the transportation infrastructure within and around Prince George that is under provincial jurisdiction.
- Encourage the exchange of knowledge and documentation of information among City staff so that information is not “locked” within individual staff members.

Community Awareness and Involvement

- Consider climate change mitigation co-benefits and trade-offs as a part of all future strategies.
- Share positive results so that other communities, particularly northern communities, can proactively adapt to climate change.
- Share positive results of continued work throughout the community.

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Appendix A: Biographies of Waterloo Team

Brian Mills:

Brian Mills is an applied climatologist with the Impacts & Adaptation Research Division of Environment Canada. He is based out of the Faculty of Environment at the University of Waterloo (Waterloo, ON). His current research contributes to Environment Canada's mandate to develop and evaluate strategies to adapt to the impacts of weather, climate, and climate change. Some of his applied work includes projects on:

- Understanding and managing the impacts of weather, climate variability, and climate change on surface transportation infrastructure and operations.
- Determining and improving the value of weather, climate and climate change information.
- Evaluating the social and economic impacts of lightning, winter storms, and other weather- or climate-related hazards.

Brian is the Chair of the Societal and Economic Research and Applications (SERA) working group. He is also a member of the World Weather Research Programme (WWRP), the World Meteorological Organization (WMO), the North American Regional Committee and the Observing System Research and Predictability Experiment (THORPEX). His recent publications include works on assessing the damages of lightening in Canada, assessing the implication of climate change on flexible pavement design and performance in southern Canada and developing frost and thaw depth indicators for decision making about variable load restrictions.

Susan Tighe:

Professor Susan Tighe, P.Eng., is the Canada Research Chair in Pavement and Infrastructure Management located in the Department of Civil and Environmental Engineering at the University of Waterloo. She is also the Director of the Centre for Pavement and Transportation Technology and the Norman W. McLeod Professor in Sustainable Pavement Engineering. Her research interests are in the area of pavement with particular interest on pavement design, life cycle economic analysis, risk and reliability, materials characterization, structural analysis and model development. Dr Tighe is very active professionally in Canada, US and abroad and has over 300 technical publications to her credit. Her accomplishments have been recognized by various awards, including the highly prestigious Canada's Top 40 Under 40 in 2006, Professional Engineers of Ontario Young Engineer Medal, the Faculty of Engineering Research Innovation Award and the Premier's Research Excellence Award.

She is a registered professional engineer and received her undergraduate degree in Chemical Engineering at Queen's University and her MAsc and PhD degrees in Civil Engineering from the University of Waterloo. She is a member of various professional committees including the

Transportation Association of Canada Chief Engineers Council, the United States Long Term Pavement Performance (LTPP) Expert Task Group on Data Analysis, and she is Chair of the International Steering Committee for the International Conference on Managing Pavement Assets (ICMPA8) She is Past Chair of the Transportation Association of Canada's, (TAC) Standing Committee on Soils and Materials. Dr. Tighe is a recognized national and international expert in Pavement Design and Management.

Jean Andrey:

Jean Andrey is a Professor in the Department of Geography and Environmental Management at the University of Waterloo. She has degrees from Wilfrid Laurier University, University of Calgary and University of Waterloo. She began her career as a public servant for the Government of Alberta in the early 1980s, working as a road safety analysis.

Over the past two decades her research has focused primarily on road safety and on weather-transportation interactions including weather-related collisions, winter maintenance practices, and planning for paved infrastructure under future climate scenarios. Her work in road safety deals with 'situational risk factors', e.g., her seminal work on young drivers' crash rates with passengers has influenced graduated licensing programs around the world. In addition, she has contributed to Canada's national assessments of climate change impacts and adaptations (1996 and 2004), and to the Intergovernmental Panel on Climate Change's AR4 Working Group on Impacts, Adaptations and Vulnerabilities (2007). She was also co-principle investigator on Canada's first conference on climate change communication.

She has published nearly 100 articles, book chapters, conference proceedings and technical reports; and supervised 180 thesis projects by students enrolled in degree programs in Geography, Planning and Civil Engineering.

Lindsay Matthews:

Lindsay Matthews is an MES candidate in the Department of Geography and Environmental Management at the University of Waterloo. Lindsay has a bachelor's of Environmental Studies degree from University of Waterloo. She has over eight years of practical experience in the field of environment and resource management through her work experience with government, NGOs, industry and academic institutions. Her Master's thesis is entitled "Sustainable Transportation Futures: A Climate Change Assessment for the City of Prince George" and is supervised by Dr. Jean Andrey.

Appendix B: Priority Impacts Selection Sheet

Adaptation Topic	Description of Topic	Priority Ranking: (0-5)	Comments
INFRASTRUCTURE	Description	Priority:0-5	comments
1. Road design: pavement performance and climate change	Examining different pavement surfacing materials, their installation depths and their resiliency to changing conditions, freeze-thaw, pothole minimization, etc.		
2. Road design: road structures and climate change	Examining road structure for resiliency to changing conditions, freeze-thaw, pothole minimization, examination of underlying geology/soil composition.)		
3. Climate change and large vehicle loads in the City	Creating a strategy to restrict large vehicles to designated truck routes that are more resilient as an adaptation strategy, studying axle loads, etc.		
4. Examining climate change and vehicle load restrictions on secondary roads	Examining how climate change will affect the typical duration and timing of load restrictions		
5. Climate change and structures	Exploring how structures, including bridges, tunnels, over/underpasses need to be designed and maintained differently with climate change		
6. Climate change and road drainage systems	Examining current system impacts of increased precipitation to drainage systems etc. and new designs adapted to impacts		
7. Assessing infra-structure vulnerability to climate change	Risk assessment and LCC approaches eg. MoTI Coquilhalla study (note links to 1. and 2.)		

OPERATIONAL PRACTICES	Description	Priority:0-5	comments
8. Road maintenance: Pavement treatments/rehabilitation strategies and climate change	How will climate change affect the type and timing of treatments and rehabilitation strategies: e.g. slurry seals, micro-pavements, rubberized sealing		
9. Road maintenance: Road condition analysis and climate change	Will climate change necessitate a different system for analyzing road conditions and prioritizing treatments and maintenance		
10. Climate change and winter road maintenance	How will these practices change and how can we adapt? (i.e. snow removal, plowing, different technologies for increases in ice, different strategies for snow removal?)		
11. Climate change and salt use: impact on infrastructure	Examining/adopting new standards, supplies (and storage), products and methods to deal with corrosion of metal piping etc. due to increased salt use		
12. Climate change and salt use: general	Examining how Prince George can plan for more salt use, researching salt supply, costs and potentially storage		
13. Climate change and road information	Examining if Intelligent Transportation information systems are needed to improve driver response to varying weather conditions due to climate change		
14. Exploring wind and transportation and traffic control	Obtaining wind projections (level and prevailing direction) and examining effects on snow-fencing, transit facilities, signals/signage stress (e.g. sideways)		
15. Climate record research for Prince George	Determine cities currently with our predicted future climate to see their management practices and infrastructure		

EXTREME EVENT RESPONSE/SAFETY	Description	Priority:0-5	comments
16. Extreme events and road placement	Examining increased extreme events (such as fires, floods, freezing rain) related to climate change implications for road planning and placement		
17. Extreme events: Transportation as a key factor in emergency response	Examining how transportation can be better designed, maintained etc. so the city can better respond to more extreme events with climate change		
18. Extreme events: Climate change, freezing rain events and transportation	Obtaining information about freezing rain predictions and examining how the city can better prepare for and respond to a potential increase in events		
19. Climate change and road safety	Examining the relationship between changing weather/climate and driver safety		
MISCELLANEOUS	Description	Priority:0-5	comments
20. Climate change and traffic patterns	Considering how climate change may alter traffic flow and traffic patterns		
21. Climate change and other forms of transportation	Examining adaptation for rail, airports, bike paths, sidewalks, etc.)		
22. Financing adaptation	Examining how to deal with upfront investments for long life resiliency, costs of increased materials and maintenance		
23. Climate change and sustainability	Examining the sustainability initiatives discussed during myPG process and how they can be implemented for transportation/infrastructure		

Appendix C: Overview of Focus Areas

Focus area A. Winter Road Maintenance and Road Safety and Climate Change

Maintenance:

Winter weather creates mobility challenges for all northern jurisdictions. Each year, road authorities in Canada spend approximately \$1.5 billion on snow removal and other winter maintenance activities. As well, the science and management of snow control are constantly evolving. This includes many activities including salting, sanding, snowplowing and the construction of snow fences (Natural Resources Canada 2007). Large storm events can make up a large proportion of total seasonal costs as well as hinder the effectiveness of emergency response. Various documents identify 'best practices' in winter maintenance, and there is growing interest in the development and adoption of decision-support systems that recommend specific treatments based on detailed forecasts and road weather information. While these types of decision-support systems may be valuable at the operational level, other tools are necessary for more strategic decisions, such as budget planning and service arrangements.

Over the past two decades, various 'winter severity' models and indices have been developed that take a more strategic view of winter maintenance. Many of these models provide reasonable statistical fit between weather variables, as input, and maintenance activities, as output; however, many of these models also have several limitations. An alternate approach involves using 'classification trees' to model decisions taken for individual trucks or fleets, at fine temporal scales (e.g., hourly or in three-hour intervals) based on both forecast and observed weather; and then aggregating the results that are produced to the day, storm or season. This type of approach is particularly suited to estimating the implications of climate change for winter road maintenance, as regional climate model output (e.g., snowfall amount, minimum and maximum temperature) for future decades is available at these same time intervals.

Safety:

It is well known that weather that reduces friction, impairs driver visibility and makes vehicle handling more difficult, creates hazardous conditions for motorists and increases crash risk. While the risk varies by weather type and intensity, and also according to driver, vehicular and other situational factors, on average, crash risk doubles during snowfall relative to 'normal' winter driving conditions. It is also worth noting that the relative risk of a serious crash during snowfall events has not changed over the past two decades, despite improved winter maintenance. It is thus, very likely, that a changed climate will affect future crash rates. Different frequencies and types of storms will create altered risk exposure and, in turn, altered crash frequencies and severities. Using police records of past crashes, it is possible to calculate the 'added' risk associated with inclement weather; and, using output from regional climate models, it is possible to project the frequency with which inclement winter weather will occur in future decades.

Focus area B. Road design and climate change

Canadians are heavily dependent on road transport, and have invested heavily in an extensive network across the country. Canadians take the vast majority of their trips by personal vehicles, and most goods are transported by road as well. Climate change has the potential to have large impacts on the 630 km of roads in Prince George. The effects of climate change can be compounded by aging infrastructure, growing demands and loads, poorly designed communities, air pollution and an aging population. Three primary deterioration processes of pavement in Canada (as discussed above) are related to the climate are: thermal cracking; frost heave and thaw weakening; and rutting. While southern parts of Canada may experience less freeze thaw cycles with climate change as temperatures remain above freezing, northern regions (such as Prince George) are expected to experience more of these cycles and experience greater road and runway deterioration. More frequent freeze-thaw cycles have been noted as a cause of potholes in Prince George, and are a reason that roads do not last nearly as long here as in more southerly regions. It is important to note that there are many different types of roads which need to be considered. These include private roads for resource extraction, gravel roads, secondary roads, arterial roads and major highways. Design standards and the materials used to construct each type are variable meaning they likely have different exposures and sensitivities to climate.

None of the conditions expected to occur in Prince George fall beyond the range of conditions already experienced in North America. Therefore appropriate materials, design standards and maintenance practices already exist to manage the problems which are expected—though this may require adoption of unfamiliar technologies and solutions and potentially larger investments in monitoring, construction, and preventive maintenance.