Climate Change Risk Assessment and Adaptation Report: Ministry of Transportation

Final Report

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Alberta Environment and Sustainable Resource Development, Climate Change Secretariat

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Executive Summary

This report presents (i) a high-level climate change risk assessment focused on the mandate of the Alberta Ministry of Transportation, and (ii) a set of adaptation measures intended to reduce the most significant risks. The risk assessment and the adaptation measures were developed through a multi-step risk management process undertaken in collaboration with the Ministry.

The purpose of the risk assessment was to identify and prioritize the potential climate change risks posed to the Ministry over the next 40 to 50 years. This task was achieved through a risk assessment workshop with participants from the core responsibility groups of the department. At the workshop, participants identified 13 potential risks, of which one was identified as 'high' and two as 'moderate' priority risks for the Department, as follows:

- High Risk: road traffic disruptions and increased accidents from more frequent winter rain, freezing rain, and wet snow.
- Moderate Risk: road washouts and blockages from more frequent high-intensity, low duration rain events, causing landslides and overwhelmed stormwater management facilities associated with transportation infrastructure.
- Moderate Risk: reduced visibility and traffic disruptions due to increased wildfires and smoke

For each of these priority risks, adaptation measures were developed through a second workshop with participants from the core responsibility groups of the department. The following table summarizes these adaptation measures:

Summary of Adaptation Measures

Risk Event	Adaptation Measure
High Risks	
Road traffic disruptions and increased accidents from more frequent winter rain, freezing rain, and wet snow	Increased winter highway maintenance including improved anti-icing measures
	Change vehicle and driver education requirements (e.g. addressing the case for winter tires and/or studs)
	Improved road weather information systems and associated outreach/awareness efforts
	Change the geometry of road design
	Increase monitoring of road traffic disruptions and increased accidents to determine if they are climate-change induced
	Identify alternate transportation modes to using roads
Moderate Risks	
Road washouts and blockages from more frequent high-intensity, low duration rain events, causing landslides and overwhelmed stormwater management facilities associated with transportation infrastructure	Change design standards to accommodate high-intensity, low duration rain events
	Survey existing infrastructure to determine "at risk" installations – candidates for retrofit
	Accelerate retrofitting of at-risk sites based on survey results
	Review/update emergency management plans to prepare for increased frequency of these events
Reduced visibility and traffic disruptions due to increased wildfires and smoke	Improve travel advisory systems

The consultant team recommends that:

- Senior Departmental management be briefed on the results of this high-level climate change risk assessment and on the adaptation measures identified to reduce the most significant risks.

- The Department support the conclusions and recommendation of this study and prepare to move forward on implementing the identified adaptation actions.

- The Department begin preparatory actions related to the three highest-rated climate risks as soon as circumstances and trend data warrant. These “first stage” actions should be of low or moderate cost, but will assist in preparing information for other start-up activities, will ensure new investments are adapted to climate risks, and will begin responding to risks that are already being felt.

- The Department familiarize and engage staff with the climate change risk assessment process and its results through a series of focus group sessions or short workshops, encouraging the input of new ideas and suggestions.

- The Department consider forming a climate change action team to make a detailed review of the screening study and undertake a more in-depth risk assessment and development of a more comprehensive adaptation strategy.

- At an appropriate time, the Department begin to engage Departmental clients on the climate change issue using the results of this study, and on any follow-on modifications, to improve understanding of the issues and to open a dialogue on adaptation measures and opportunities. In this way the Department can take a leadership position on the climate change issue with its clients and partners.

- Recognizing that a key element of the risk management process is that it is iterative, the Department review the climate projections and risk assessments no less than once every five years.

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1 Introduction

1.1 Background

This climate change risk assessment and adaptation report for the Ministry of Transportation is one of seven reports being prepared for the following departments/ministries within the Government of Alberta (GoA):

- Agriculture and Rural Development;
- Energy;
- Health;
- Infrastructure;
- Municipal Affairs;
- Tourism, Parks and Recreation; and
- Transportation.

Through the coordinating work of the Alberta Climate Change Adaptation Team (ACCAT), the GoA has embarked on a proactive approach to understand and mitigate risk from a changing climate as it might affect the ability and capacity of government operations to carry out their policy and program mandates. Alberta's *Climate Change Strategy* – launched in January 2008 – calls for the development of an adaptation strategy for the province. ACCAT began the process of developing a provincial strategy by drafting a Climate Change Adaptation Framework, which provides guidance to GoA Ministries. The GoA has already undertaken province-wide vulnerability assessment research as well as climate change scenario planning exercises. Climate change adaptation risk assessment and the ensuing adaptation strategy will help each ministry develop inputs related to climate change risks and opportunities to their business and risk management plans.

The GoA's climate change risk assessment approach is consistent with the International Organization for Standardization (ISO) 31000 Risk Management Standard. Due to the uncertainties involved in anticipating climate change impacts, using a risk-based framework is an appropriate tool for adaptation planning for departmental operations.

1.2 Departmental Mandate, Strategic Priorities, and Business Goals

The Ministry of Transportation comprises the Department of Transportation and the Transportation Safety Board[1]. The Ministry plans, develops, and preserves a safe, affordable and sustainable transportation system that supports Alberta's economy, society, environment, and fiscal parameters.

The Department of Transportation has a variety of responsibilities including:

- Overseeing the provincial highway network
- Leading transportation safety services, education and enforcement programs
- Designing and constructing water management infrastructure on behalf of Alberta Environment and Sustainable Resource Development
- Managing grant programs
- Representing Alberta's interests in a safe, sustainable road-rail-air-port transportation system.

[1] Government of Alberta, Ministry of Transportation website, http://www.transportation.alberta.ca/3017.htm

The Transportation Safety Board is the administrative authority for making operator licence determinations. The Board reports to the Minister of Transportation.[2]

The departmental vision is to see Alberta Transportation as a Centre of Excellence for transportation in North America. The mission is to contribute to Alberta's prosperity and quality of life by providing and supporting a safe, innovative, and sustainable provincial transportation system, and water management infrastructure.

1.2.1 Business Context

Transportation supports tourism, provides access to domestic and export markets and is the circulatory system of economic exchange. It is the one system that virtually all Albertans utilize and rely on daily. The following key statistics provide an overview of the value provided by the transportation sector:[3,4]

- Truck, rail, and air move about 40% of the $73 billion worth of international exports to market (2004), with the reminder moved by pipeline;
- In 2004 more than $13 billion of goods were imported by the truck, rail, air, or airplane;
- Transportation represents approximately 6% of provincial GDP in 2008;
- It employs directly over 98,500 employees, who collectively earn over $3.7 Billion in salaries annually;
- In the 1998-2003 period, this sector's GDP increased over 22%, employment increased 17% and similar increases were realized in the value and volume of goods carried – figures well above the Canadian averages for this sector;
- Official statistics do not accurately capture the total spectrum of transportation activity and its importance to the Alberta economy - up to 50% underestimation related to private trucking or in-house services, for example.

The Department is responsible for managing a total of 30,896 kilometres (km) of provincial highway network. In addition, the Department is also responsible for managing over 150 km of major water management systems (dams, diversion works, weirs, control structures) and 510 km of main irrigation canals, infrastructure which is closely linked to the transportation system[5]. The Department of Transportation represents Alberta's interests in a safe, sustainable road-rail-air-port transportation system at all levels of government, national and international trade agreements and regulatory harmonization. The road and rail network is supported by dozens of airports (federal and municipal), seven ferries, and a virtual Port. Through Alberta's ready access to major rail lines and extensive highway networks, Port Alberta is able to facilitate access to two of Western Canada's most important ports: Port Metro Vancouver and the Port of Prince Rupert by offering Alberta businesses the opportunity to find collective solutions to individual transportation and logistics issues, Port Alberta offers global opportunities that take advantage of the Capital Region's rail connections to marine transportation.

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[2] The rest of this report refers to the "Department" of Transportation.
[3] Government of Alberta, *The Transportation Sector in Alberta: Present Position and Future Outlook - An Update* – prepared by PROLOG Canada Inc., and The Van Horne Institute, April 30, 2005.
[4] The 2008 GDP figures published by the Government of Alberta include utilities in the same category as transportation so this figure is aggregated for the two sub-sectors.
[5] Government of Alberta website http://www.transportation.alberta.ca/3704.htm accessed January 13, 2011.

1.2.2 Strategic Priorities and Business Goals

The department's strategic priorities are outlined as follows[6]:

- Work within the fiscal context to optimize the value of provincial investment in highway repaving and bridge repair.
- Develop the provincial transportation system to support Alberta's regional and provincial economic development – this includes areas such as: road networks in northern Alberta and high growth areas; North-South Trade Corridor; Asia-Pacific Gateway; Port-to-Plains Corridor; and Alberta's integrated road-rail-air-port transportation system.
- Implement innovative approaches to reduce the environmental impact of Alberta's transportation system including the Green Transit Incentives Program (GreenTRIP) to support new public transit, reduce the number of vehicles on the road and reduce greenhouse gas emissions.
- Develop high speed rail and other transportation modes to support Alberta's population growth.
- Continue to implement a provincial Traffic Safety Plan to reduce the number of collisions, injuries and fatalities on Alberta roads.

The departmental business plan outlines a series of 4 business goals which support these strategic priorities. Within each business goal there are a number of strategies which the department undertakes to support each goal. These are outlined in Exhibit 1.

The department has a budget of approximately $2.25 billion for the 2009-2010 fiscal year. A majority of this funding goes toward Goal 3 (51%). The balance is spent on Goal 1 (37%), Goal 2 (4%), and Goal 4 (8%).

Exhibit 1 Core Business Goals

Goal 1: Alberta's provincial highway network connects communities and supports social and economic growth

- Develop long-term provincial and regional highway plans to address the future needs of Albertans in keeping with the government's Land-Use Framework to ensure smart growth, and the complementary development of land and transportation infrastructure.
- Continue with capital projects to improve the provincial transportation network throughout the province, in keeping with the government's 20 Year Capital Plan.
- Continue to plan, design and construct ring roads in Calgary and Edmonton to reduce congestion and provide vital transportation links to these regions.
- Continue developing access routes and inter-modal trade corridors that better connect Alberta to the United States and other world markets, including the North-South Trade Corridor, Port-to-Plains Corridor and the Asia-Pacific Gateway and Corridor Initiative.
- Develop public-private partnerships and other cost effective ways to expand the provincial highway network as needed to support the province's economic opportunities and social growth.
- Adopt innovative ways to maintain provincial highways, bridges and overpasses and reduce capital costs.

[6] Transportation Business Plan 2010-13.

Goal 2: Alberta has the safest road and rail system in Canada

- Develop and implement the Alberta Traffic Safety Action Plan 2010-2020 to reduce collisions, injuries and fatalities on Alberta roadways in support of Canada's national road safety strategy.
- Continue to implement the Alberta Traffic Safety Plan, Community Mobilization Strategy and Aboriginal Traffic Safety Strategy to facilitate community-led traffic safety initiatives within Alberta communities.
- Develop legislation, regulations and policies to support provincial traffic safety programs.
- Enhance school bus safety for students across the province by implementing the recommendations from government's report, Ensuring the Safety of our Children: A Report of School Bus Safety in Alberta.
- Expand the Graduated Driver Licensing Program (GDL), including strategies to address the needs of teen drivers and new Canadians.
- Improve highway safety by enhancing cooperation and harmonization in the issuance of driver licences through the National Driver Licensing Compact and the development of the Canadian Driver Licence Agreement.
- Enhance the safety of commercial drivers and vehicles on our highways by implementing new initiatives to better identify drivers and carriers at risk, enhancing vehicle safety standards, mandating inspection programs and monitoring and enforcing of the National Safety Code. Also encourage performance improvement through the introduction of a Commercial Driver Profile and North America Fatigue Management program.
- Develop approaches to address new and emerging types of vehicles, including requirements for Off -Highway Vehicles to support the safety of all travelers.
- Improve highway safety through Intelligent Transportation Systems that provide commercial vehicle operators with road weather and other information.

Goal 3: Alberta policy and program interests in an integrated road-air-rail-port transportation system are well represented

- Develop an overarching bus policy for all of Alberta to improve transportation options for rural and urban communities.
- Implement Green Transit Incentives Program (GreenTRIP) to support public transit, reduce the number of vehicles on the road and reduce greenhouse gas emissions.
- Implement the Open Skies Declaration with British Columbia and Saskatchewan to create air service agreements that promote trade, tourism and job creation.
- Work with provinces and territories on a new Western Canada Transportation Infrastructure Strategy to ensure investment in transportation is a top priority for all levels of government.
- Support the Asia-Pacific Gateway and Corridor Implementation Planning Team to develop transportation linkages in support of emerging economic opportunities.
- Develop a transportation infrastructure plan for Fort McMurray and support the government's 20 Year Strategic Plan for the sustainable development of Alberta's oil sands.
- Administer the federal stimulus package, and grant funding under the Building Canada Gas Tax Fund agreement, Building Canada Communities Component, Infrastructure Stimulus Fund, as well as the Canada-Alberta Municipal Rural Infrastructure Fund which supports municipal transportation systems, water/wastewater and transit infrastructure. In addition, administer other provincial-municipal grant programs including the Resource Road Program to help rural municipalities, towns and villages address resource and new industry-based traffic.

Goal 4: Alberta has safe and effective provincial and municipal water management infrastructure

- Continue to work with Environment and northern Alberta rural municipalities to identify, prioritize, design and construct eligible drainage projects under the Northern Alberta Erosion Control Program.
- Continue to rehabilitate the Carseland-Bow River Headworks.
- Assist municipalities with water supply, water treatment and wastewater treatment and disposal facilities by providing funding through the Alberta Municipal Water/Wastewater Partnership Program and the Water for Life program.
- Ensure environmental practices are integrated into the design, development and delivery of provincial water management projects.

1.3 Climate Change Vulnerabilities and Adaptive Capacity

The following information presents the identification of key vulnerabilities resulting from climate change for the Department of Transportation. It is primarily drawn from Chapter 8 of the *Alberta Vulnerability Assessment*,[7] Chapters 4.7, 5.7, and 6.2 of the Climate Change *Vulnerability Assessment for Alberta,*[8] and Chapter 7 of the *Economic Scoping Study on Climate Change Adaptation in Alberta.*[9]

Vulnerability to climate change is often considered to be a function of three factors:[10]

- **Exposure**: the degree to which the system of interest will experience significant change in climate (discrete events such as storms; continuous events such as temperature increases and precipitation changes; and permanent abrupt change such as melting of permafrost);
- **Sensitivity**: features of the system that influence the severity of the impact of exposure (demographics, the economy, infrastructure age);
- **Adaptive capacity**: the potential to reduce impacts through the use of existing social, political or economic resources (adjustments to reduce vulnerability to current climate variability and extreme events as well as longer-term climate change). This is a feature of both individuals and systems – indicators include a variety of system/sector/location-specific characteristics including available technology, distribution of resources, stock of human capital, institutional and decision making capacity, and the public's perceived attribution of the source of stress.

A description of the key types of vulnerabilities for the transportation sector is outlined below. Note that the factors outlined in the paragraph above are considered to be variables which will contribute to changing the degree of vulnerability experienced.

1.3.1 Vulnerability

Transportation in Canada and in Alberta is changing and is continually adapting to the socio-economic environment as well as the physical environment. Growth in different modes correlates differently with Gross Domestic Product (GDP). Although the transportation system is constantly changing, road-related demand in particular continues to grow. Climate change is one aspect among many that needs to be considered in long-term planning, since climate and weather affects nearly all aspects of the transportation sector: planning, design, construction, maintenance and performance.

Consequences of climate change are varied and include both physical and economic dimensions. These could translate into service interruptions or delay, as well as major impacts such as threats to public safety and infrastructure damage. There are social, economic, environmental and political implications to most consequences[11].

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[7] Sauchyn, Dave. *Alberta Vulnerability Assessment: Assessment of Biophysical Vulnerability*. Produced for Alberta Environment, Final Report, January 25, 2008.
[8] Weber, M., D. Davidson, and D. Sauchyn. *Climate Change Vulnerability Assessment for Alberta. December 2008.*
[9] Klein, K., J. Anyangah, H. Bjornlund, C. Chiang, R. Kalischuck, D. Johnson, D. Le Roy, A. Walburger. University of Lethbridge, Alberta, *Economic Scoping Study on Climate Change Adaptation in Alberta*, Final Report, March 2006.
[10] Intergovernmental Panel on Climate Change, 2001 (a) as referenced in, Weber, M., D. Davidson, and D. Sauchyn. *Climate Change Vulnerability Assessment for Alberta. December 2008.*
[11] Transport Canada – Canmore Workshop, "Impacts of Climate Change on Transportation in Canada", Final Workshop Report produced by Marbek, 2003.

Exhibit 2 presents some potential climate change impacts to the transportation sector:

Exhibit 2 Potential Climate Change Impacts to the Transportation Sector in Alberta

Climate Change Issue	Transportation Component Directly Impacted	Type of Impact (Temporary or Permanent; Short or Long-term)	Responsibility	Cumulative Impact
Extreme weather event (flood, dust storm, forest fire, wind storms)	Flooding (primarily in valleys and urban centres) can cause waterlogged soils, overwhelm water control infrastructure causing road or rail closures, or complete failure (i.e. washouts). Flooding in mountain regions can cause landslides and infrastructure failure of adjacent roads or railways.	Minor events: temporary / short term (i.e. closures); Major events (infrastructure failure): temporary but long-term to repair	Public sector (roadways) Private sector (railways)	Isolation of impacted communities with associated social, health and economic impacts. Economic impacts for all sectors which cannot find alternative routes. Budgetary impacts to the provincial government for major infrastructure repair.
	Dust storms or forest fires can result in inaccessibility of the corridor due to poor visibility or safety concerns.	Temporary event.	Public sector (roadways)	Economic impacts to trucking industry which can experience penalties for delay of shipment of goods.
	Wind storms can cause cross-wind hazards for long-haul trucks.	Temporary event.	Public sector (roadways)	Economic impacts to trucking industry which can experience penalties for delay of shipment of goods.
Shorter winters / warmer winters causing loss of permafrost	Loss of ice roads in the north or reduced season for ice roads	Long-term impact, permanent change to northern transportation routes	Public sector	Isolation of northern communities, social, health and economic impacts for northern communities. Economic impacts for forestry and energy sectors with northern operations which rely on ice roads.
Warmer winters causing more freeze/thaw cycles	Pavement buckling causing safety issues	Short-term (i.e. less than a month), temporary impact – can be repaired	Public sector	Higher maintenance costs on existing transportation corridors.
Increased temperatures in summer (heat events)	Softer pavement, pavement buckling; longitudinal depression in the wheel paths and bleeding of asphalt in the wheel paths.	Short-term (i.e. less than a month), temporary impact – can be repaired	Public sector	Higher maintenance costs on existing transportation corridors.

The impacts identified in Exhibit 2 are associated with both physical and economic vulnerabilities, as elaborated in more detail below.

Physical Vulnerability

Modes of transportation which involve permanent infrastructure such as railways and roadways are the most vulnerable to changes in climate that involve atypical temperatures or precipitation. The same also applies to water management infrastructure. Permanent infrastructure has been planned, designed and developed using criteria based on historical weather patterns. If future conditions are significantly different from the present and past patterns this could lead to premature degradation or failure of the infrastructure.

Some examples of the vulnerabilities to railways and roadways include: extreme heat could lead to pavement softening on permanent roads, which may in turn induce longitudinal depression in the wheel paths and migration and collection of liquids on pavement surfaces. Ageing and high volume truck traffic pavements are particularly vulnerable to these types of problems. In addition, the cumulative effect of successive freeze-thaw cycles will cause expansion and cracking, scaling, crumbling, and pot holes – leading to shorter pavement life and potential safety hazards. Changes in the frequency and intensity of precipitation may also affect road and rail infrastructure due to flooding (primarily in valleys and urban centres) and slope failure or landslides (primarily in mountainous regions).

Winter ice roads and bridges provide a cost-effective means of transportation for many communities in northern Alberta when ground or watercourses are frozen (i.e. the Athabasca River Delta). Warmer winters would reduce the length of ice-road/bridge season and impact these communities.

In the case of water management infrastructure, vulnerabilities could include: damage due to ice jams, and failure to operate correctly due to inadequate capacity to face extreme intensity rainfall events.

Economic Vulnerability

Vulnerability to private enterprises could occur to the forestry sector. Forest operations such as harvesting and transportation usually occur in winter when the ground is frozen. It often occurs on wetlands – which are frozen during the winter time. This allows access to forest that is inaccessible in summer and reduces environmental impacts from use of heavy machinery. Under warmer winter conditions, the length of time during which frozen wetlands are accessible will likely be reduced. If this pattern continues over the long term, up to 50% of some Forest Management Agreement areas[12] may be inaccessible, which would in effect reduce the area available for harvest and have economic impacts for the forest sector. Populations dependent on the forest sector will be vulnerable to the economic impact this could have.

The public sector is responsible for the majority of the highway physical infrastructure described above which is vulnerable to climate change. Therefore, increased costs to upgrade or maintain this infrastructure as a result of climate change is the responsibility of the provincial government.

Local roads, streets and water/wastewater infrastructure are the responsibility of municipalities, however, increased costs to upgrade or maintain this infrastructure are likely to result in pressure for increased provincial and federal grants.

1.3.2 Adaptive Capacity

The sensitivity and adaptive capacity related to the climate change impacts anticipated for the transportation sector of Alberta are described below, and are drawn from the Chapters 5 and 14 of the *Social Dimensions of Climate Change Vulnerability in Alberta: A Preliminary Assessment*,

[12] Forest Management Agreements are negotiated between the Government of Alberta and forest companies. They provide companies with rights to harvest and reforest trees on Crown land and ensure activities are carried out in a sustainable manner. Government of Alberta, Sustainable Resource Development website, www.srd.alberta.ca/ManagingPrograms/ForestManagement/ForestManagementPlanning/ForestManagementPlans/Default.aspx accessed January 19, 2011.

as well as Chapter 7 of the *Economic Scoping Study on Climate Change Adaptation in Alberta* and Chapter 9 of *The New Normal: The Canadian Prairies in a Changing Climate*[13].

In terms of sensitivity, providers of transportation services by air or water are not particularly impacted by the effects of global warming and have adaptive capacity to respond to it. Providers of other modes of transportation service such as road and rail, as well as water management infrastructure, have increased sensitivity to climate change from the effects of extreme weather events, shorter winters, and increased temperature. In particular, the literature suggests that the province has a greater sensitivity in those transportation networks that service the northern regions. In the developed south, communities and businesses have the benefit of redundant transportation systems, so if one road is closed, there are likely other options available. This is less true of communities and economic activities located in the north, many of which may be reliant on a single transportation route (the Town of High Level has been cited as an example of this vulnerability, while another example of this vulnerability is Fort McMurray). If the only road into an area was closed because of a forest fire, evacuation would be impossible, medical emergencies would be more dangerous, and residents would be cut off from basic supplies.

In some ways, the transportation system in the Alberta region is considered to be well-prepared for climate change due to well-established systems in place to deal with weather related hazards. For example: there are already adequate fleets of plows and salting systems for inclement winter weather, real-time road weather information systems, and the aviation industry uses real time atmospheric condition monitoring systems[14]. In response to recent climate impacts, all-weather roads and river crossings are being developed to access many communities formerly reliant on winter roads, while forest companies are using high-floatation tires on logging equipment to deal with wet soil conditions[15].

Adaptive capacity involves many facets – policy, management practices, and institutional mechanisms. Some of the key strategies for increasing adaptive capacity identified in the literature are presented below. That said, the literature review also identified a significant information gap related to climate change adaptation for the transportation sector.

Policy Changes to Increase Adaptive Capacity

The literature review revealed an information gap related to research of climate change adaptation capability in the transportation sector, and for this reason, climate change scenarios have rarely been incorporated into transportation infrastructure decisions anywhere in Canada[16].

For the province of Alberta, climate change adaptation needs to be integrated into routine government planning for all new transportation investments, as well as for maintenance and upgrading of existing infrastructure[17]. For new infrastructure, enhanced design could improve the likelihood of continuous operation of the infrastructure during extreme weather events. Building-up the information base to support the business case for increased investments in

[13] Sauchyn, D, H. Diaz, and S. Kulshreshtha, Eds., *The New Normal: The Canadian Prairies in a Changing Climate*. Canadian Plains Research Centre, 2010.
[14] Sauchyn, D, et.al, Eds., *The New Normal: The Canadian Prairies in a Changing Climate*. Canadian Plains Research Centre, 2010.
[15] Warren, F.J., Kulkarni, T. and Lemmen, D.S., editors (2010): *Canada in a Changing Climate*; Government of Canada, Ottawa, ON
[16] Infrastructure Canada, 2006, as cited in Sauchyn, D, et.al, Eds., *The New Normal: The Canadian Prairies in a Changing Climate*. Canadian Plains Research Centre, 2010.
[17] Transport Canada – Canmore Workshop, "Impacts of Climate Change on Transportation in Canada", Final Workshop Report produced by Marbek, 2003.

adaptation planning for transportation infrastructure over the long-term is key. A first step in determining appropriate adaptive strategies for the transportation sector is to assess the current status of existing infrastructure with a comprehensive vulnerability assessment. This would include process aspects for short term emergency response such as the adequacy of evacuation routes, as well as engineering features such as the ability of a bridge to hold in the case of extreme flooding. In conducting the assessment, recommendations in the literature have highlighted the need to study the non-climate factors which were part of the original design of the infrastructure, such as the original intent of use (i.e., high-traffic roads were designed differently than regional roads). These differences affect vulnerability[18].

The literature notes that the current transportation policy framework is tilted in favour of adaptation through the supply side of infrastructure. Supply side adaptation measures are those that focus on expanding infrastructure in order to enhance its ability to accommodate stress. This often involves higher capital cost investments and higher maintenance costs. A need for an integrated strategy that balances supply-side upgrades and demand-side measures has been identified. For example, demand-side public policies to induce individuals to modify their demand for transportation services include bridge tolls and higher fuel taxes to fund replacement of vulnerable roads and bridge infrastructure.

Management and Infrastructural Changes to Increase Adaptive Capacity

In terms of specific examples with respect to road networks in particular, short term measures to reduce the vulnerability of public and private transportation to increased freeze-thaw cycles includes more frequent and extensive maintenance procedures, along with seasonal weight restrictions to reduce pavement degradation. Long term adaptive strategies could include use of improved technologies. The literature has suggested that a gap exists between available technology and the current state of management practice for the implementation of new transportation technologies which are available to address some issues related to climate change. For example, technological advancements exist for strengthening pavements exposed to higher temperatures, as well as bridges, and other structures[19]. In fact, as early as 2003 technologies already existed in the road-building sector to build more durable roads that can withstand an increase in frost heave cycles, but often industry relies on government to provide direction for implementation of new technologies[20]. Government direction for these new technologies could include support for technology deployment, or, for developed technologies, through specifications in Requests-for-Proposals for road construction contracts.

Long-term strategies that may be important include structural changes such as relocation or significant upgrading of some infrastructure, as well as management changes such as better forecasting, warning and response systems, and transportation modal shifts in some areas[21].

Institutional Changes to Increase Adaptive Capacity

Relative to other regions across Canada, Alberta may be in a better position than some, since existing infrastructure is relatively modern. Alberta was settled 100 years ago, and much of the

[18] Soskolne et al., 2004 as cited in Klein, K., et al. University of Lethbridge, Alberta, *Economic Scoping Study on Climate Change Adaptation in Alberta*, Final Report, March 2006.
[19] Klein, K., et al. University of Lethbridge, Alberta, *Economic Scoping Study on Climate Change Adaptation in Alberta*, Final Report, March 2006.
[20] Transport Canada – Canmore Workshop, "Impacts of Climate Change on Transportation in Canada", Final Workshop Report produced by Marbek, 2003.
[21] Klein, K., et al. University of Lethbridge, Alberta, *Economic Scoping Study on Climate Change Adaptation in Alberta*, Final Report, March 2006.

transportation infrastructure has occurred since 1950. While this does not imply that the costs of infrastructure maintenance and improvement will be insignificant, it does mean that in comparison to places with much older infrastructure, costs will be relatively lower. There will still be capital investments required to absorb costs of climate change adaptation. It is anticipated that there will be some government support for these capital investments, however it is unlikely that the province will be in a position to completely absorb these expenses, so increased public awareness of the need for these investments is an important institutional change. Decision-makers could review experience with innovative funding mechanisms used elsewhere to finance significant capital outlays and learn from others' experience.

1.3.3 Summary

The transportation system in Alberta is a vital economic segment of the province, responsible for transporting a large volume of exports, imports, and people. Stresses already exist for this sector, such as increased demand, and climate change impacts are anticipated to affect certain aspects of this system more than others – most notably roads and water management infrastructure. This will pose challenges for the Department to maintain the existing high level of services. Alberta has the resources and capacity needed to successfully adapt to climate change, but this ability needs to be applied in order to adequately deal with the magnitude of anticipated impacts for this sector. In summary, indications in the literature are that the potential impacts of climate change could be mitigated through policy, management, and institutional responses summarized below:

- **Policy**: appropriate decision-making and policies that balance both supply-side upgrades and demand-side measures; conducting a comprehensive vulnerability assessment of the current status of existing infrastructure will build-up the information base to support the business case for increased investments in adaptation planning over the long-term;

- **Management**: more frequent and extensive maintenance procedures, along with seasonal weight restrictions on the most vulnerable roadways; improved forecasting, warning and response systems are seen as key short-term measures. Long-term measures that may be important include: support for technology development and/or deployment; as well as structural changes such as relocation or significant upgrading.

- **Institutional changes**: innovative financing mechanisms might be required to finance some of the longer-term transportation infrastructure adaptation needs, but the shorter term adaptation needs are less expensive.

2 Climate Trends and Projections for Alberta

The summary of observed and expected climate change in Alberta that is used in this risk assessment has been drawn from an extensive literature, including Chapter 7 of the publication *"From Impacts to Adaptation: Canada in a Changing Climate 2007".*[22]

The climate projections are based on the following factors:

- Observed climate trends since the 1960s which have been increasingly driven by the greenhouse effect and have covered several Pacific Decadal Oscillations, projected forward to 2050;

- Expected climate trends resulting from projected and accelerating greenhouse gas concentrations in the atmosphere using General Circulation Models and the Canadian Regional Climate Model; and

- Short-term variations around the long-term trends caused by the PDO and ENSO effects.

Trends and projections of climate change for Alberta have been developed for three regions: North (north of an east-west line through Fort McMurray), Central, and South (south of an east-west line through Red Deer). In the South and Central regions, the foothills and the east slopes of the Rockies exhibit different climate characteristics than the large plains areas to the east. In these higher elevation areas temperatures are similar to those in the North region but precipitation is the greater than in any other region of Alberta (Alberta Environment, 2005).

The climate projections are presented in Appendix A in a highly summarized, user-friendly form that departmental staff can use with ease and confidence. A more detailed discussion can be found in the guide prepared as part of this project, entitled *Adapting to Climate Change: A Risk-based Guide for the Government of Alberta*.

These projections are entirely consistent with the work of the Prairie Adaptation Research Collaborative (PARC) and earlier work sponsored by Alberta.

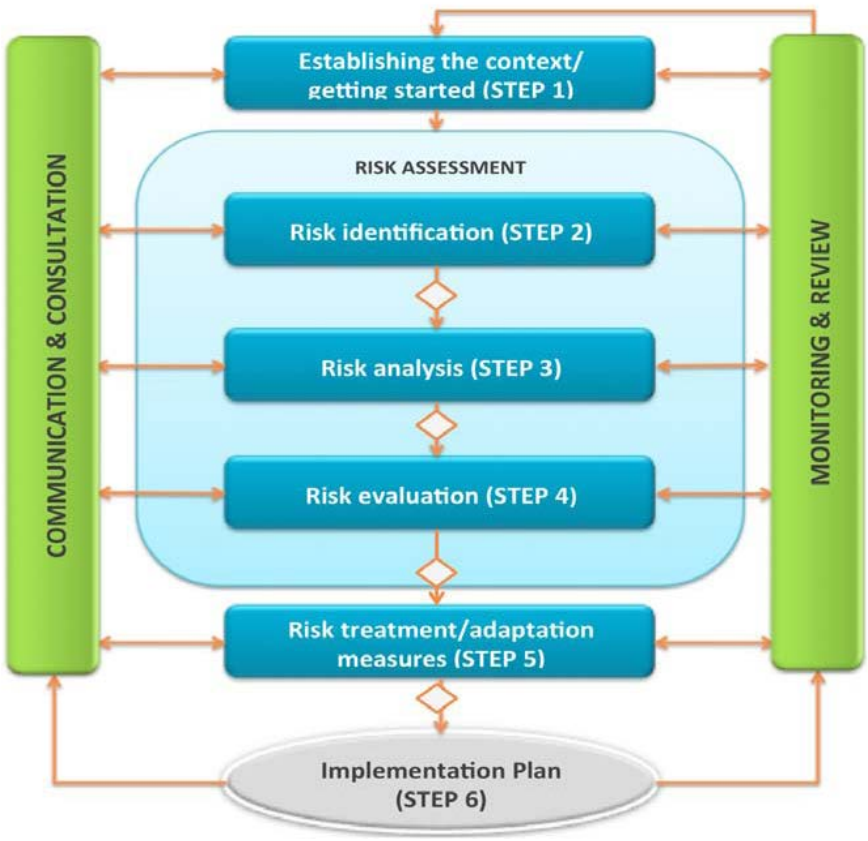
[22] This publication is available at http://adaptation2007.nrcan.gc.ca.

3 The Risk Assessment and Treatment Process

Risk management is a process for selecting the best course of action in uncertain situations. It does this by helping to identify, understand, analyze and treat risks and to communicate to others about them. A guidebook was developed (*Adapting to Climate Change: A Risk-based Guide for the Government of Alberta*) to facilitate this process in the context of a changing climate in Alberta. This Guide is a tool to help Government of Alberta departments and agencies and other organizations make sensible and practicable decisions to adapt to a changing and more variable climate.

It uses a process that is based on an international risk management standard (ISO 31000) that is accepted by senior managers, scientists and the financial community across Canada and in most countries of the world. The Guide follows the framework for risk management described in the International Organization for Standardization's document *ISO 31000 Risk management – Principles and guidelines* (2009). The process is shown below in Exhibit 3:

Exhibit 3 ISO 31000 Risk Management Process



For ease of reference the individual steps have been numbered and a sixth step, the implementation plan, added. A full description of the risk management process followed in this project can be found in the handbook *Adapting to Climate Change: A Risk-based Guide for the Government of Alberta.*

Phase 1 of this project covered the process from Step 1 through to the end of Step 4. Phase 2 of this project was based on Steps 5 and 6 and the output from Phase 1, together with information from Departmental staff. In a workshop format Departmental experts considered what measures could or should be taken to reduce the most serious of the climate change risks developed in Phase 1 to more acceptable levels and how these adaptation measures could be articulated in a departmental briefing or series of planning priorities. Also, the acceptability and costs of the potential adaptation measures were considered along with how these should integrate with departmental planning priorities.

The overarching goal of the entire process, as noted above, was to assist the department to determine its exposure to climate changes over the next 40 to 50 years and to develop strategies for adaptation responses and opportunity exploitation using a consistent methodology. The results of this project are intended to provide important inputs to the department's ERM and Strategic Business Planning processes and to the government's long-term climate change strategic response plan.

4 Risk Assessment

This section summarizes the results of the Phase 1 Climate Change Risk Assessment for the Department. The process included a workshop held on June 1, 2011 with representatives of key areas of the department to review and expand upon the risk identification and assessment prepared by the consultant team (see Appendix D for a list of workshop participants).

4.1 Step 1: Establishing the Context/Getting Started

This step occurred prior to the risk assessment work commencing. An internal working paper outlining the context for climate adaptation planning in Alberta for transportation was developed and a summary is summarized in Sections 1, 2 and 3 of this document. The working paper provided a high-level, strategic assessment of the impact of a changing climate on the Department's operations and principal stakeholders over a future 40 to 50 year time frame. It assisted our team in assessing the risks and opportunities of climate change for transportation.

4.2 Step 2: Risk Identification

In Step 2, climate trends projections[23] for Alberta were considered; first by the consultant team and secondly in a workshop with representatives of the department. To ensure the identified risks were comprehensive and inclusive of all potential climate change scenarios, risks were identified under one of five types of climate change anticipated in Alberta within the next 40 to 50 years:

1. Higher temperatures;
2. Increasing extreme weather events;
3. Increased lightning, wildfire frequency; and
4. Increased drought
5. General

Furthermore the risks were considered in relation to the five components of the Transportation mandate:

1. Overseeing the provincial highway network
2. Leading transportation safety services, education and enforcement programs
3. Designing and constructing water management infrastructure on behalf of Alberta Environment and Sustainable Resource Development
4. Managing grant programs
5. Representing Alberta's interests in a safe, sustainable road-rail-air-port transportation system.

During the workshop with department staff, it was noted that the first three components were likely to be the main concerns, since the policy on grants programs was largely outside of the control of the department, and the rail-air-port portions of the transportation system were mainly under federal jurisdiction.

Overall, 16 risk events and one opportunity were identified. Of these, 13 were considered significant enough and relevant enough to warrant more detailed assessment, as follows:

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[23] See section 3 above. For a detailed explanation of the climate projections a report, *Climate Change Projections for Alberta: A Guide for Regions of Alberta (Draft)*, prepared by Dr. James Bruce is also available.

1. Increasing damage to transportation infrastructure (roads, bridges, overpasses) due to increased freeze/thaw cycles
2. Damage to water management infrastructure due to ice jams caused by increased freeze/thaw cycles
3. Softening and distortion of road pavement due to increased likelihood of hot days
4. Loss of ice roads/bridges due to warmer and shorter winters
5. Shorter duration of winter-weight on highway network
6. Longer exposure of vulnerable road users (pedestrians, cyclists, etc.) due to longer summer
7. Road washouts and blockages from more frequent high-intensity, low duration rain events, causing landslides and overwhelmed stormwater management facilities associated with transportation infrastructure[24]
8. Inadequate capacity of water management infrastructure to deal with extreme rainfall and rain on snow melt events, leading to flooding
9. Road closure and hazards due to severe wind storms and blizzards
10. Damage to signage due to extreme high winds and blockage of roads due to fallen trees, power lines, etc.
11. Road traffic disruptions and increased accidents from more frequent winter rain, freezing rain, and wet snow
12. Reduced visibility and traffic disruptions due to increased wildfires and smoke
13. Just-in-time delivery threatened by road closures related to weather events

4.3 Step 3: Risk Analysis[25]

In Step 3, the nature of the remaining 13 risk events was considered to assess likelihood and consequences.

For each event, the assessment of likelihood began with a determination of whether the event was a significant single event or of an ongoing nature. Within each category, the likelihood was assessed against specific benchmarks in a range from very low to very high. In the case of consequences, these were assessed in a range from very low to very high, in 11 areas, grouped as "people", "economic" and "environment".

Results are summarized in Exhibit 4. Descriptions of the risks and their assessments are included as Appendix B.

[24] This risk event was originally called “Road washouts and blockages from more frequent increased rainfall, causing overwhelmed culverts and drainage systems, and landslides”. The risk event was renamed during Phase 2 to provide greater clarity and precision.

[25] The term "analysis" is used for conformity with ISO 31000. In this context, "analysis" signifies a review of the risk to rate likelihood and consequences.

Exhibit 4 Analysis of Risk Events

Risk Event	Likelihood		Consequence (highest rating given)			
	Single Event	Ongoing	People	Economic	Environmental	Final
Increasing damage to transportation infrastructure (roads, bridges, overpasses) due to increased freeze/thaw cycles		L	VL	L	VL	L
Damage to water management infrastructure due to ice jams caused by increased freeze/thaw cycles		L	L	L	L	L
Softening and distortion of road pavement due to increased likelihood of hot days		L	L	L	VL	L
Loss of ice roads/bridges due to warmer and shorter winters		M	L	L	L	L
Shorter duration of winter-weight on highway network		L	L	M	VL	L
Longer exposure of vulnerable road users (pedestrians, cyclists, etc.) due to longer summer		L	M	L	VL	L
Road washouts and blockages from more frequent high-intensity, low duration rain events, causing landslides and overwhelmed stormwater management facilities associated with transportation infrastructure		M	M	M	M	M
Inadequate capacity of water management infrastructure to deal with extreme rainfall and rain on snow melt events, leading to flooding	M		M	M	L	L
Road closure and hazards due to severe wind storms and blizzards		M	M	L	L	L
Damage to signage due to extreme high winds and blockage of roads due to fallen trees, power lines, etc.	M		L	L	L	L
Road traffic disruptions and increased accidents from more frequent winter rain, freezing rain, and wet snow		H	H	H	M	M
Reduced visibility and traffic disruptions due to increased wildfires and smoke		H	M	L	L	L
Just-in-time delivery threatened by road closures related to weather events		L	L	L	VL	L

4.4 Step 4: Risk Evaluation

Following the risk analysis, the risks were compared and prioritized using the risk evaluation matrix. This provided an opportunity to ensure that final risk ratings were consistent with one another and with the mandate and responsibilities of the Department.

Exhibit 5 summarizes the results of the risk assessment, including the likelihood and consequence ratings for each risk. The matrix can be read with the following colour legend:

	Extreme Risk: Immediate controls required
	High Risk: High priority control measures required
	Moderate Risk: Some controls required to reduce risks to lower levels
	Low Risk: Controls likely not required
	Negligible Risk: Scenarios do not require further considerations

Exhibit 5 Risk Evaluation

Consequences		Very Low	Low	Moderate	High	Very High
	Very High					
	High					
	Moderate			• Road washouts and blockages from more frequent high-intensity, low duration rain events, causing landslides and overwhelmed stormwater management facilities associated with transportation infrastructure	• Road traffic disruptions and increased accidents from more frequent winter rain, freezing rain, and wet snow	
	Low		• Increasing damage to transportation infrastructure (roads, bridges, overpasses) due to increased freeze/thaw cycles • Damage to water management infrastructure due to ice jams caused by increased freeze/thaw cycles • Softening and distortion of road pavement due to increased likelihood of hot days • Shorter duration of winter-weight on highway network • Longer exposure of vulnerable road users (pedestrians, cyclists, etc.) due to longer summer • Just-in-time delivery threatened by road closures related to weather events	• Loss of ice roads/bridges due to warmer and shorter winters • Inadequate capacity of water management infrastructure to deal with extreme rainfall and rain on snow melt events, leading to flooding • Road closure and hazards due to severe wind storms and blizzards • Damage to signage due to extreme high winds and blockage of roads due to fallen trees, power lines, etc.	• Reduced visibility and traffic disruptions due to increased wildfires and smoke	
	Very Low					
		Very Low	Low	Moderate	High	Very High
		Likelihood				

4.5 Stakeholders and Risk Perception

An important consideration and input to the risk management process is an understanding of the different perceptions of risk not only by people in different positions or responsibility areas within the Transportation department, but also by the various stakeholders whether they be staff of other GOA departments, transportation providers, infrastructure providers or users of the transportation system. Each will see the risks differently and these views should be considered by the risk assessment team.

There was insufficient time to consider stakeholders and risk perception in Phase 1. An initial tentative listing of stakeholder categories is included in Appendix C.

5 Step 5: Risk Treatment/Adaptation Measures

5.1 Introduction

The Risk Evaluation matrix (Exhibit 5) graphically portrays the High and Moderate risks. Step 5 in the risk management process involves development and evaluation of risk treatment and adaptation measures.

These measures were reviewed by departmental participants at a workshop held on October 25, 2011 (see Appendix D for a list of workshop participants). As the adaptation measures were developed, they were evaluated with respect to: the time frame in which they should be implemented; the general magnitude of the cost; the effectiveness in terms of reducing risk levels; and the acceptability to key stakeholders.

These initial adaptation measures and their evaluations are presented below for the three High and Moderate risk events. For each risk event, a brief explanation is provided, followed by a brief profile of each identified adaptation measure, including the overview evaluation of each measure.

The evaluation of each measure is based on the following criteria and rating scale:

Time Frame	Cost	Effectiveness	Acceptability
Short – can be implemented within 10 years	**$** (Low) - can be completed within existing or planned budget allocation	**Low** – will have minor effect on risk event	**Low** – significant public/corporate/stakeholder resistance
Medium – can be implemented within 10-20 years	**$$** (Moderate) - will require additional funding	**Moderate** – will have moderate effect on risk event	**Moderate** – moderate public/corporate/stakeholder resistance
Long – can be implemented within 20 – 50 years	**$$$** (High) - will require major additional funding/major capital program	**High** – will virtually overcome risk event	**High** – little or no public/corporate/stakeholder resistance

5.2 Adaptation Measures to Address High Risks

Risk Event: Road traffic disruptions and increased accidents from more frequent winter rain, freezing rain, and wet snow.

An approximate 20% increase in the frequency of freezing rain events and generalized increase in rain and wet snow events will disrupt traffic and create treacherous conditions that could lead to increased traffic accidents. This ongoing risk event is considered likely to become critical within a decade and is assessed as having high consequences on road safety and a resulting financial impact on stakeholders (drivers). There will be moderate impacts on the reputation of the Department, as well as on the finances of the GOA. There will also be moderate impacts on ecosystems.

Adaptation measures that could be applied to reduce this risk may include:

Adaptation Measure: Increased winter highway maintenance including improved anti-icing measures				
Description: This measure involves increased effort and additional technologies and techniques to mitigate the effects.				
Time Frame	**Cost**	**Effectiveness**	**Acceptability**	**Comment**
Medium term	Moderate	Moderate	Moderate	There is a limit to what can be achieved by modifying highway characteristics since the risk is a result of driver-vehicle-road interaction.

Adaptation Measure: Change vehicle and driver education requirements				
Description: This measure involves changing vehicle characteristics (e.g. winter tires and/or studs) or driver behaviour and preparation for hazardous driving conditions.				
Time Frame	**Cost**	**Effectiveness**	**Acceptability**	**Comment**
Medium term	Low	Moderate	Low	This could be reasonably effective but is difficult to implement.

Adaptation Measure: Improved road weather information systems and associated outreach/awareness efforts				
Description: This measure involves providing more complete and timely information and improving the understanding and appropriate response of the public to that information.				
Time Frame	**Cost**	**Effectiveness**	**Acceptability**	**Comment**
Medium term	Moderate	Low	High	Additional analysis is required to clarify current practice and assess potential improvements.

Adaptation Measure: Change the geometry of road design				
Description: This measure involves changing designs to provide for improved drainage and provide greater safety conditions.				
Time Frame	**Cost**	**Effectiveness**	**Acceptability**	**Comment**
Long term	High	Low/moderate	High	This would be expensive and therefore would need to be targeted carefully at high risk locations.

Adaptation Measure: Increase monitoring of road traffic disruptions and increased accidents to determine if they are climate-change induced				
Description: This measure involves tracking, reporting and analysis of disruptions and accidents to assess the effect climate change is having and distinguish this effect from other potential causes. This will allow mitigation measures to be implemented at the appropriate time.				
Time Frame	**Cost**	**Effectiveness**	**Acceptability**	**Comment**
Short/medium term	Moderate	Low	High	Not effective on its own but should allow better response overall.

Adaptation Measure: Identify alternate transportation modes to using roads				
Description: This measure involves shifting traffic to other modes of transportation (e.g. public transportation) to reduce volume of traffic and thus probability of disruptions and accidents.				
Time Frame	**Cost**	**Effectiveness**	**Acceptability**	**Comment**
Long term	Low	Low	Moderate	Unlikely to have more than minor impact in the short/medium term.

5.3 Adaptation Measures to Address Moderate Risks

Risk Event: Road washouts and blockages from more frequent high-intensity, low duration rain events, causing landslides and overwhelmed stormwater management facilities associated with transportation infrastructure.

An increased frequency and amount of high intensity rains and rain on snow melt will overwhelm stormwater management facilities associated with transportation infrastructure, causing landslides, road washouts and blocking roads. However natural channels will bear the brunt of the impact before the changes affect the infrastructure itself. Older infrastructure which is hydraulically inadequate will be affected first. Consequences are mitigated by improvements in designs that have already been implemented in a significant proportion of the provincial infrastructure. This ongoing risk event is assessed as likely to become critical in 10-30 years and is assessed as having moderate consequences on the reputation of the Department. There are also likely to be moderate infrastructure damages, financial impact on stakeholders, and impacts on water. Note: this does not apply to bridges.

Adaptation measures that could be applied to reduce this risk may include:

Adaptation Measure: Change design standards to accommodate high-intensity, low duration rain events				
Description: This involves changes to increase hydraulic functionality and provide more robust operation.				
Time Frame	**Cost**	**Effectiveness**	**Acceptability**	**Comment**
Short term	Moderate	Moderate	High	Important first step. Will be effective for new infrastructure but because of relatively long lifespan will take time to effectively mitigate system risks.

Adaptation Measure: Survey existing infrastructure to determine "at risk" installations				
Description: This measure involves the conduct of detailed vulnerability assessments to identify locations that may be subject to problems based on rainfall models and trends. These can be classified as candidates for retrofit, candidates for upgrade at end of life, or low risk.				
Time Frame	**Cost**	**Effectiveness**	**Acceptability**	**Comment**
Short term	Low/Moderate	Low	High	Also important initial step but will have limited impact unless acted upon.

Adaptation Measure: Accelerate retrofitting of at-risk sites based on survey results				
Description: This measure involves early investments to improve infrastructure at high risk sites through retrofit in advance of scheduled end-of-life replacement.				
Time Frame	**Cost**	**Effectiveness**	**Acceptability**	**Comment**
Medium/long term	Moderate	Moderate	High	Only very high risk locations will merit accelerated retrofit. Though effective at these sites, the overall system will only be moderately more protected.

Adaptation Measure: Review/update emergency management plans to prepare for increased frequency of these events				
Description: This measure involves increasing and improving preparedness for events that may occur at locations that have not yet been upgraded.				
Time Frame	**Cost**	**Effectiveness**	**Acceptability**	**Comment**
Short term	Low	Low	High	Emergency Plans can be improved at the margins but this will not make a large difference.

Risk Event: Reduced visibility and traffic disruptions due to increased wildfires and smoke

Increased dry spells and lightning strikes will lead to more frequent and intense wildfires especially in boreal forests in northern and central areas. In turn, this will create more frequent episodes of reduced visibility and associated traffic disruptions. This ongoing risk event is assessed as likely to become critical in a decade and is assessed as having moderate consequences for road safety.

The following adaptation measure could be applied to reduce this risk:

Adaptation Measure: Improve travel advisory systems				
Description: This measure involves providing more frequent and timely information concerning road visibility to the public.				
Time Frame	**Cost**	**Effectiveness**	**Acceptability**	**Comment**
Short term	Moderate	Moderate	High	Additional analysis is required to clarify current practice and assess potential improvements.

5.4 Low Risk Events

The following risk events were all categorized as low risks and do not require any specific risk reduction or adaptation measures beyond that currently being undertaken by the Department and its partners. They are listed below to ensure that they are included in any short-term climate change planning undertaken by the Department, and to recognize that they may have some longer-term significance.

Loss of ice roads/bridges due to warmer and shorter winters

Warmer and shorter winters will result in the loss or reduced duration of ice roads and ice bridges in northern areas. But this is assessed as having low or very low consequences in all areas.

Inadequate capacity of water management infrastructure to deal with extreme rainfall and rain on snow melt events, leading to flooding

An increased frequency and amount of high intensity rains and rain on snow melt will cause dam capacity to be exceeded requiring spillage and flooding (but not dam failure). Consequences are mitigated by improvements in designs that have already been implemented in a large proportion of the infrastructure. As a result, this risk event is assessed as having only moderate consequences on the Department's reputation and on the finances of stakeholders (those affected by the flooding). All other consequences are expected to be low or very low.

Road closure and hazards due to severe wind storms and blizzards

Extreme winds including from downslope conditions (up to 140km/hr in southern regions), coupled with snow/blizzards will create road hazards and lead to road closures. This could have moderate consequences on road safety but the other consequences would be low or very low.

Damage to signage due to extreme high winds and blockage of roads due to fallen trees, power lines, etc.

Extreme winds including from downslope conditions (up to 140km/hr in southern regions) will damage signage and blow over trees or other obstacles onto road surfaces. This could have moderate consequences on road safety but the other consequences would be low or very low.

Increasing damage to transportation infrastructure (roads, bridges, overpasses) due to increased freeze/thaw cycles

Higher temperatures in winter and spring and a significant increase in freeze/thaw cycles are unlikely to cause damage to transportation infrastructure since the cycles may be less severe. As a result, this risk event is assessed as having low or very low consequences in all areas.

Damage to water management infrastructure due to ice jams caused by increased freeze/thaw cycles

Higher temperatures in winter and spring and a significant increase in freeze/thaw cycles will lead to an increased number of ice jams causing damage to water management infrastructure. However, the ice jams may be less severe. As a result, this risk event is assessed as having low or very low consequences in all areas.

Softening and distortion of road pavement due to increased likelihood of hot days

Increased frequency of hot days will soften and distort road pavement. However, the relatively slow pace of change should allow designs to adapt naturally. As a result, this risk event is assessed as having low or very low consequences in all areas.

Shorter duration of winter-weight on highway network

Warmer and shorter winters are unlikely to result in reduced duration of winter-weight conditions on the highway network. This could have moderate financial impacts on stakeholders but remaining consequences are low or very low.

Longer exposure of vulnerable road users (pedestrians, cyclists, etc.) due to longer summer

Longer summers and shorter winters are unlikely to result in increased length of the season for active transportation thus extending the exposure of vulnerable road users. This could have moderate consequences in the area of road safety but the other consequences are low or very low.

Just-in-time delivery threatened by road closures related to weather events

An increase in the frequency of extreme weather events is unlikely to result in road closures that will disrupt delivery schedules for goods, jeopardizing logistics relying on just-in-time delivery. This risk event is assessed as having low or very low consequences in all areas.

5.5 Summary of Adaptation Measures

Exhibit 6 below displays the adaptation measures identified for each of the High and Moderate level risks and illustrates their implementation priority or sequence. Measures that are already underway or should be undertaken as an early priority are shown in **green** highlighting; those that should be considered a priority in the medium-term are in **purple** highlighting; and those that should be considered in the longer-term are in **brown** highlighting.[26]

Exhibit 6 Summary of Adaptation Measures

Risk Event	Adaptation Measure	Time Frame	Cost	Effective-ness	Accept-ability	Residual Risk/Comment
High Risks						
Road traffic disruptions and increased accidents from more frequent winter rain, freezing rain, and wet snow.	Increased winter highway maintenance including improved anti-icing measures	m	$$	m	m	There is a limit to what can be achieved by modifying highway characteristics since the risk is a result of driver-vehicle-road interaction.
	Improved road weather information systems and associated outreach/awareness efforts	m	$$	l	h	Additional analysis is required to clarify current practice and assess potential improvements.
	Increase monitoring of road traffic disruptions and increased accidents to determine if they are climate-change induced	s/m	$$	l	h	Not effective on its own but should allow better response overall.
	Change vehicle and driver education requirements (e.g. addressing the case for winter tires and/or studs)	m	$	m	l	This could be reasonably effective but is difficult to implement.
	Identify alternate transportation modes to using roads	l	$	l	m	Unlikely to have more than minor impact in the short/medium term.
	Change the geometry of road design					

[26] See Section 5.1 for an explanation of the rating scale used in this table.

Risk Event	Adaptation Measure	Time Frame	Cost	Effective-ness	Accept-ability	Residual Risk/Comment
Moderate Risks						
Road washouts and blockages from more frequent high-intensity, low duration rain events, causing landslides and overwhelmed stormwater management facilities associated with transportation infrastructure.	Change design standards to accommodate high-intensity, low duration rain events	s	$$	m	h	Important first step. Will be effective for new infrastructure but because of relatively long lifespan will take time to effectively mitigate system risks.
	Survey existing infrastructure to determine "at risk" installations – candidates for retrofit	s	$/$$	l	h	Also important initial step but will have limited impact unless acted upon.
	Review/update emergency management plans to prepare for increased frequency of these events	s	$	L	h	Emergency Plans can be improved at the margins but this will not make a large difference.
	Accelerate retrofitting of at-risk sites based on survey results	m/l	$$	m	h	Only very high risk locations will merit accelerated retrofit. Though effective at these sites, the overall system will only be moderately more protected.
Reduced visibility and traffic disruptions due to increased wildfires and smoke	Improve travel advisory systems	s	$$	m	h	Additional analysis is required to clarify current practice and assess potential improvements.
Low Risks						
Loss of ice roads/bridges due to warmer and shorter winters	No adaptation measures needed					
Inadequate capacity of water management infrastructure to deal with extreme rainfall and rain on snow melt events, leading to flooding	No adaptation measures needed					
Road closure and hazards due to severe wind storms and blizzards	No adaptation measures needed					
Damage to signage due to extreme high winds and blockage of roads due to fallen trees, power lines, etc.	No adaptation measures needed					

Increasing damage to transportation infrastructure (roads, bridges, overpasses) due to increased freeze/thaw cycles	No adaptation measures needed
Damage to water management infrastructure due to ice jams caused by increased freeze/thaw cycles	No adaptation measures needed
Softening and distortion of road pavement due to increased likelihood of hot days	No adaptation measures needed
Shorter duration of winter-weight on highway network	No adaptation measures needed
Longer exposure of vulnerable road users (pedestrians, cyclists, etc.) due to longer summer	No adaptation measures needed
Just-in-time delivery threatened by road closures related to weather events	No adaptation measures needed

It is important to note that the adaptation measures identified here are general goal-type measures which need further consideration to develop specific actions to be taken either solely by the department or together with other government or private sector partners. Also more consideration is needed to develop specific time lines, cost and related monitoring factors for each.

In addition to the adaptation measures themselves, the department will need access to improved climate and weather prediction in order to support the analysis and implementation of the measures.

6 Considerations for Adaptation Implementation Planning

As noted several times throughout this study, the risk assessment and risk treatment process used here and which was the subject of two workshops attended by Departmental experts, is a high-level screening process. It is designed to identify and prioritize the risks and opportunities presented by a changing climate to Departmental operations over a 40 to 50 year time horizon, and to develop adaptation measures which might reduce the risks to acceptable levels and exploit opportunities.

Brief consideration has also been given to important factors affecting the adaptation measures at the strategic level. These include:

1. Implementation time frame (short, medium or long-term)
2. Cost of implementation (low, moderate, high)
3. Effectiveness in reducing risk levels (low, moderate, high)
4. Acceptability to the Department, other government departments, key stakeholders (in general only) (low, moderate , high)
5. Residual risk level (where it can be estimated).

These factors need to be further considered and developed as part of implementation planning. Of particular concern will be the views of key stakeholders within the Department, within the GoA and other governments which have an interest or partnership arrangement, and the Department's clients in terms of users of the transportation system and partners in the design, construction, operation and maintenance of the system.

This leads to the conclusion that follow-on work is required beyond this high-level screening exercise before full implementation of adaptation strategies is begun, and should include the following:

- Obtain the concurrence of senior management with the initial screening study.
- Obtain the views of a broader section of Departmental staff on the climate change risk assessment.
- Conduct a more detailed examination of the three most serious risk situations to confirm and amplify this preliminary analysis. These include:

High	Road traffic disruptions and increased accidents from more frequent winter rain, freezing rain, and wet snow.
Moderate	Road washouts and blockages from more frequent high-intensity, low duration rain events, causing landslides and overwhelmed stormwater management facilities associated with transportation infrastructure.
Moderate	Reduced visibility and traffic disruptions due to increased wildfires and smoke.

After further review of this screening study within the Department, decisions will be required regarding the need for more in-depth studies and more detailed implementation planning activities.

In the immediate future, reviews should be conducted of the Departmental ERM and Strategic Business plans to determine what and how much of the screening study recommendations should be introduced into these shorter-term plans.

Consideration should also be given to broadening the familiarization process within the Department and among key stakeholders to improve understanding and knowledge about future climate scenarios, possible risks and opportunities and the general adaptation strategies that were developed during this process. This will help to better position the Department take a leadership position with its clients and partners.

The most important adaptation advantage is time: time to develop adaptation measures, time to implement them and time to achieve the necessary results.

7 Conclusions and Recommendations

7.1 Conclusions

The objective of this project was to assess the risk and opportunities that a changing climate may present to the Department of Transportation over the next 40 to 50 years and examine possible adaptation strategies. This is a high-level screening which is intended to lead to more detailed assessments of the most serious risks. Long-term adaptation strategies will be developed from this, which can be built into the Department's shorter-term ERM and Strategic Business plans.

The risk assessment identified 13 risks to departmental operations over the 40-50 year time horizon as illustrated in Exhibit 7 below:

Exhibit 7 Risks to the Ministry of Transportation

Risk Event	Rank and Risk Level
Road traffic disruptions and increased accidents from more frequent winter rain, freezing rain, and wet snow	**1. High**
Road washouts and blockages from more frequent high-intensity, low duration rain events, causing landslides and overwhelmed stormwater management facilities associated with transportation infrastructure	**2. Moderate**
Reduced visibility and traffic disruptions due to increased wildfires and smoke	**3. Moderate**
Inadequate capacity of water management infrastructure to deal with extreme rainfall and rain on snow melt events, leading to flooding	**4. Low**
Road closure and hazards due to severe wind storms and blizzards	**5. Low**
Loss of ice roads/bridges due to warmer and shorter winters	**6. Low**
Damage to signage due to extreme high winds and blockage of roads due to fallen trees, power lines, etc.	**7. Low**
Shorter duration of winter-weight on highway network	**8. Low**
Damage to water management infrastructure due to ice jams caused by increased freeze/thaw cycles	**9. Low**
Longer exposure of vulnerable road users (pedestrians, cyclists, etc.) due to longer summer	**10. Low**
Softening and distortion of road pavement due to increased likelihood of hot days	**11. Low**
Just-in-time delivery threatened by road closures related to weather events	**12. Low**
Increasing damage to transportation infrastructure (roads, bridges, overpasses) due to increased freeze/thaw cycles	**13. Low**

Exhibit 8 summarizes the adaptation measures that were developed at the strategic level for the High and Moderate risks:

Exhibit 8 Summary of Adaptation Measures

Risk Event	Adaptation Measure
High Risks	
Road traffic disruptions and increased accidents from more frequent winter rain, freezing rain, and wet snow	Increased winter highway maintenance including improved anti-icing measures
	Change vehicle and driver education requirements (e.g. addressing the case for winter tires and/or studs)
	Improved road weather information systems and associated outreach/awareness efforts
	Change the geometry of road design
	Increase monitoring of road traffic disruptions and increased accidents to determine if they are climate-change induced
	Identify alternate transportation modes to using roads

Risk Event	Adaptation Measure
Moderate Risks	
Road washouts and blockages from more frequent high-intensity, low duration rain events, causing landslides and overwhelmed stormwater management facilities associated with transportation infrastructure	Change design standards to accommodate high-intensity, low duration rain events
	Survey existing infrastructure to determine "at risk" installations – candidates for retrofit
	Accelerate retrofitting of at-risk sites based on survey results
	Review/update emergency management plans to prepare for increased frequency of these events
Reduced visibility and traffic disruptions due to increased wildfires and smoke	Improve travel advisory systems

7.2 Recommendations

The consultant team recommends that:

1. Senior Departmental management be briefed on the results of this high-level climate change risk assessment and on the adaptation measures identified to reduce the most significant risks.

2. The Department support the conclusions and recommendation of this study and prepare to move forward on implementing the identified adaptation actions.

3. The Department begin preparatory actions related to the three highest-rated climate risks as soon as circumstances and trend data warrant.[27] This includes:

   For traffic disruptions and accidents from more rain, freezing rain and wet snow:
   - Increase winter highway maintenance including improved anti-icing measures
   - Improve road weather information systems and associated outreach/awareness efforts
   - Increase monitoring of road traffic disruptions and increased accidents to determine if they are climate change-induced.

   For road washouts & blockages from more frequent high-intensity, low duration rain events:
   - Change design standards to accommodate high-intensity, low duration rain events
   - Survey existing infrastructure to determine "at risk" installations
   - Review/update emergency management plans to prepare for increased frequency of these events.

   For reduced visibility and traffic disruptions due to increased wildfires and smoke:
   - Improve travel advisory systems.

   These “first stage” actions should be of low or moderate cost in terms of both funding and staff resources, but will assist in preparing information for other start-up activities, will ensure new investments are adapted to climate risks, and will begin responding to risks that are already being felt.

[27] Based on the risk assessment, two of the three risks (“traffic disruptions and accidents from more rain, freezing rain and wet snow” and “reduced visibility and traffic disruptions due to increased wildfires and smoke”) are likely to become critical within a decade. The third highly-rated risk (“road washouts and blockages from more frequent high intensity, low duration rain events”) is likely to become critical in 10-30 years.

4. The Department familiarize and engage staff with the climate change risk assessment process and its results through a series of focus group sessions or short workshops, encouraging the input of new ideas and suggestions.

5. The Department consider forming a climate change action team to make a detailed review of the screening study and undertake a more in-depth risk assessment and development of a more comprehensive adaptation strategy.

6. At an appropriate time, the Department begin to engage Departmental clients on the climate change issue using the results of this study, and on any follow-on modifications, to improve understanding of the issues and to open a dialogue on adaptation measures and opportunities. In this way the Department can take a leadership position on the climate change issue with its clients and partners.

7. Recognizing that a key element of the risk management process is that it is iterative, the Department review the climate projections and risk assessments no less than once every five years.

Appendix A Climate Trends and Projections for Alberta

Alberta's climate over the past four or five decades has been affected by factors that are similar to those that will be responsible for driving the climate system from now to 2050, and beyond.[28] One of the drivers is the large scale internal variability of the climate system, manifest in El Nino Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO) and the Arctic Oscillation (AO). These can cause significant year to year or even longer term variations in Alberta. The other main factor is the increasing concentration of greenhouse gases in the global atmosphere which is driving longer-term, decade to century, trends. It has been shown (IPCC, 2007) that since the late 1960s greenhouse gas increases have overwhelmed natural forcings of the climate, such as changes in solar energy. Thus Alberta has experienced a gradual warming since then with year to year departures from the overall warming trend due to internal variability factors such as ENSO.

This situation suggests three ways of estimating probable climatic changes over the next four decades. First, one can use the best of some fourteen Atmosphere-Ocean Global Climate Models (AOGCM's) driven by estimates of future greenhouse gas concentrations. These give somewhat varying projections of conditions for say 2050 and beyond. Secondly, one can use Regional Climate Models embedded within one or other AOGCM to get finer scale projections. Finally, the observed decadal trends since the 1960s are likely to continue or accelerate slightly, since the climate driving factors will be similar in the next forty years or more, to those experienced in the past forty years.

However, greenhouse gas concentrations have been increasing at an accelerated rate and are projected to continue to do so for a number of decades. This rate of increase has been faster than that used in most model projections in the literature and in IPCC assessments, suggesting that the highest model projections are likely most reliable and even they may underestimate the changes. This also suggests that there may be a modest acceleration in future in observed temperature trends.

But it is not temperature alone that affects society, environment and resources. Along with temperature trends, changes are occurring in precipitation, in frequency and intensity of extreme weather events, in glaciers and permafrost, in river flows and lake levels, and in wildfires.

In the following tables, published information on observed trends of these various climate related parameters are given for the past four or five decades, for three regions of Alberta. Projections for the next four decades, to 2050, are also given. These projections make use of all three of the methods outlined above. For a few parameters, some adjustments using physical reasoning have been made. In general, projections made by climate models with the highest emission scenarios, and by extension of observed trends, are in good agreement, especially for temperature and parameters closely related to temperature.

This manner of presentation of trends and changes has been found to be valuable to communities from Canada's south to the high Arctic. It is most useful in determining the relative priority of adaptation measures through a risk-based Guide. To go on towards development of costly adaptation measures, more detail may be required and a bibliography of references that may be useful is appended. In cases where these references were important in determining values given in the boxes in the Tables, the number of the reference is given in that box.

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[28] This section was prepared by Dr. James P. Bruce, OC, FRSC

The tables that follow are highly summarized climate projections. The full discussion of Alberta climate and an extensive list of references are provided in Annex 1 of in the handbook, *Adapting to Climate Change: A Risk-based Guide for the Government of Alberta.*

Trends and Projections to 2050

The following tables summarize trends and projections to 2050 by region. When there was one or two key reference(s) for the figures provided in the tables, it has been noted in the appropriate box. In some cases, a multitude of reference material has been used, so no specific reference is given.

REGION: SOUTHERN ALBERTA

	OBSERVED TRENDS	BY 2050 (from 2010)

TEMPERATURE — See note 1

Temperature °C (1950-2007)

	Max. °C	Min. °C	By 2050: °C
Annual	1.5 to 2.5	0.5 to 1.5	2 to 4
Winter	2.5 to 3	1.5 to 3	3 to 4
Spring	2.5 to 3	2.5 to 3	2 to 4
Summer	0.5 to 2.5	-0.5 to 1.5	2 to 3
Autumn	-0.5 to 0.5	-1.5 to 0.5	2 to 3
		(Ref.17)	*(Ref.14)*

	Observed trends	By 2050
Frost free days	-5 to 20 days	25 days
Growing Season >5 °C	15 to 30 days	30 days
	(Ref.17)	

PRECIPITATION — See note 1

Precipitation (1950-2007)

	% of long term average	By 2050: %
Annual	-20 to +10	0 to 10
Winter	-15 to -5	5 to 10
Spring	0 to 5	5 to 10
Summer	5 to -10	0 to -10
Autumn	5 to -5	0 to 5
	(Ref. 17)	*(Ref. 8, 14)*

Ratio of Snow to Total Precipitation (1950-2003)

	%	By 2050: %
Annual	-20 to -5	-15
Winter	0 to 3	-10
Spring	-20 to 0	-20
Autumn	0 to -5	-10
	(Ref.17)	

Intense Precipitation (1958-2007)

Observed trends	By 2050
P_{20}: 25 to 50 mm: average 1981-2000/day P>99%: 13% frequency (adjacent USA) P>99%: 15% amount (adjacent USA) *(Ref. 8)*	P_{20}: 10 to 15% severity $P_{20} \rightarrow P_{10\text{-}15}$ frequency *(Ref.9)*

WIND — See Note 2

Intense Winter Storms

Observed trends		By 2050
<970hpa central pressure Northern Hemisphere	8%	8 to 15% *(Ref. 10)*

REGION: SOUTHERN ALBERTA (continued)

	OBSERVED (TRENDS)	BY 2050 (from 2010)
RIVERFLOW	**Dates of Spring break-up (1950-2005)** Earlier date some significant (10 to 15 days) *(Ref.11)*	Continue earlier by 30 days
	Snow Pack - 1 April (1950-1997) -20%	-40% *(Ref.12)*
See Note 3	**Glaciers – (1965-2004)** **-22% of mass balance (Peyto)** *(Ref. 4)*	Continued loss
	Streamflow (1967-1996) Annual: -10 to -20% Minimum Daily: 20 to -30% Maximum Daily: -20 to -10 *(Ref19)*	-5 to -15% -10 to -20% 0 *(Ref. 5,14)*
LIGHTNING [5] **Flash density**	**(1999-2008)** Average 0.5 to 3.5 flash/km^2/year Max 0.5 to 4 flash/km^2/year (Many forest fires caused by lightning) *(Ref.3)*	Increase *(Ref. 13)*
DROUGHT	**(1900-2002)** Palmer drought severity index: significant trend towards increased severity *(Ref. 2)*	Severe droughts twice as frequent *(Ref.14)*

Note 1: Ranges in observed and projected values indicate differences over the region.

Note 2: Wind-disaster records of Public Safety Canada indicate for storms >100km/h national frequency rose 16% from 1970 to 1990 with most in coastal regions, except for tornadoes.

Note 3: Major floods and landslides (from PSC data base), where intense rains, or rain on snow, apparently increased 80% nationally between the 1970s and 1990s. However, 1970s event recording may have been less thorough than in 1990s. Data base extends only to 2005. Generally winter flows increasing and summer and autumn flows declining. Flash floods in small basins becoming more frequent spring and summer.

Note 4: Annual variability above and below climate change driven trends is related to large-scale modes of the natural climate system. This region is especially affected by ENSO (El Nino-La Nina) and the Pacific Decal Oscillation (PDO). When PDO is in a warm phase and El Nino conditions develop, warmer, drier conditions with lower stream flow occur in Western Canada as departures from the global trend. Temperature trends in 1950-99 of 2.5°C were estimated in Western mountainous regions to have been 0.5°C less without a generally positive PDO. (Bonfils et al. 2008)

Note 5: Most wild fires set by lightning. Global estimate lightning increase by 44% in 21st century. (Price & Rind, 1994)

Note 6: P_{20} signifies the precipitation likely to be equalled or exceeded only once in 20 years on average a long period.

REGION: CENTRAL ALBERTA

	OBSERVED TRENDS	BY 2050 (from 2010)

TEMPERATURE

See Note 1

Temperature °C (1950-2007) — Observed trends

	Max. °C	Min. °C
Annual	1 to 2.5	1 to 2.5
Winter	1.5 to 3	1.5 to 3
Spring	2.5 to 3.5	1.5 to 2.5
Summer	0.5 to 1.5	0.5 to 1.5
Autumn	-0.5 to 0	-1.5 to -0.5

(Ref.17)

By 2050 (from 2010)

	°C
Annual	2 to 4
Winter	3 to 4
Spring	3 to 4
Summer	2 to 3
Autumn	2 to 3

(Ref. 14)

	Observed trends	By 2050 (from 2010)
Frost free season	10 to 20 days	25 days
Growing season >5 °C	10 to 30 days	30 days

(Ref. 17)

PRECIPITATION

See Note 1

Precipitation (1950-2007) — Observed trends

	%
Annual	-10 to -20
Winter	-5 to 0
Spring	-5 to 0
Summer	-5 to -10
Autumn	-5 to 5

(Ref.17)

By 2050 (from 2010)

	%
Annual	5 to 10
Winter	5 to 10
Spring	10 to 15
Summer	0 to -5
Autumn	5 to 10

(Ref. 8, 14)

Ratio of Snow to Total Precipitation (1950-2003) — Observed trends

	%
Annual	-5 to -10
Winter	0
Spring	-5 to -15
Autumn	-5 to -10

(Ref. 17)

By 2050 (from 2010)

	%
Annual	-15
Winter	-10
Spring	-15
Autumn	-5

Intense Precipitation (1958-2007)

Observed trends: No significant change

By 2050 (from 2010):
P_{20} 5 to 10%$_{amount}$
$P_{20} \rightarrow P_{10\ to\ 15\ frequency}$
(Ref.9)

Freezing precipitation (rain and drizzle) average (1961-1990)

Observed trends:
Precipitation: 15 to 20 hrs
Increase up to 20% extreme North
(Ref.3)

By 2050 (from 2010): Increase

WIND

See Note 2

Intense Winter Storms

Observed trends: Northern Hemisphere
(1950-2000) 8%

By 2050 (from 2010): 8 to 15%
(Ref. 10)

REGION: CENTRAL ALBERTA (continued)

	OBSERVED TRENDS	BY 2050 (from 2010)
RIVERFLOW	**Dates of Spring break-up (1973-1999)** 10 days earlier (Peace River) *(Ref. 18)*	20 days earlier
	Snow Pack - 1 April (1950-1997) -20%	-30% *(Ref.12)*
See Note 3	**Glaciers – (1965-1997)** Average decrease 25% *(Ref.16)*	Continued decrease (~5%/decade)
	Streamflow (1967-1996)	
	%	%
	Annual: -20	-20
	Minimum daily: -20 to 10	-20
	Maximum daily: -10 to -30	0 -10
	(See text) (Ref. 18,19)	*(Ref.7,14)*
PERMAFROST THAW	Declining at higher elevations in western areas	Continue decline to higher elevations
WILDFIRES and LIGHTNING **See Note 4**	National area burned increased (1970-2000) 100,000km^2 per ^{o}C warming *(Ref. 6)*	Continued increase. Area burned increase 15% *(Ref. 6,13)*
DROUGHT	**Palmer Drought Severity Index:** significant increase in frequency and intensity over 20th century *(Ref.2)*	Continued more intense drought: doubled frequency of severe events *(Ref.14)*

Note 1: Ranges in observed and projected values indicate differences over the region.

Note 2: Wind-disaster records of Public Safety Canada indicate for storms >100km/h national frequency rose 16% from 1970 to 1990 with most in coastal regions, except for tornadoes.

Note 3: Major floods and landslides (from PSC data base), where intense rains, or rain on snow, apparently increased 80% nationally between the 1970s and 1990s. However, 1970s event recording may have been less thorough than in 1990s. Data base extends only to 2005.

Note 4: Most fires set by lightning. Global estimate lightning increase by 44% in 21st century. (Price and Rind, 1994)

REGION: NORTHERN ALBERTA

<table>
<tr><th></th><th>OBSERVED TRENDS</th><th>BY 2050 (from 2010)</th></tr>
<tr><td>TEMPERATURE

See Note 1</td><td>Temperature °C (1950-2007)
<table><tr><th></th><th>Max. °C</th><th>Min. °C</th></tr><tr><td>Annual</td><td>1 to 2.5</td><td>1 to 2.5</td></tr><tr><td>Winter</td><td>1.5 to 3</td><td>1.5 to 3</td></tr><tr><td>Spring</td><td>1.5 to 3</td><td>1.5 to 2.5</td></tr><tr><td>Summer</td><td>0.5 to 1.5</td><td>0.5 to 1.5</td></tr><tr><td>Autumn</td><td>0 to -1</td><td>-0.5 to -1.5</td></tr></table>(Ref. 17)</td><td><table><tr><th>°C</th></tr><tr><td>2 to 4</td></tr><tr><td>3 to 4</td></tr><tr><td>2 to 4</td></tr><tr><td>2 to 3</td></tr><tr><td>2 to 3</td></tr></table>(Ref. 14)</td></tr>
<tr><td></td><td>Frost free season 10 to 20 days
Growing season >5 °C 10 to 30 days
(Ref.17)</td><td>25 days
30 days</td></tr>
<tr><td>PRECIPITATION

See Note 1</td><td>Precipitation (1950-2007)
<table><tr><th></th><th>%</th></tr><tr><td>Annual</td><td>10 to -10</td></tr><tr><td>Winter</td><td>5 to 10</td></tr><tr><td>Spring</td><td>0 to 5</td></tr><tr><td>Summer</td><td>5 to -5</td></tr><tr><td>Autumn</td><td>5 to -5</td></tr></table>(Ref.17)</td><td><table><tr><th>%</th></tr><tr><td>0 to 10</td></tr><tr><td>0 to 15</td></tr><tr><td>0 to 15</td></tr><tr><td>-5 to 10</td></tr><tr><td>0 to 10</td></tr></table>(Ref. 8,14)</td></tr>
<tr><td></td><td>Ratio of Snow to Total Precipitation (1950-2003)
<table><tr><th></th><th>%</th></tr><tr><td>Annual</td><td>-10 to 0</td></tr><tr><td>Winter</td><td>0</td></tr><tr><td>Spring</td><td>-5 to -10</td></tr><tr><td>Autumn</td><td>-5 to -10</td></tr></table>(Ref. 17)</td><td><table><tr><th>%</th></tr><tr><td>-10</td></tr><tr><td>-5</td></tr><tr><td>-10</td></tr><tr><td>0</td></tr></table></td></tr>
<tr><td></td><td>Intense Precipitation (1958-2007)
Increase trend: not statistically significant
P_{20} 25 to 50mm average/day (1981-2000)</td><td>P_{20} 10 to 15%
$P_{20} \rightarrow P_{10\ to\ 15}$
(Ref. 9)</td></tr>
<tr><td></td><td>Freezing precipitation (rain and drizzle) average (1961-1990)
Precipitation: <25hrs
Rain: <10hrs
Increase up to 20% extreme North
(Ref. 15)</td><td>Continued Increase</td></tr>
<tr><td>WIND
See Note 2</td><td>Intense Winter Storms
Northern Hemisphere
(1950-2000) 8%</td><td>8 to 15%
(Ref. 10)</td></tr>
</table>

REGION: NORTHERN ALBERTA (continued)

	OBSERVED TRENDS	BY 2050 (from 2010)
RIVERFLOW	**Dates of Spring break-up (1950-2005)** Earlier dates non-significant *(Ref. 11)*	Continue earlier
	Snow Pack - 1 April (1950-1997) -20%	-25%
See Note 3	**Streamflow (1967-1996)** Annual: 0-20% Minimum daily: -30 to 30% Maximum daily: +10 to -30% *(See text) (Ref. 18,19)*	Annual: -10 Minimum daily: -20 Maximum daily: 0
PERMAFROST THAW	In discontinuous permafrost areas *(Ref.14)*	Drying of peatland. Increase of active layer depth by 50% and continued reduction of areas with permafrost
WILDFIRES and LIGHTNING **See Note 4**	0.5 to 2 flashes/km^2/year (1999-2008) National area burned increased (1970-2000) 100,000km^2 per ^{o}C warming *(Ref. 3,6)*	Increased lightning and fire incidence. Area burned increase 25% *(Ref.6)*

Note 1: Ranges in observed and projected values indicate differences over the region.

Note 2: Wind-disaster records of Public Safety Canada indicate for storms >100km/h national frequency rose 16% from 1970 to 1990 with most in coastal regions, except for tornadoes.

Note 3: Major floods and landslides (from PSC data base), where intense rains, or rain on snow, apparently increased 80% nationally between the 1970s and 1990s. However, 1970s event recording may have been less thorough than in 1990s. Data base extends only to 2005.

Note 4: Most fires set by lightning. Global estimate lightning increase by 44% in 21st century. (Price and Rind, 1994)

REFERENCES

1. Bonfils et al., 2008. Detection and attribution of temperature changes in the mountainous western U.S., J. of Climate 21.23:6404-6424.
2. Dai, A.K., K.E. Trenberth and T. Qion, 2004. A global data set of Palmer Drought Severity Index for 1870-2002, J. of Hydrology 5:1117-1129.
3. Burrows. W., et al., 2010. Canadian lightning data, Atmosphere-Ocean (in press).
4. Demuth, M.N., et al., 2008. Recent and past century variations in the glacier resources of the Canadian Rocky Mountains: Nelson River system, in Teria Glacialis, L. Bernardi, Ed. Servizie, Special Issue, Servizia Glaciologicico Lombardo, 27-52.
5. Demuth, M.N., and A. Pietroniro, 2003. The impacts of climate change on the glaciers of the Canadian Rocky Mountain eastern slopes and implications for water-resource related adaptation in the Canadian Prairies: Prairie Adaptation Research Collaborative, Regina, Project P55, 95pp.
6. Flannigan, M.D. et al., 2005. Future area burned in Canada, Climate Change 72:1-16.
7. Gan, T.Y. and E. Kerkhoven, 2004. Modeling the hydrology and possible impact of climate change on Athabasca River basin by a modified ISBA with GCM-scale data, Proc. of 10th Annual Scientific Meeting of Mackenzie, GEWEX Study (MAGS), 163-176.
8. Karl, T.R., J.M. Melillo and T.C. Peterson, Eds., 2009. Global climate change impacts in the United States, U.S. Global Change Research Program, 188pp.
9. Kharin, V.V., F. W. Zwiers, X. Zhang, and G.C. Hegerl, 2007. Changes in temperature and precipitation extremes in the IPCC ensemble of global coupled model simulations, J. of Climate 20.8:1419-1444.
10. Lambert, S.J., 2004. Changes in winter cyclone frequencies and strengths in transient enhanced greenhouse warming simulations using two coupled models, Atmosphere-Ocean 42.3:173-181.
11. Meteorological Service, Environment Canada, 2007. Icewatch 2007: Changes in lake ice signal a changing climate, 12p.
12. Pomeroy, J., 2010. Where are the snows of yesterday? in Canadian Water Securities – the Critical Role of Science, CFCAS, Ottawa, May 2010:18-20.
13. Price, C. and D. Rind, 1984. Possible implications of global climate change on lightning distribution and frequencies, J. Geophys. Res. 99:10823-31.
14. Sauchyn, D. and S. Kulshreshtha, et al., 2008. Prairies, Ch. 7 *in* From Impacts to Adaptation, NRCan, D.S. Lemmen, et al., Eds, pp275-328.
15. Stuart, R.A. and G.A. Issac, 1999. Freezing precipitation in Canada, Atmosphere-Ocean, 37.1:87-102.
16. United Nations Environment Program, 2008. Global glacier changes: facts and figures, Univ. of Zurich, 88p.
17. Vincent, L. and E. Mekis, 2009, Trends in temperature and precipitation indices in Canada for the periods 1950 to 2007 and 1900 to 2007, Climate Research Division, Environment Canada, 41pp.
18. Woo, M-K, and R. Thorne, 2003. Streamflow in the Mackenzie Basin, Canada, Arctic 56.4:328-340.
19. Zhang, X., K.D. Harvey, W.D. Hogg and T.R. Yuzyk, 2001. Trends in Canadian Streamflow, Water Resources Research 37.4:987-998.

Appendix B Risk Assessments

High Risk Events

Road traffic disruptions and increased accidents from more frequent winter rain, freezing rain, and wet snow

An approximate 20% increase in the frequency of freezing rain events and generalized increase in rain and wet snow events will disrupt traffic and create treacherous conditions that could lead to increased traffic accidents.

Likelihood: This ongoing risk event is considered likely to become critical within a decade.

Consequence for Transportation: This risk event is assessed as having high consequences on road safety and a resulting financial impact on stakeholders (drivers). There will be moderate impacts on the reputation of the Department, as well as on the finances of the GOA. There will also be moderate impacts on ecosystems.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
High	Moderate	**High**

Moderate Risk Events

Road washouts and blockages from more frequent high-intensity, low duration rain events, causing landslides and overwhelmed stormwater management facilities associated with transportation infrastructure

An increased frequency and amount of high intensity rains and rain on snow melt will overwhelm stormwater management facilities associated with transportation infrastructure, causing landslides, road washouts and blocking roads. However natural channels will bear the brunt of the impact before the changes affect the infrastructure itself. Older infrastructure which is hydraulically inadequate will be affected first. Consequences are mitigated by improvements in designs that have already been implemented in a significant proportion of the provincial infrastructure.

Likelihood: This ongoing risk event is assessed as likely to become critical in 10-30 years.

Consequence for Transportation: This risk event is assessed as having moderate consequences on the reputation of the Department. There are also likely to be moderate infrastructure damages, financial impact on stakeholders, and impacts on water.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
Moderate	Moderate	**Moderate**

Reduced visibility and traffic disruptions due to increased wildfires and smoke

Increased dry spells and lightning strikes will lead to more frequent and intense wildfires especially in boreal forests in northern and central areas. In turn, this will create more frequent episodes of reduced visibility and associated traffic disruptions.

Likelihood: This ongoing risk event is assessed as likely to become critical in a decade.

Consequence for Transportation: This risk event is assessed as having moderate consequences for road safety but remaining consequences are low or very low.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
High	Low	**Moderate**

Low Risk Events

Loss of ice roads/bridges due to warmer and shorter winters

Warmer and shorter winters will result in the loss or reduced duration of ice roads and ice bridges in northern areas.

Likelihood: This risk event is assessed as likely to become critical in 10 – 30 years.

Consequence for Transportation: This risk event is assessed as having low or very low consequences in all areas.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
Moderate	Low	**Low**

Inadequate capacity of water management infrastructure to deal with extreme rainfall and rain on snow melt events, leading to flooding

An increased frequency and amount of high intensity rains and rain on snow melt will cause dam capacity to be exceeded requiring spillage and flooding (but not dam failure). Consequences are mitigated by improvements in designs that have already been implemented in a large proportion of the infrastructure.

Likelihood: This single risk event is assessed as likely to occur every 10 – 30 years.

Consequence for Transportation: This risk event is assessed as having moderate consequences on the Department's reputation and moderate financial impacts on stakeholders (those affected by the flooding). All other consequences are expected to be low or very low.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
Moderate	Low	**Low**

Road closure and hazards due to severe wind storms and blizzards

Extreme winds including from downslope conditions (up to 140km/hr in southern regions), coupled with snow/blizzards will create road hazards and lead to road closures.

Likelihood: This single risk event is likely to occur every 10 – 30 years.

Consequence for Transportation: This risk event is assessed as having moderate consequences on road safety but remaining consequences are low or very low.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
Moderate	Low	**Low**

Damage to signage due to extreme high winds and blockage of roads due to fallen trees, power lines, etc.

Extreme winds including from downslope conditions (up to 140km/hr in southern regions) will damage signage and blow over trees or other obstacles onto road surfaces.

Likelihood: This risk event is assessed as likely to become critical in 10 – 30 years.

Consequence for Transportation: This risk event is assessed as having moderate consequences on road safety but remaining consequences are low or very low.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
Moderate	Low	**Low**

Increasing damage to transportation infrastructure (roads, bridges, overpasses) due to increased freeze/thaw cycles

Higher temperatures in winter and spring and a significant increase in freeze/thaw cycles will cause damage to transportation infrastructure; however the cycles may be less severe.

Likelihood: This ongoing risk event is assessed as becoming critical in 30 – 50 years.

Consequence for Transportation: This risk event is assessed as having low or very low consequences in all areas.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
Low	Low	**Low**

Damage to water management infrastructure due to ice jams caused by increased freeze/thaw cycles

Higher temperatures in winter and spring and a significant increase in freeze/thaw cycles will lead to an increased number of ice jams causing damage to water management infrastructure. However, the ice jams may be less severe.

Likelihood: This ongoing event is assessed as likely to become critical in 30 – 50 years.

Consequence for Transportation: This risk event is assessed as having low or very low consequences in all areas.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
Low	Low	**Low**

Softening and distortion of road pavement due to increased likelihood of hot days

Increased frequency of hot days will soften and distort road pavement. However, the relatively slow pace of change should allow designs to adapt naturally.

Likelihood: This risk event is assessed as likely to become critical in 30 – 50 years.

Consequence for Transportation: This risk event is assessed as having low or very low consequences in all areas.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
Low	Low	**Low**

Shorter duration of winter-weight on highway network

Warmer and shorter winters will result in reduced duration of winter-weight conditions on the highway network.

Likelihood: This risk event is assessed as likely to become critical in 30 – 50 years.

Consequence for Transportation: This risk event is assessed as having moderate financial impacts on stakeholders but remaining consequences are low or very low.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
Low	Low	**Low**

Longer exposure of vulnerable road users (pedestrians, cyclists, etc.) due to longer summer

Longer summers and shorter winters will result in increased length of the season for active transportation thus extending the exposure of vulnerable road users.

Likelihood: This risk event is assessed as likely to become critical in 30 – 50 years.

Consequence for Transportation: This risk event is assessed as having moderate consequences in the area of road safety but remaining consequences are low or very low.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
Low	Low	**Low**

Just-in-time delivery threatened by road closures related to weather events

An increase in the frequency of extreme weather events will result in road closures that will disrupt delivery schedules for goods, jeopardizing logistics relying on just-in-time delivery.

Likelihood: This risk event is assessed as likely to become critical in 30 – 50 years.

Consequence for Transportation: This risk event is assessed as having low or very low consequences in all areas.

Overall Risk Rating:

Likelihood	Consequence	Risk Level
Low	Low	**Low**

Appendix C Stakeholders

The following table provides a preliminary list of the categories of stakeholder who may have an interest in transportation-related climate change impacts and adaptation. For illustrative purposes the table also provides examples of stakeholder groups in each category.

Listing of Possible Transportation Stakeholder Categories

Category	Examples
Commercial/Industrial Users of the Transportation System	Alberta Motor Transport Association (AMTA) Canadian Association of Oilwell Drilling Contractors (CAODC) Petroleum Services Association of Canada (PSAC) Alberta Forest Products Association (AFPA)
Municipalities	Individual Municipalities Alberta Urban Municipalities Association (AUMA) Alberta Association of Municipal Districts and Counties (AAMDC)
Other Provincial Departments	Ministry of Environment and Sustainable Resource Development Alberta Health Services
Public Users	Travelling Public School Boards Alberta Motor Association (AMA)
Regulators	Transport Canada (Navigable Waters Protection Act) Ministry of Environment and Sustainable Resource Development
Transportation Infrastructure Providers	Road Maintenance Contractors Road Construction Contractors Engineering Companies Professional Associations
Transportation Service Providers	Canadian Council of Motor Transport Administrators (CCMTA) Transportation Association of Canada (TAC) Bus Lines

Appendix D Workshop Participants

June 1, 2011

Alberta Transportation	• Peter Dzikowski – Strategic Policy Branch • Des Williamson – Technical Standards Branch (Bridge Engineering and Water Management) • Chuck McMillan – Technical Standards Branch (Surface Engineering and Aggregates) • Don Snider - Technical Standards Branch (Environmental Management Services) • Mitch Fuhr – Driver Programs • Chris Yanitski – Office of Traffic Safety (Vehicle Safety)
Alberta Environment and Sustainable Resource Development	• Bob Manteaw
ICF Marbek Project Team	• Greg McGuire • Mark Egener • Rob Black • Harvey Alton

October 25, 2011

Alberta Transportation	• Peter Dzikowski – Strategic Policy Branch • Des Williamson – Technical Standards Branch (Bridge Engineering and Water Management) • Chuck McMillan – Technical Standards Branch (Surface Engineering and Aggregates) • Darren Carter - Technical Standards Branch (Environmental Management Services)
Alberta Environment and Sustainable Resource Development	• Bob Manteaw
ICF Marbek Project Team	• Greg McGuire (by phone) • George Matheson • Rob Black