Aspects of the Potential Impacts of Climate Change on Seasonal Weight Limits and Trucking in the Prairie Region

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of the research is to characterize potentially significant impacts which could result from climate change-induced modifications to seasonal weight limits applied to commercial truck operations on prairie region highways.

1.2 BACKGROUND

Seasonal weight limits play a significant role in the economic development and performance of the prairie region. The adverse economic impact of infrastructure deterioration under spring road conditions, as well as the economic benefits obtained under winter road conditions, make it important to evaluate potential changes in seasonal weight limits as a result of external factors such as climate change.

There is the potential for climate change to significantly affect the seasonal timing and duration of winter weight premium and spring weight restriction conditions on prairie province roads. As these seasonal weight limits currently span up to seven months of the year in the prairie region, the potential for large economic effects is real. The trucking sector is vital to the economy of western Canada, and any changes to the roadbed weight tolerance due to climate change may adversely affect many trucking movements, and hence impact rural economies. This research addresses potential impacts of climate change on seasonal weight limits as related to the prairie road network.

1.3 OBJECTIVES AND SCOPE

This research has the following objectives:

- To understand previous research on the subject by conducting a literature review about climate change and its impacts on seasonal weight limits, and trucking activity in the region.

- To understand the aspects of winter weight premium (WWP) and spring weight restriction (SWR) regulations in the region that would be particularly vulnerable to climate change. The aspects of particular interest are road links and networks, regulatory procedures, and the timing of seasonal weight limits.

- To discuss plausible climate change scenarios related to temperature only, for the region using feasible climate change models.

- To discuss illustrative examples of the effects of seasonal weight limits on truck productivity based on the Trimac Truck Operating Cost Model.

- To understand the types of potential modifications to seasonal weight limits under different climate change scenarios, and the impacts of these modifications on commodities and trucking operations in the region.

- To discuss possible adaptation strategies.

The scope of this research is defined by the Canadian prairie provinces of Manitoba, Saskatchewan, and Alberta, and by the northern U.S. states of Minnesota, North Dakota, and Montana. This research is concerned with public, year round highways. The question of winter/snow/ice roads, which is relevant to certain communities in the region, is beyond the scope of the research.

Certain public highways in the study area—particularly in northern Manitoba—run through areas of intermittent permafrost. The question of the potential effects of climate change on highways known to experience permafrost conditions is also beyond the scope of the research. Permafrost effects could affect the whole weight limit issue on such roads—and the seasonal matter of specific interest to this research would be just incidental to this much broader subject.

The research is concerned with a 25-year time horizon.

1.4 METHODOLOGY

The work in this research was conducted with the following methodological considerations:

- Seasonal weight limits, and the analysis of the effects of changes in them, were referenced to basic weight limits for purposes of defining the incremental changes to be examined.

- Temperature-related climate change scenarios were used to identify potential changes to seasonal weight limits.

- Truck cost effects were estimated using the most recent version of the Operating Costs of Trucks in Canada model, produced by Trimac Logistics Ltd. for Transport Canada.

- Industrial intelligence, gathered in discussions with truck industry and government experts, was used to assist the research team in identifying system vulnerability issues.

- An enhanced version of the Geographic Information System (GIS) platform developed for the original work on this subject was used for the geographic-based analysis required for the research.

1.5 REPORT ORGANIZATION

Chapter 2 presents the results of a literature review on: (1) climate change and its impacts on seasonal weight limits; and (2) trucking activity in the prairie region. This literature review involved searches of the Transportation Research Information Services (TRIS), the Transportation Research Board, the U.S. National Transportation Library, Transport Canada, Natural Resources Canada, and previous work conducted by the research team.

Chapter 3 discusses weight regulations and current practices involving the application of seasonal weight limits in the study region. Previous research conducted by the team (Montufar et al., 2000) addresses the regulatory situation in the late 1990s. This chapter presents the current situation involving seasonal weight limit applications for each of the jurisdictions in terms of substantive changes that have taken place over the last 5 years.

Chapter 4 defines the climate change scenarios used in this research. These are plausible scenarios, related to temperature only, using different climate change models that apply to the region.

Chapter 5 describes the development of the methodology to estimate truck cost impacts of seasonal weight limits in the prairie region. Changes in seasonal weight limits will affect truck payloads and hence productivity and truck operating costs. Truck cost impacts are developed using the “Operating Costs of Trucks in Canada – 2001” model, produced by Trimac Logistics Ltd. for Transport Canada.

Chapter 6 synthesizes the results of earlier chapters for the purpose of characterizing issues that decision makers should consider in deliberations about seasonal weight limit regulation and how it might be affected by climate change over the next 25 years in the prairie region. It also provides illustrative examples of possible effects. The chapter is sub-divided into three sections: (1) the time dimension of seasonal weight limits; (2) highway routing and network questions; and (3) commodity considerations.

Chapter 7 provides concluding remarks.

2.0 LITERATURE REVIEW

This chapter presents the results of a literature review on: (1) climate change and its impacts on seasonal weight limits; and (2) trucking activity in the prairie region. This literature review involved searches of the Transportation Research Information Services (TRIS), the Transportation Research Board, the U.S. National Transportation Library, Transport Canada, Natural Resources Canada, and previous work conducted by the research team.

2.1 CLIMATE CHANGE AND ITS IMPACTS ON SEASONAL WEIGHT LIMITS

There is little literature on the subject of climate change and its impact on transportation in general. There is even less literature on the specific issue of climate change and its impact on seasonal weight limits. Warren et al. (2004) indicate that climate change impacts and adaptation in the Canadian transportation sector represent a relatively new field of study. Similarly, Mills and Andrey (2003) indicate that the available peer-reviewed literature addressing climate change and transportation is very limited.

Climate change, as defined by Environment Canada (2004), is “a shift in the ‘average weather’ that a given region experiences.” This includes changes in temperature, wind patterns, precipitation, and storms.

Global climate change refers to the changes that are occurring within the climate system of the earth as a whole. The Intergovernmental Panel on Climate Change (IPCC) estimates that global surface temperatures have increased between 0.4 and 0.8°C since the late 19th century. On average, the rate of temperature increase since 1976 has been 0.15^{o}C/decade (Houghton et al., 2001).

Canadian researchers predict that global surface temperatures could increase by as much as 0.5^{o}C/decade over the next century (Environment Canada, 2004). Similarly, Caldwell et al. (2002) indicate that in the U.S., the scientific community has reached a general consensus that temperatures worldwide could rise by 3 to 10 degrees Fahrenheit by the year 2100. Smith and Levasseur (2002) indicate that historical temperature trends show the most warming in Canada and Alaska since 1950, and recent research conducted by Bonsal and Prowse (2003) reveals significant trends toward earlier springs over most of western Canada, including dramatic shifts to earlier dates during the last 20 to 30 years. This could have a large impact on the application of seasonal weight limits in the region.

Climate change is expected to impact transportation through changes in temperature, precipitation, extreme events (such as hurricanes) and water levels (Warren et al., 2004). This will likely result, according to Caldwell et al. (2002), in changes in the origins from which freight is shipped, and will impact the design, safety, operations, and maintenance of the physical infrastructure used to move freight.

According to Smith and Levasseur (2003), warming and thawing permafrost foundations are the most serious climate change consequences to land transportation services. In areas where permafrost is common, such as Canada, Alaska, and northern tier U.S. states, permafrost degradation is a major concern. Research conducted in Alaska for the U.S. Department of Transportation's workshop on "The Potential Impacts of Climate Change on Transportation" found that the softening ground is causing pavement to buckle, disrupting some freight movements which take place by road and rail in the state (Smith and Levasseur, 2003). Also, Mills and Andrey (2003) quote research by Haas et al. (1999) where it was found that increased frequencies of freeze-thaw cycles have been related to premature deterioration of road pavements, primarily where subgrades are composed of fine-grained, saturated material—conditions that are conducive to frost heaving and thaw weakening.

According to Caldwell at al. (2003), warmer winters will reduce the time trucks are allowed to take advantage of winter weight premiums in northern regions, which could result in significant negative impacts on the transportation of freight by truck.

2.2 TRUCKING ACTIVITY IN THE PRAIRIE REGION

The material in this section is drawn from previous research conducted by the research team (Clayton et al., 2002; and DS-Lea and UMTIG, 1998).

2.2.1 Road Network

The highway network in the prairie region is comprised of roadways in Manitoba, Saskatchewan, Alberta, Minnesota, North Dakota, and Montana. Figure 2-1 illustrates the extent of this network. There are nearly 75,000 kilometers of provincial highways in the three Canadian provinces, and approximately 53,000 kilometers of interstate and state highways in the three U.S. tier states. The impact of seasonal weight limits is considered for this entire network.

2.2.2 Truck Traffic

Truck flows for the region are shown in Figure 2-2. The following observations are drawn from the figure:

- Highways with very low truck volumes (less than 150 AADTT) account for one-half of the region's provincial highway kilometers. Manitoba accounts for 41 percent of these kilometers, Saskatchewan for 33 percent, and Alberta for 26 percent. However, note that the road network considered in this figure is not as extensive as that in Figure 2-1. The addition of Alberta's secondary highway network to the primary highway system (see Figure 2-1) results in a much more extensive network of low-volume highways in the region.

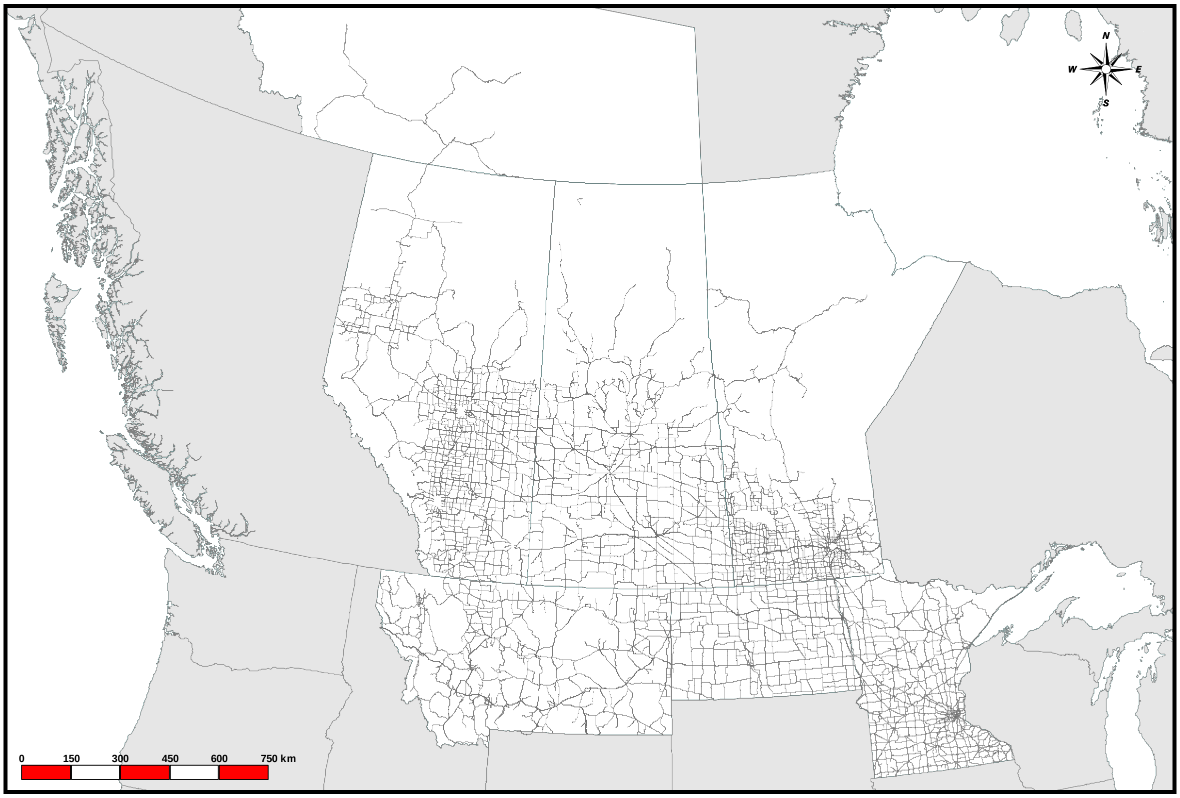

Figure 2-1: Prairie Region Highway Network © UMTIG 2005

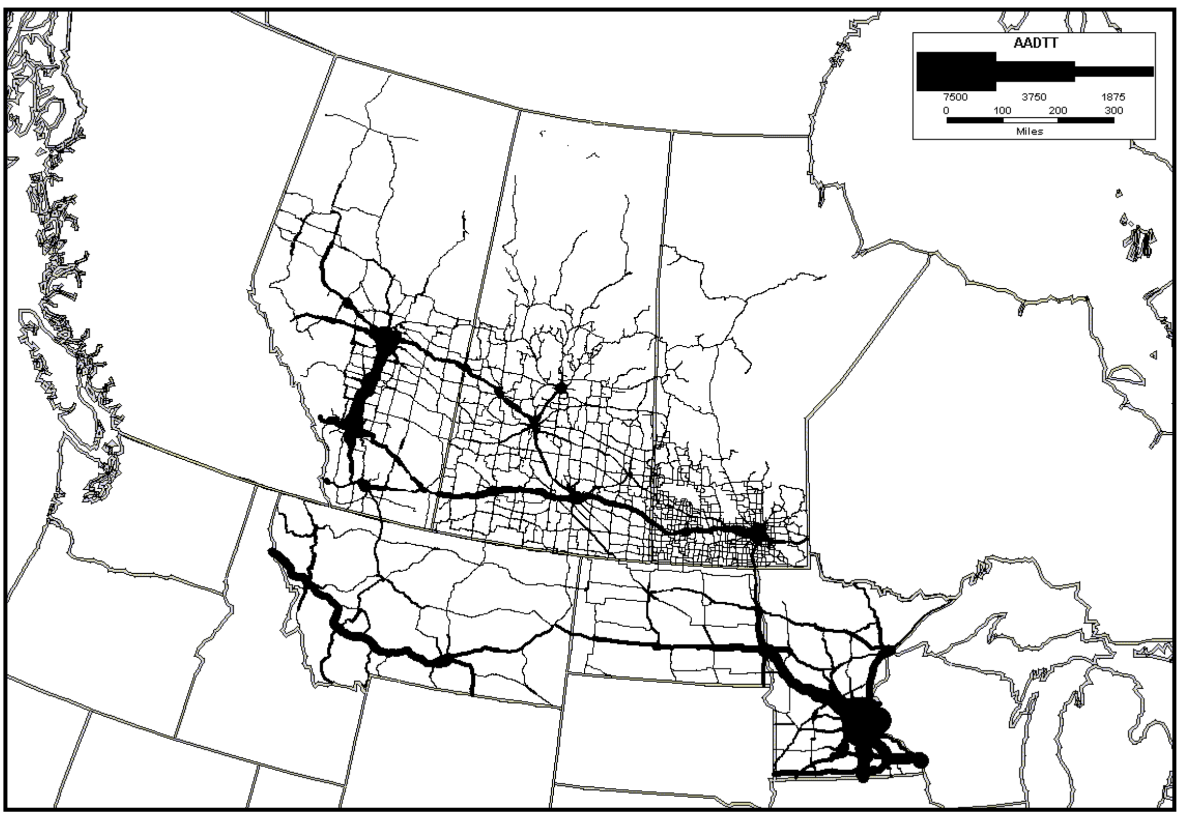

Figure 2-2: Truck Traffic in the Prairie Region © UMTIG 2005

- Highways with low truck volumes (151 to 400 AADTT) account for 31 percent of the region's provincial highway kilometers. Manitoba accounts for 14 percent of these kilometers, Saskatchewan for 30 percent, and Alberta for 56 percent.

- Highways with medium truck volumes (401 to 1,000 AADTT) account for 15 percent of the region's provincial highway kilometers. Manitoba accounts for 11 percent of these kilometers, Saskatchewan for 31 percent, and Alberta for 58 percent.

- Highways with high truck volumes (greater than 1,000 AADTT) account for five percent of the region's provincial highway kilometers. Manitoba accounts for 19 percent of these kilometers, Saskatchewan for 11 percent, and Alberta for 70 percent.

- The highways that carry the highest truck volumes in the tier states are I-94 and I-35 in Minnesota (approximately 3,500 AADTT), I-94 and I-29 in North Dakota (2,000 AADTT close to Fargo), and I-90 in Montana between Billings and the Montana-Idaho border (3,000 AADTT).

In considering weight limits and their effects on regional trucking activity it is important to recognize that the region is national and international in scope, as illustrated in Figure 2-3. There is one connection to Ontario and eastern Canada, four major connections into British Columbia and beyond, one into the Northwest Territories, and three major connections into the tier states of North Dakota, Minnesota, and Montana. The three major connections into the tier states are Couttes-Sweet Grass in Alberta, Estevan-Portal in Saskatchewan, and Emerson-Pembina in Manitoba. These border crossings combined account for approximately 80 percent of all the trucking activity to and from the U.S.

Figure 2-4 illustrates the southbound truck movements through the three major border crossings. The figure also illustrates the flows through the other border crossings in the region. Over the last 10 years, the prairie region has observed an overall growth in cross-border truck traffic of about 6 percent per year. Pembina-Emerson and Sweetgrass-Couttes have seen an overall increase in trucking activity. Portal-Estevan have seen almost no growth over the same time period.

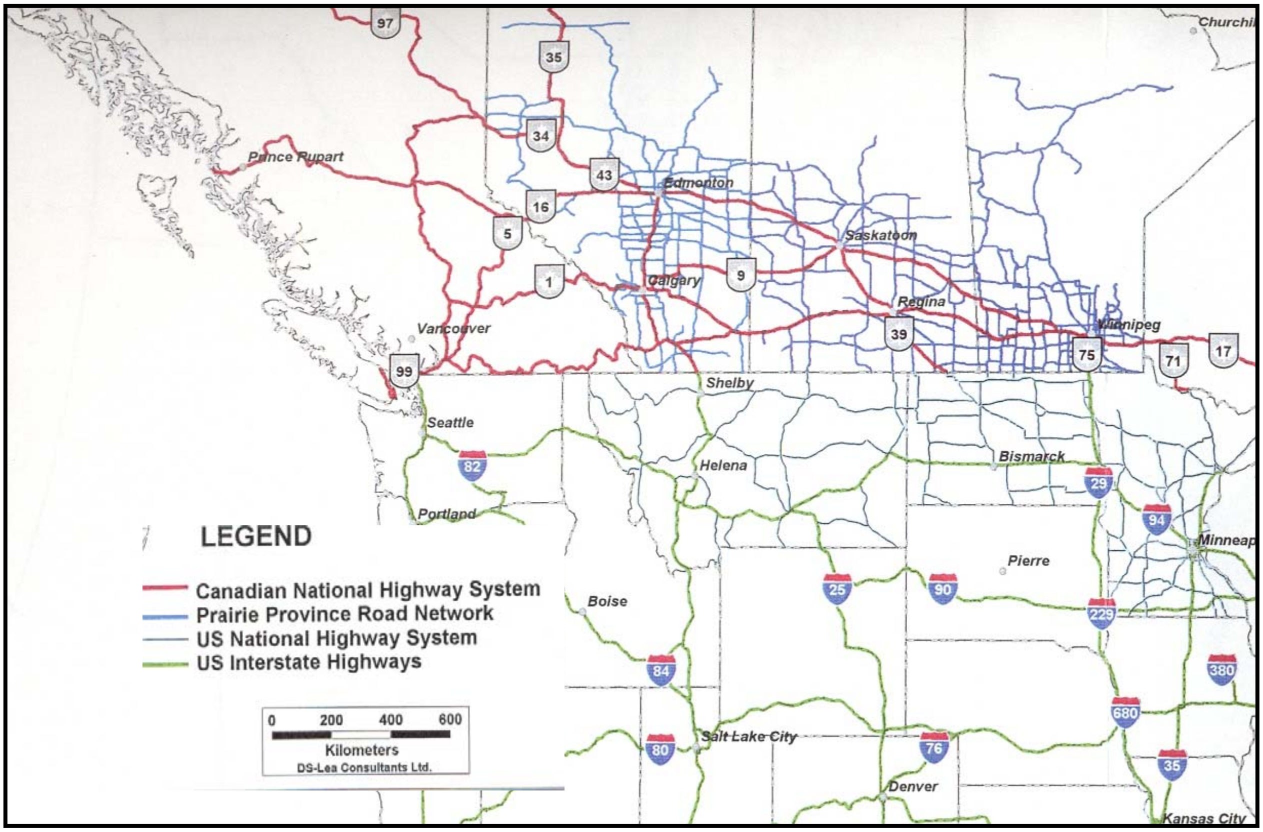

Figure 2-3: The Region and its Connections
Source: DS-Lea and UMTIG, 1998

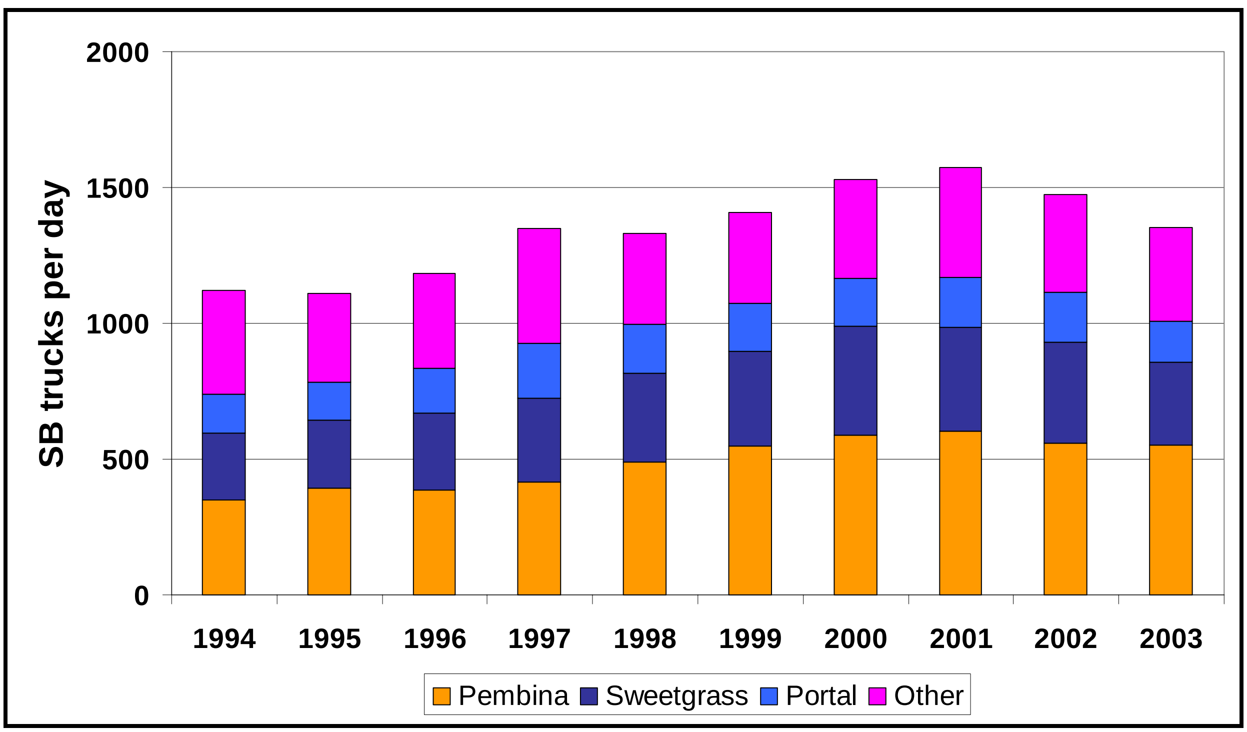

Figure 2-4: Southbound Truck Movements in the Region
Source: Bureau of Transportation Statistics

2.2.3 Commodity Movements

This section describes commodity flows in the prairie region. The content is a synthesis of relevant material from a previous UMTIG report conducted for Transport Canada in 2002 (Clayton et al., 2002). The material presented in this research refers to the Canadian Council of Motor Transport Administrators (CCMTA) 1999 National Roadside Survey only, as this database presents weight-related information.

The international portion of the CCMTA 1999 National Roadside Survey investigates truck movements to the U.S., Mexico, and other parts of the world. This analysis has been limited to movements within Canada and the U.S. The survey analysis presents: (1) origin-destination patterns of truck movements by direction of travel in the prairie provinces (Alberta, Saskatchewan, and Manitoba); and (2) major commodity flows pertaining to the prairie provinces.

2.2.3.1 Origin-Destination Patterns

Trucking activity associated with the prairie provinces is of 3 types: local, regional, and long distance. The largest percentage of movements originates and terminates in Alberta, followed by Saskatchewan and Manitoba. The major origins and destinations in the U.S. are the western Canada-U.S. border states, and other states such as Illinois, California, Texas, and the north-eastern states.

Manitoba-related trucking operates mainly to and from North Dakota, South Dakota, Minnesota, Illinois, and the north-eastern states. Saskatchewan-related trucking operates mainly to and from the western Canada-U.S. border states, Illinois, Texas, and California. Alberta deals mainly with the western Canada-U.S. border states, California, and Texas.

Table 2.1 shows the origin and destination of trucking activity associated with the prairie provinces as derived from the CCMTA 1999 National Roadside Survey.

Table 2.1: 1999 CCMTA Trucking Activity Associated with the Prairie Provinces

Tonnes per year								
DESTINATION								
ORIGIN	**Eastern Canada**	**Manitoba**	**Saskatchewan**	**Alberta**	**B.C.**	**Northern Territories**	**USA**	**Total**
Eastern Canada	--	974,299	210,606	1,049,113	--	--	--	--
Manitoba	1,376,875	2,064,336	467,265	602,491	114,163	**	1,805,979	**6,431,109**
Saskatchewan	158,324	1,390,475	4,144,623	1,937,494	378,905	59	1,014,493	**9,024,373**
Alberta	553,965	992,560	2,290,528	10,639,635	3,777,986	156,516	2,387,686	**20,798,876**
B.C.	--	316,124	264,994	2,918,245	--	--	--	**--**
Northern Territories	--	**	**	83,098	--	--	--	--
USA	--	1,674,375	424,345	2,280,904	--	--	--	--
Total	--	**7,412,169**	**7,802,361**	**19,510,980**	**--**	--	--	--

Source: Clayton et al., 2002

Note: ** denotes less than 1 tonne per year

-- denotes not calculated

Key observations regarding commodity movements associated with the prairie provinces are:

- 25 percent of tonnage originates in the prairie provinces and is destined for places beyond the prairie provinces; 22 percent of tonnage originates in places beyond the prairie provinces and is destined for the prairie provinces; and 53 percent moves between origins and destinations within the prairie provinces.

- Of the tonnage moved by truck out of the prairie provinces:
  - 59 percent originates in Alberta
  - 28 percent originates in Manitoba
  - 13 percent originates in Saskatchewan
  - Of this tonnage, 44 percent is destined for the U.S.; 36 percent is destined for British Columbia; 18 percent is destined for Eastern Canada; and the remaining 1 percent is destined for the Northern Territories.

- Of the tonnage moved by truck into the prairie provinces:
  - 43 percent originates in the U.S.
  - 34 percent originates in British Columbia
  - 22 percent originates in Eastern Canada
  - 1 percent originates in the Northern Territories
  - Of this tonnage, 62 percent is destined for Alberta; 29 percent is destined for Manitoba; and 9 percent is destined for Saskatchewan.

- Of the tonnage moved by truck within the prairie provinces:
  - Alberta is the origin for 57 percent and the destination for 54 percent
  - Saskatchewan is the origin for 30 percent and the destination for 28 percent
  - Manitoba is the origin for 13 percent and the destination for 18 percent

2.2.3.2 Major Commodities

The 10 most common commodities identified in the CCMTA survey moving to and from each of the prairie provinces are shown in Table 2.2. The table shows the distribution of freight tonnage carried by all trucks observed on the main highways in each of the three provinces by direction. These commodities represent international and domestic movements combined.

Major inbound commodities moved to Manitoba are cereal grains, agricultural products (except live animals), and pulp and paper products. These commodities account for three-quarters of the tonnage moved to the province. Major outbound commodities moved from Manitoba are agricultural products (except live animals), wood products, and unclassified products, accounting for 41 percent of the tonnage.

Major inbound commodities moved to Saskatchewan are agricultural products (except live animals), vehicles and prepared foods. These commodities account for over one-half of the tonnage moved into Saskatchewan. Major outbound commodities moved from Saskatchewan are fuel oils, wood products, and pulp and products. These account for 41 percent of the tonnage moved out of Saskatchewan.

Major inbound commodities moved to Alberta are agricultural products, prepared foods, unclassified products, base metals, and wood products. These account for 56 percent of the inbound tonnage. Major outbound commodities moved from Alberta are wood products, agricultural products, pulp and products, meat products, and unclassified products. These account for one-half of the tonnage.

Table 2.2: Major Commodities by Truck
CCMTA 1999 National Roadside Survey

Province	Inbound Truck Movements by Tonnage		Outbound Truck Movements by Tonnage	
	Major Commodity	**Percentage**	**Major Commodity**	**Percentage**
Manitoba	Cereal Grains	50.6	Agricultural Products Except Live Animal	16.1
	Agricultural Products Except Live Animal	17.9	Wood Products	13.6
	Pulp, Newsprint, Paper and Paperboard	5.8	Unclassified	11.7
	Animal Feed and Feed Ingredients	4.7	Petroleum Refining and Coal Products	9.2
	Prepared Foodstuffs, Fats and Oils	3.4	Animal Feed and Feed Ingredients	7.3
	Fertilizers and Fertilizer Materials	2.0	Base Metals	6.3
	Base Metals	1.9	Pulp, Newsprint, Paper and Paperboard	6.1
	Waste and Scrap	1.6	Prepared Foodstuffs, Fats and Oils	6.0
	Vehicles	1.5	Plastics and Rubber	3.9
	Machinery	1.3	Vehicles	2.5
	All Other Commodities Combined	9.2	All Other Commodities Combined	17.3
	Total	**100.0**	**Total**	**100.0**
Saskatchewan	Agricultural Products Except Live Animal	40.4	Fuel Oils	19.3
	Vehicles	6.7	Wood Products	11.1
	Prepared Foodstuffs, Fats and Oils	6.1	Pulp, Newsprint, Paper and Paperboard	10.7
	Alcoholic Beverages	5.9	Fertilizers and Fertilizer Materials	9.5
	Electonic and Other Electrical Equipments	5.9	Coal	9.2
	Unclassified	5.2	Base Metals	5.0
	Machinery	3.4	Live Animals and Live Fishs	4.5
	Articles of Base Metals	3.4	Basic Chemicals	4.1
	Fertilizers and Fertilizer Materials	3.3	Non-Metallic Mineral Products	3.7
	Waste and Scrap	2.6	Meat, Fish, Seafood and Peparations	3.5
	All Other Commodities Combined	17.1	All Other Commodities Combined	19.4
	Total	**100.0**	**Total**	**100.0**
Alberta	Agricultural Products Except Live Animal	25.2	Wood Products	17.9
	Prepared Foodstuffs, Fats and Oils	8.8	Agricultural Products Except Live Animal	8.3
	Unclassified	7.5	Pulp, Newsprint, Paper and Paperboard	7.6
	Base Metals	7.4	Meat, Fish, Seafood and Peparations	7.6
	Wood Products	7.0	Unclassified	6.9
	Natural Sands	5.1	Live Animals and Live Fishs	5.2
	Pulp, Newsprint, Paper and Paperboard	4.7	Vehicles	4.8
	Meat, Fish, Seafood and Peparations	3.9	Non-Metallic Mineral Products	3.8
	Articles of Base Metals	2.8	Gravel and Crushed Stone	3.1
	Basic Chemicals	2.8	Milled Grain Products and Prepations	3.1
	All Other Commodities Combined	24.9	All Other Commodities Combined	31.6
	Total	**100.0**	**Total**	**100.0**

Source: Clayton et al., 2002

Commodity movements by truck associated with the prairie provinces are dominated by three types of high-density commodities: (1) agriculture-related products; (2) forestry-related products; and (3) petroleum-based products. Movements of these commodities is therefore substantially affected by seasonal weight limits.

3.0 WEIGHT REGULATIONS IN THE REGION

This chapter discusses weight regulations and current practices involving the application of seasonal weight limits in the study region. Previous research conducted by the team (Montufar et al., 2000) addresses the regulatory situation in the late 1990s. This chapter presents the current situation involving seasonal weight limit applications for each of the jurisdictions in terms of substantive changes that have taken place over the last 5 years.

3.1 BASIC WEIGHT REGULATIONS

There are a myriad of laws, regulations, and policies governing the operating weights and dimensions of trucks in the prairie region. These regulations have a direct impact on the types of trucks that operate on the road network, their operating characteristics, and productivity issues.

Basic weight regulations (BWRs) are weight regulations that govern truck operations without the requirement for a special permit, winter premium allowances, or spring restrictions. These regulations are controlled and specified in the region by provincial and state departments of transportation, rural municipal councils, major urban transportation agencies, U.S. Federal Highways, national parks, and Public Works and Government Services Canada. They are often enforced by other agencies.

There are many BWR systems and system details governing trucking operations in the region. All roads under the jurisdiction of Alberta, Montana, North Dakota, and Minnesota transportation authorities are subject to a single, jurisdiction-specific, BWR system. Alberta BWRs are based on the Road and Transportation Association of Canada (RTAC) standards on all its highways. Montana, North Dakota, and Minnesota use the U.S. Federal Bridge Formula B, although each is subject to different GVW limits. Saskatchewan has two BWR systems: primary (RTAC); and secondary (GVW limit of 62.5 and 53.5 tonnes, respectively). Manitoba has three BWR systems: RTAC, A1, and B1 (GVW limit of 62.5, 53.5, and 47.6 tonnes, respectively). Details about these regulations can be obtained from Montufar et al. (2000).

Two standards with broad application and influence in terms of basic limits are: (1) Canadian RTAC weight provisions — particularly respecting principal highways in Alberta, Saskatchewan, Manitoba, and major connecting highways in adjacent Canadian jurisdictions and into urban centers; and (2) U.S. Federal truck size and weight law — particularly respecting interstate highways, and its influence on state regulations. Principal differences between the two systems are as follows:

- Basic RTAC limits are higher for tandem axle weights, tridem axle weights, and Gross Vehicle Weights (GVWs) than basic limits allowed in the adjacent U.S. states on both interstate and non-interstate highways.

- The RTAC system is vehicle-specific (e.g., a higher GVW limit for an 8-axle B-train compared with an 8-axle A-train), whereas the U.S. system is governed by Bridge Formula B.

- The RTAC system controls front steering axle loads (5500 kg on tractors), whereas the U.S. system generally does not (this may be done, however, by individual states).

- The RTAC system has no explicit bridge formula, whereas the U.S. system in these states includes an explicit bridge formula (Bridge Formula B) which controls GVWs on axle groups as a function of number of axles and axle spacings, subject to a GVW cap. This cap is 80,000 pounds in Minnesota, 105,500 pounds in North Dakota, and 132,000 pounds in Montana (it is 138,000 pounds in Montana only for travel between Sweetgrass and Shelby).

3.2 SEASONAL WEIGHT LIMITS

Seasonal weight limits are an important aspect of truck transportation regulation in the region. Premium weight allowances in winter provide opportunities to increase truck productivity and lower shipping costs for dense commodities. In doing so, they can attract certain freight movements to periods of higher strength frozen pavement conditions from lower strength (thawing or normal) periods. This can be beneficial to reducing the rate at which infrastructure deteriorates in serving its function of handling required freight movements. By the same token, reduced loading on certain roads during spring thaw helps reduce inordinate deterioration often associated with weak pavement and/or subgrade conditions.

Taking the region as a whole, seasonal weight limits are in effect at one place or another for a 7-month period, with winter weight premiums starting as early as November 16 and spring weight restrictions terminating as late as June 30. Hence, for a significant period of time each year, seasonal weight limits play a part in managing the balance between protecting the region’s highway infrastructure and influencing commercial vehicle characteristics and operations.

In 1999, the research team conducted a comprehensive study on the harmonization of spring weight restrictions and winter weight premiums for roads in the prairie region (Montufar et al., 2000). One of the recommendations of the study was for jurisdictions to adopt a condition-based approach for spring weight restrictions and winter weight premiums. This involves a system which combines measurements of the physical condition of the road (e.g., frost depths, thaw depths, and strength) and predicted weather conditions with engineering analysis to set, adjust, suspend, or terminate seasonal weight limits.

As of 2004, all jurisdictions had implemented, in one way or another, condition-based systems for seasonal weight regulation. Some of these systems apply only in the winter, some apply only in the spring, and some systems apply in both seasons to manage seasonal weight limits.

3.2.1 Winter Weight Premiums

Winter weight premiums (WWP) are weight limits that are applied during frozen periods in some systematic manner allowing truck operations at higher than basic weight limits without the use of permits.

A variety of WWP systems are used, varying both among and within jurisdictions. They include: (1) a constant percent increase system (e.g., 10% in Minnesota), sometimes capped by the basic GVW limit and sometimes uncapped; (2) a flat axle weight increase system (e.g., 1000 kg per axle group in Alberta); and (3) the up-class system used in Manitoba, where a low basic weight class road (e.g., B1) is increased to a higher basic weight class road in winter (e.g., "seasonal" RTAC). Figure 3-1 shows the road network subject to winter weight premiums in the period between December 2003 and July 2004.

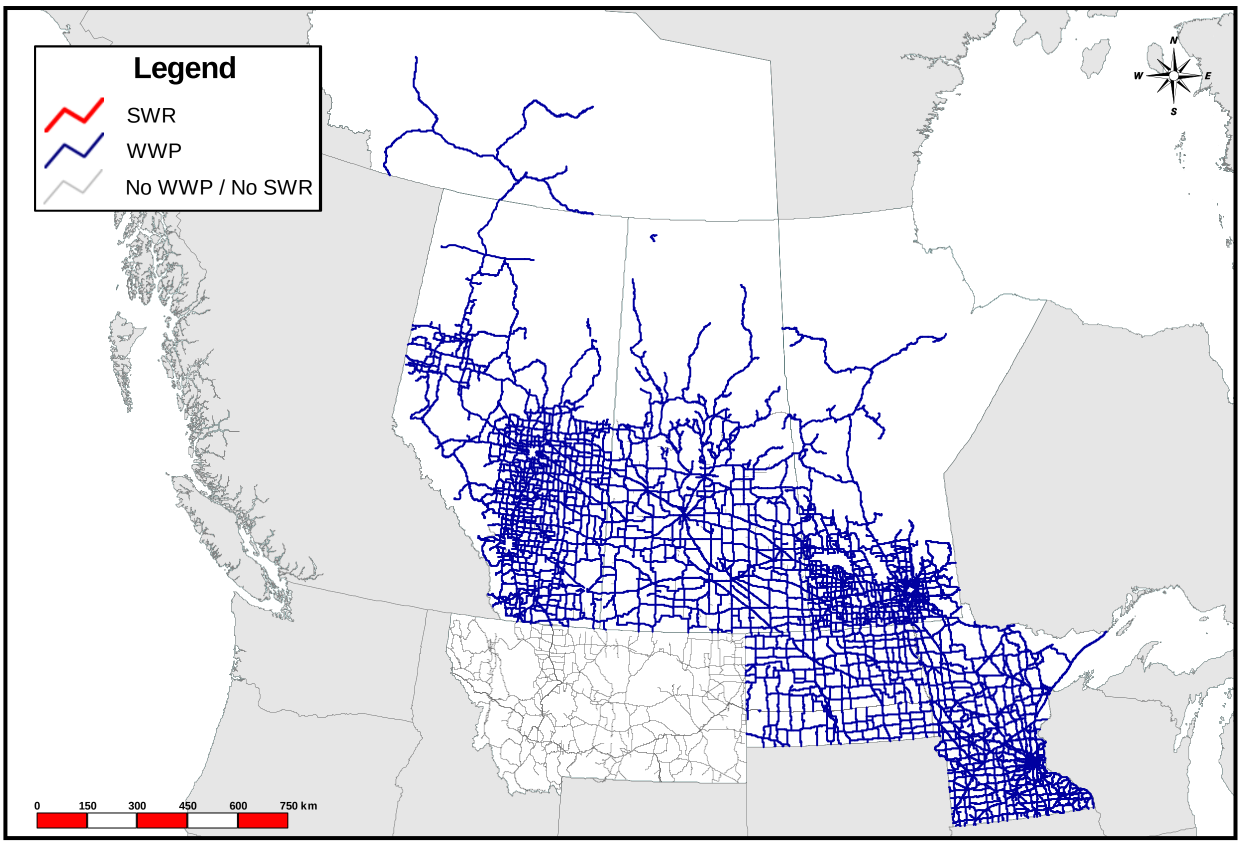

Figure 3-1: Highways Subject to WWP (December 2003 - July 2004) © UMTIG

As the figure indicates, WWPs are allowed in all jurisdictions except in Montana, and on the Interstate Highway System in North Dakota.

Manitoba uses a fixed-time system to implement WWPs throughout the province. Premium weight allowances are provided during the winter period (defined in the Highway Traffic Act as the period from December 1 to the last day of February of the following year) using two methods: (1) the "10 percent premium" method; and (2) the "designated seasonal route" method. Under the 10 percent premium method, the province provides a winter weight premium of 10 percent on provincial highways from December 1 in a year to the last day of February of the following year. The allowances vary by vehicle type, road class (RTAC, A1, or B1), and axle types. Under the designated seasonal route method, the province reclassifies certain routes from a lower class (i.e., B1 or A1) to a higher class (i.e., A1 or RTAC) for the winter period. In so doing, the allowable limits on these routes increase from their basic limits (B1 or A1), to the limits applicable on A1 or RTAC highways in the winter (this includes winter premiums applicable to those routes).

Saskatchewan has moved to a more conditioned-based system for WWP over the last 5 years. The current implementation of WWPs is partially based on weather conditions. Winter weights are effective November 16 and continue until March 14 of the following year. The period from November 16 to December 1 and the period from the last day in February until March 14 is subject to change depending on weather conditions. This was not the case in the past, where WWPs spanned from December 1 to March 1 of the following year under a fixec-time system.

In Alberta, the implementation of WWPs has remained the same as what it was 5 years ago. The only change that has taken place in Alberta between 2000 and the present day is the inclusion of the former secondary highways as part of the primary highway network. The former secondary highways are treated in the same manner as the former primary highway network. Winter weight premiums are applied in Alberta on a regional basis after a minimum of one meter of frost (measured from the surface) has entered the pavement structure and subgrade. The WWPs are generally removed when the subsurface thaw for a given area is greater than 30 cm—or will exceed 30 cm within a few days. WWPs can be in place in one region on some roads, while spring weight restrictions are in place in another region on other roads.

North Dakota allows WWPs in the form of a "Winter Time 10 Percent Weight Exemption Permit" that can be purchased for $50 for a period of 30 days. This permit is valid between December 1 of a given year and March 7 of the following year. The permit allows a vehicle 10 percent more weight when hauling a divisible load, but caps the gross vehicle weight to 105,500 pounds (the maximum basic weight allowed in the state). If spring load restrictions become effective prior to March 7, the state indicates that the 10 percent weight exemption permit is cancelled. The permit is valid for 10 percent over legal axle weights and/or 10 percent over legal exterior bridge distance (measurement between extreme axle centers), whichever is more restrictive. North Dakota does not allow WWPs on the Interstate highway system. The way in which North Dakota applies WWP has not changed over the last 5 years.

Minnesota introduced some changes to the procedure for the implementation of seasonal weight limits in October 2004. Under the new rules, the start of the winter weight premium period is now condition-based. It is determined for each frost zone using measured and forecasted daily temperatures for several cities within each zone. The criteria used to determine when the winter load increases will begin is when the cumulative freezing index for a zone exceeds 156 ^{o}C days based on the 3-day weather forecast, with predicted increases well in excess of 156 ^{o}C days.

The end of the winter load increase period is not tied to the starting date of spring load restrictions. Winter load increases are not removed during temporary thaw events that are followed by extended freezing periods during the months of December and January, and therefore, are not typically removed prior to February 1. After which time, winter load increases are removed when the extended forecast predicts daily thawing, as indicated by the cumulative thawing index, and the impending placement of spring load restrictions. This approach is different from what was in place 5 years ago. The state has moved to a fully condition-based approach to implementing WWPs.

3.2.2 Spring Weight Restrictions

Spring weight restrictions (SWRs) are weight limits that are applied during spring thaw periods in some systematic manner restricting truck operations to lower than basic weight limits. As is the case with WWPs, the way in which spring weight restrictions apply also varies by jurisdiction. Figure 3-2 shows the road network subject to spring weight restrictions between December 2003 and July 2004.

Overall, the jurisdictions in the region have moved to a more condition-based approach for the implementation of SWRs.

In Manitoba, the implementation of SWRs has become more responsive to road conditions over the last 5 years. The province now uses a fixed-variable timing method, which allows flexibility in the start dates of the load restrictions. In 2004, Manitoba started using the “thawing index” approach used by Minnesota, which resulted in a later timing for the implementation of SWRs.

In Saskatchewan, SWRs are partially dependent on weather conditions. Over the last 5 years the province has implemented a network of thermistors to assist in decisions on when spring weight restrictions should be placed on the thin membrane highway network. There are 16 thermistor sites located in different geographic and climatic areas across the province. As the temperature profile changes in the spring and frost leaves the grade, decision-makers implement SWRs to reduce the thaw-related damage to non-structural roads. Typically, restrictions start in the first week of March, generally in the southwest of the province, and the remainder follow over a two or three week period. When restrictions are implemented, they may be in place for up to six weeks. However, if a prolonged cold weather period occurs during the restriction season, they may be removed until conditions warrant their implementation again.

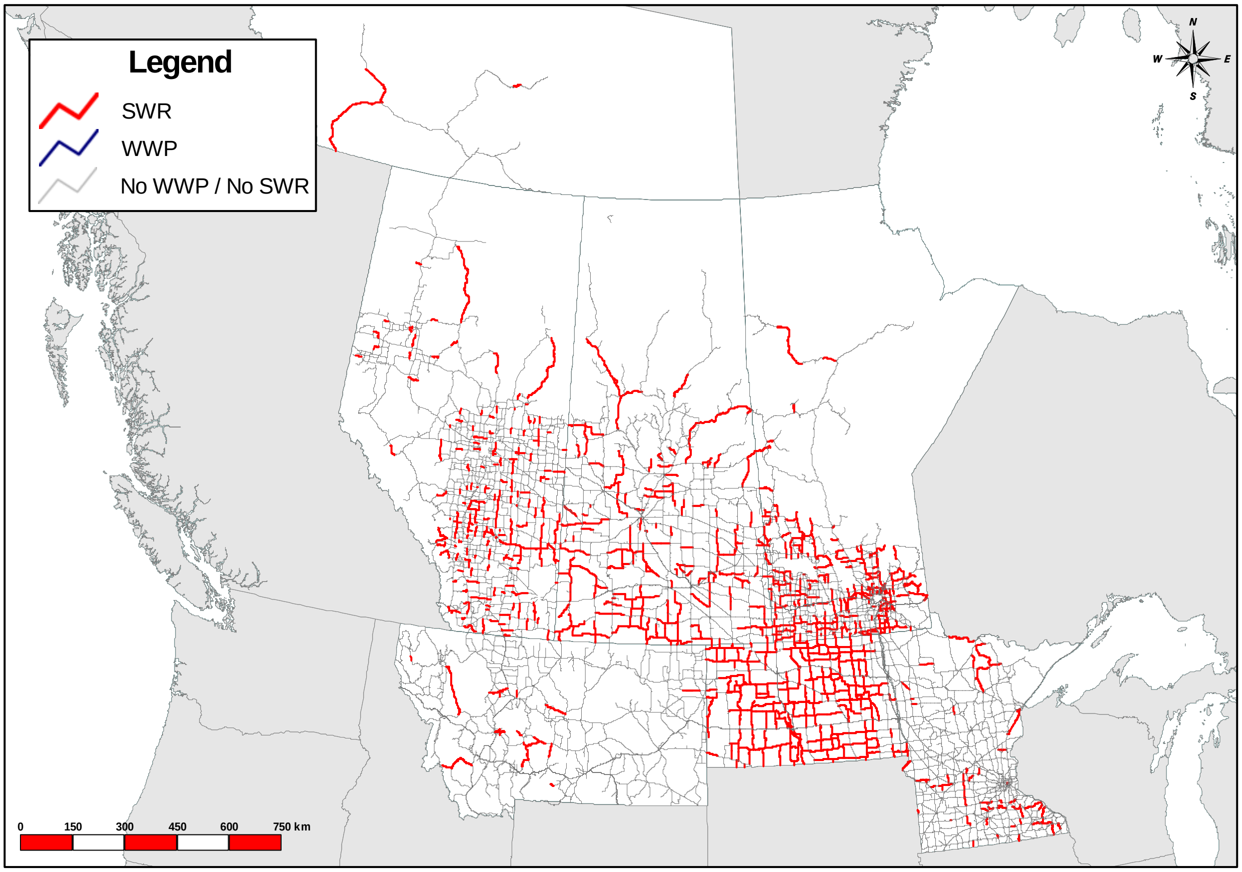

Figure 3-2: Highways Subject to SWR (December 2003 - July 2004) © UMTIG

The implementation of SWRs in Alberta has remained the same over the last 5 years. This condition-based system prescribes SWRs in terms of "percentage of axle weight" allowed on carrying (i.e., non-steering) axles. The percentage reductions are typically 90 percent, 75 percent, and in extreme cases—50 percent. First stage base/pavement structures—except for roads in Primary Subsystem 1—are typically subject to a SWR of 75 percent. Roads in "Primary Subsystem 1" (Highways 1, 2, 3, 4, 9, 16, 35, 43, and 63) are seldom subject to SWR (whether or not the structure is in its first stage of construction). The Primary Subsystem 1 network is considered to be the backbone of the provincial highway system in Alberta. It comprises the corridors most essential to the movement of people and goods within and through the province.

It is possible for Alberta's SWR level to change through the spring season (i.e., from 75 to 90 to 100 percent) depending on the results of on-going falling weight deflectometer (FWD) testing and consultation with the regional engineers. The timing and level of a SWR and the timing of its removal are both done on a road by road basis. Criteria for setting SWRs are based on when the "thaw front" enters subgrade. Electronic subsurface temperature sensors and liquid-filled tubes ("frost probes") are used to establish actual thaw conditions. A heat flow model may be used to predict thaw advance based on forecast air temperatures and other factors. Criteria for removing SWR is based on FWD testing. Results are compared with previous year's inventory FWD test programs, recovery trends, and regional input.

North Dakota has moved to a more condition-based system of implementing SWRs over the last 5 years. The state sets load restrictions as weather and roadbed conditions require, and lifts them when roadbeds are strong enough to carry traffic without damage. The initiation of load restrictions can come as early as late February to mid March. Load restrictions normally are initiated in the southwest portion of the state, and are phased out in the northeastern portion of the state by late May. The state primarily uses three factors in the posting of load restrictions. These factors or indicators are:

- Temperature probes in the base layers of pavement sections: As these temperatures approach 32 ^{o}F, the state starts planning the posting of highways with pavement sections which do not have sufficient strength to sustain the transport of heavy loads during periods of soft base structures.

- Long range temperature forecasts: When long range temperature forecasts indicate that low temperatures are approaching the freezing point, with daily highs in the upper 30's or 40's (^{o}F), load restrictions are planned.

- Falling weight deflectometer (FWD): This equipment measures the strength of the bases, as well as the asphaltic pavement surfaces. The state utilizes the FWD to evaluate pavement strengths for purposes of forecasting when load restrictions may be lifted. The database generated by the FWD, in combination with long range weather forecasts and area wide moisture conditions, provides the basis for lifting load restrictions.

Past experience has shown that the most significant pavement damage occurs during the first four weeks after the onset of the spring thaw. Because of this, the state has shifted towards close monitoring of both weather forecasts, along with sub-base temperatures, and posting of load restrictions on short notification.

Minnesota also sets load restrictions based on weather conditions. This condition-based approach has become more sophisticated over the last 5 years. The start of the load restriction period is determined for each zone using measured and forecast daily air temperatures for several cities within each frost zone. The criteria used to determine when the load restrictions will be placed is when the cumulative thawing index for a zone exceeds 14C degree-days based on the 3-day weather forecast, with predicted increases well in excess of 14C degree-days. The end of the load restriction period is determined for each zone using the following variables for several cities within each frost zone:

- Measured and forecast daily air temperatures
- Cumulative spring precipitation
- Accumulated fall precipitation measured during the preceding year
- Maximum cumulative freezing index resulting from the preceding winter freeze period.

This approach takes into account the preceding winter freeze and current spring thaw seasons and therefore, varies from year to year and during the current monitoring season as rain events occur. The minimum duration of spring load restrictions is 4 weeks and the maximum duration is 8 weeks.

The method of implementing SWRs in Montana has not changed over the last 5 years. Interstate highways in Montana are not weight restricted in the spring. State highways may be restricted as required. The start and end dates of the restriction are variable. The timing and level of restrictions are generated by field personnel using visual inspection. These restrictions may be removed and then reinstated as deemed necessary by field personnel. Montana has a spring restriction policy unique to the region which sometimes invokes a speed limit reduction coupled with spring restrictions.

3.2.3 Progression of Seasonal Weight Limits Through the Year

Montufar et al. (2000) detail the progression of seasonal weight limits in the study region between November 30, 1998 and July 1, 1999. In this research, a similar analysis was done for the period November 30, 2003 to July 1, 2004. Figures 3-3a to 3-9b compare the progression of these seasonal weight limits between these two periods, 5 years apart. Differences in the two geographic information systems used in the first versus the second period do not permit direct GIS comparisons of the equivalent map bases—only visual comparisons are possible.

Because seasonal weight limits change at different times in different jurisdictions, the basic comparisons are made on a constant day (the second Thursday) of each month. The two most significant differences between 1998/1999 and 2003/2004 are: (1) in Alberta, the secondary highway system is included in the 2003/2004 period—leading to many more spring restricted roads in that jurisdiction in the second time period; and (2) all jurisdictions had moved their regulatory practices to totally or partially condition-based by the second period—versus a much more prescriptive regulatory system in 1998/1999. The following is a summary of how seasonal weight limits progressed through this period, and how this progression compares to that of 1998/1999.

- As of November 30 1998 and November 30 2003, BWRs applied on all highways in the region. No seasonal weight limits were in place.

- On December 10 1998, WWPs were in place throughout Manitoba, Saskatchewan, and North Dakota (except on interstate highways), and in the northern region of Minnesota. In all four of these jurisdictions, WWPs were put in place on December 1. The same situation held true for December 11 2003, except WWPs had also been applied to the northern half of Alberta, and a few roads were spring restricted in the southern half of the province.

- As of January 14 1999, WWPs had also been introduced throughout Alberta and in southern Minnesota (including on Minnesota interstate highways). The same situation held true for January 15 2004, except WWPs had not been applied in the southern portion of Alberta, and a few roads remained spring weight restricted.

- The WWP situation throughout the region remained the same as of February 11 1999, except that a few road sections in Alberta had been placed under a SWR by this date. On February 12 2004, the same situation held, with the addition of some SWRs in place in Montana.

- On March 11, 1999, WWPs were in effect on most highways in Alberta north of and including the Trans-Canada Highway. WWPs had been discontinued in all other jurisdictions by this time (nearly two weeks earlier than Alberta). At the same time, most highways in southern Saskatchewan and southwest North Dakota, and a few in Alberta, Montana and Minnesota, were under SWRs. The same situation held true on March 11 2004, except WWPs remained only on roads in the northern half of Alberta and SWRs applied on many Alberta roads in the southern half of the province (and a few in the north).

- As of April 8, 1999, WWPs had been removed and SWRs were in place in all jurisdictions. SWRs were particularly extensive in Saskatchewan, Manitoba, and North Dakota. The same situation held true on April 8 2004 except, with the addition of the secondary road system to the Alberta network, Alberta also applied SWRs over a large network of its highways.

- The SWRs were progressively removed in May and June, with the situation returning to BWRs throughout the region by July 1 1999. The same situation held true for July 1, 2004 except Saskatchewan had removed all SWRs by May 13 of that year.

Cursory examination of the 2004/2005 year indicates that all jurisdictions continue to move forward on their condition-based approaches to seasonal weight regulation. Nonetheless, fundamental questions continue to arise from the progression of seasonal weight limits in 2003/2004. They include:

- In some jurisdictions, certain roads were moved more or less immediately from allowing WWPs to requiring SWRs. Does this mean that on one day the pavement structure was frozen, while on the next it had been weakened by thawing?

- Another question involves odd discontinuities. WWPs were in effect in northern Alberta as of March 11 2004, but had been removed nearly two weeks earlier on adjacent principal highway in Saskatchewan. Were productivity opportunities foregone because Sakatchewan (and maybe Alberta) removed WWPs earlier than necessary? Did Alberta expose itself to excessive pavement damage by retaining its WWP allowance longer than appropriate? Similar discontinuities (and related questions) involve the SWR issue. To this effect, SWRs had been removed from Saskatchewan highways by May 13 2004, but were still in place on extensive, adjacent highway networks in Manitoba and North Dakota.

This analysis and comparison of the progression of seasonal weight limits helps to understand that climate change-induced effects on seasonal weight limits will at best be highly obscured for some years to come—behind a complicated phenomenon on the one hand and an ever-changing and improving technologically-founded approach to dealing with the subject on the other.

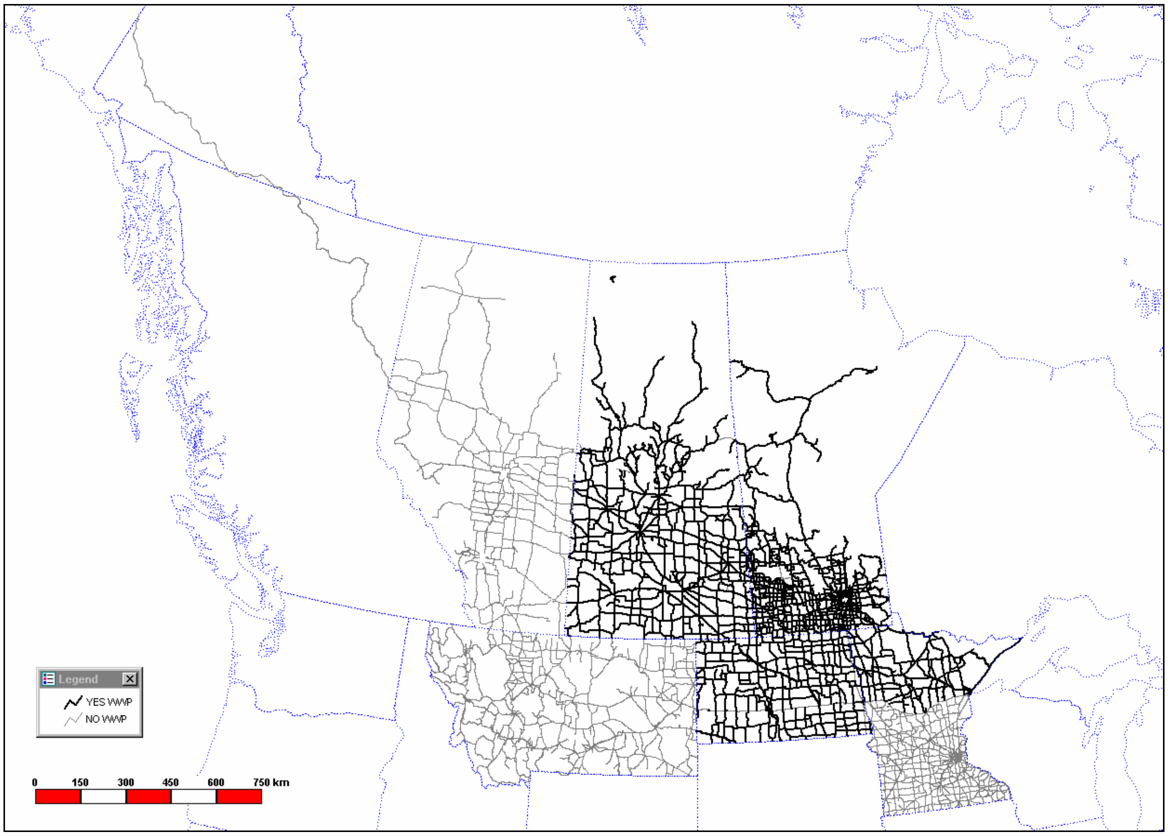

Figure 3-3a: Regional Winter Weight Premiums and Spring Weight Restrictions (Dec 10 1998)

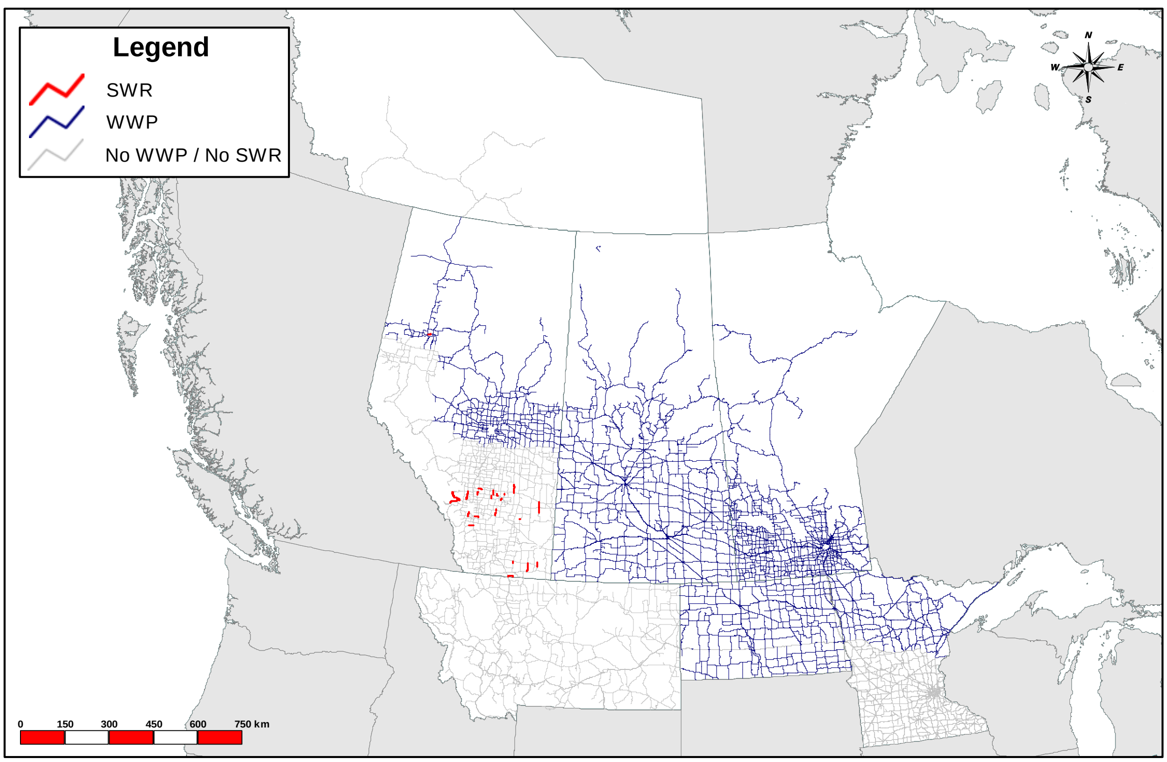

Figure 3-3b: Regional Winter Weight Premiums and Spring Weight Restrictions (Dec 11 2003)

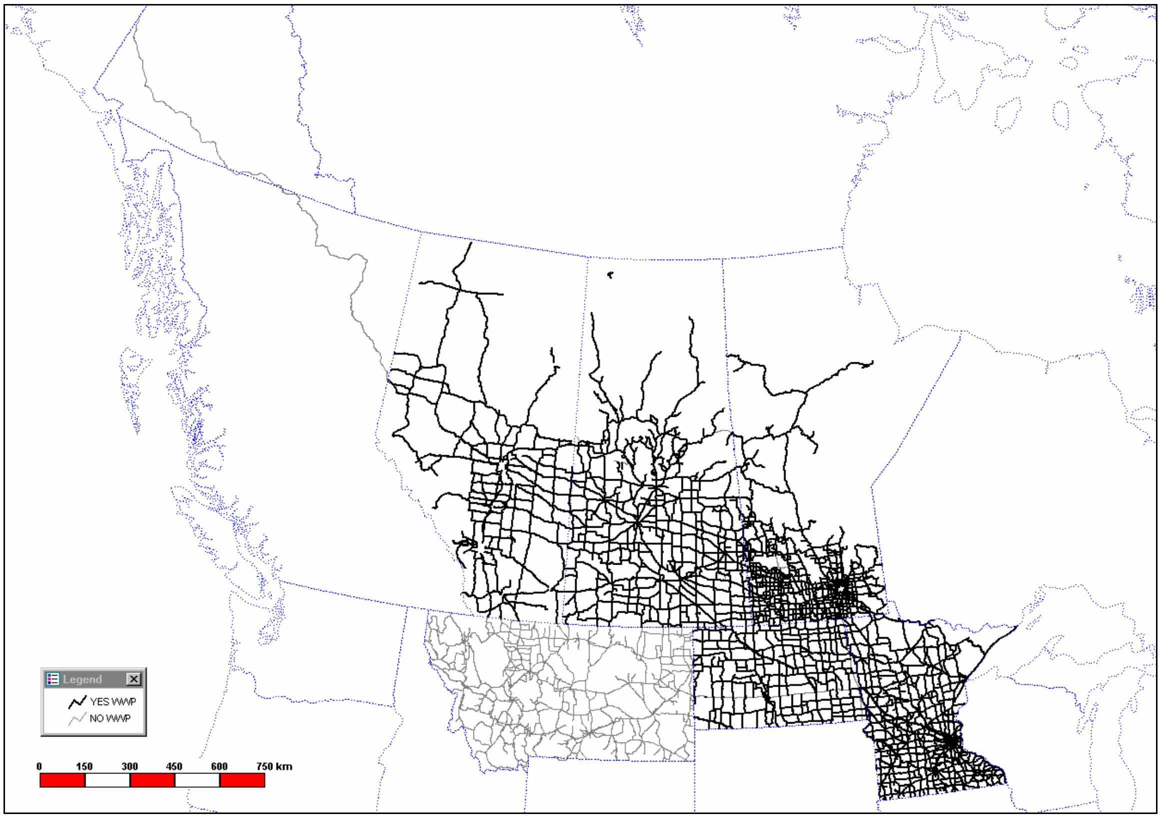

Figure 3-4a: Regional Winter Weight Premiums and Spring Weight Restrictions (Jan 14 1999)

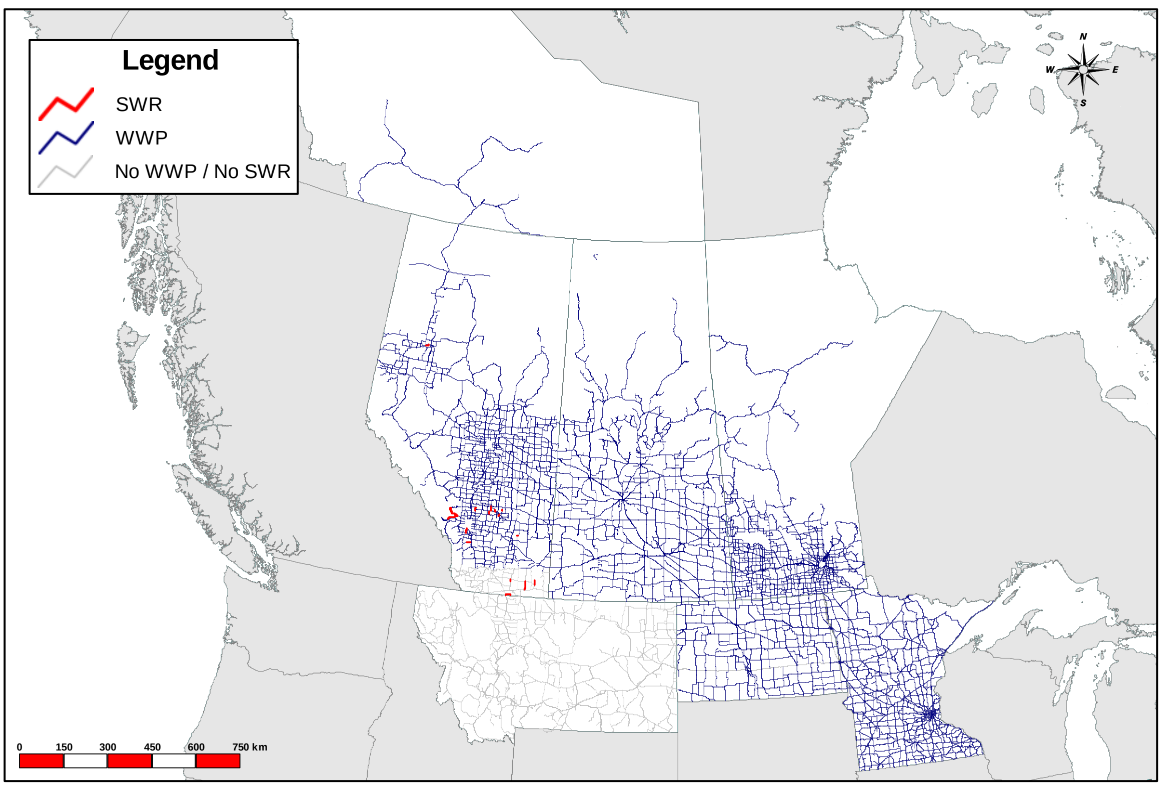

Figure 3-4b: Regional Winter Weight Premiums and Spring Weight Restrictions (Jan 15 2004)

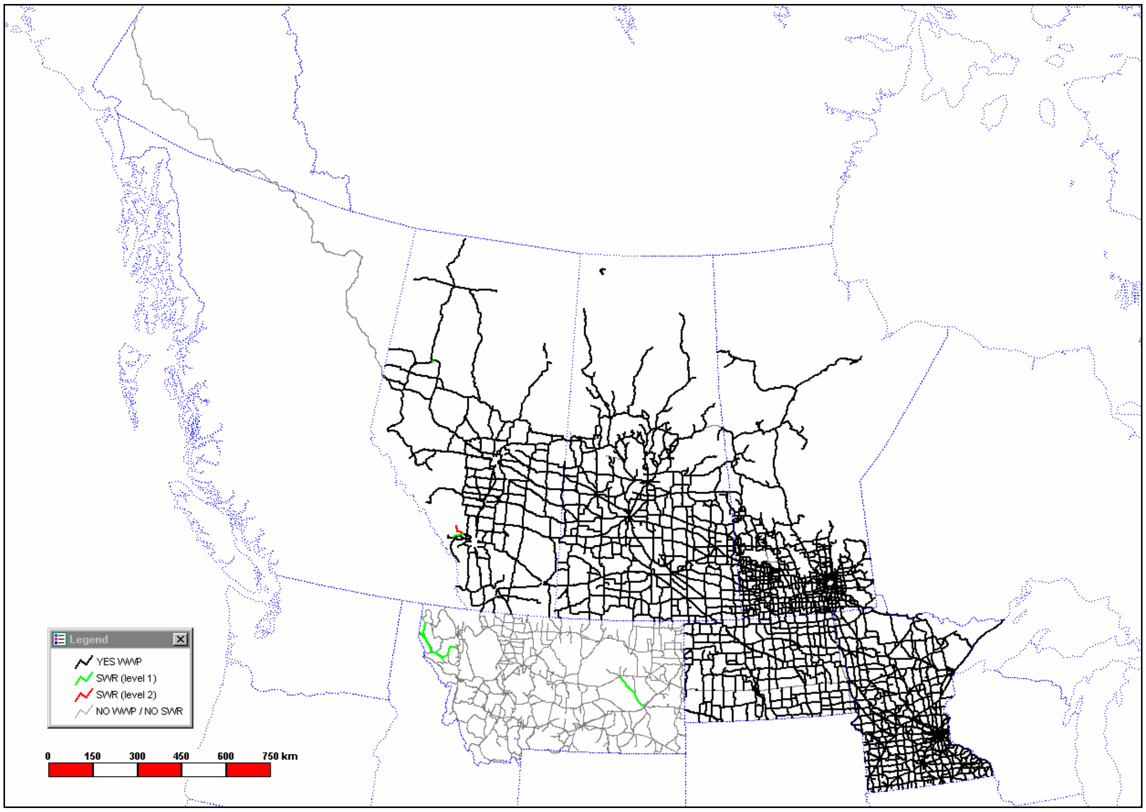

Figure 3-5a: Regional Winter Weight Premiums and Spring Weight Restrictions (Feb 11 1999)

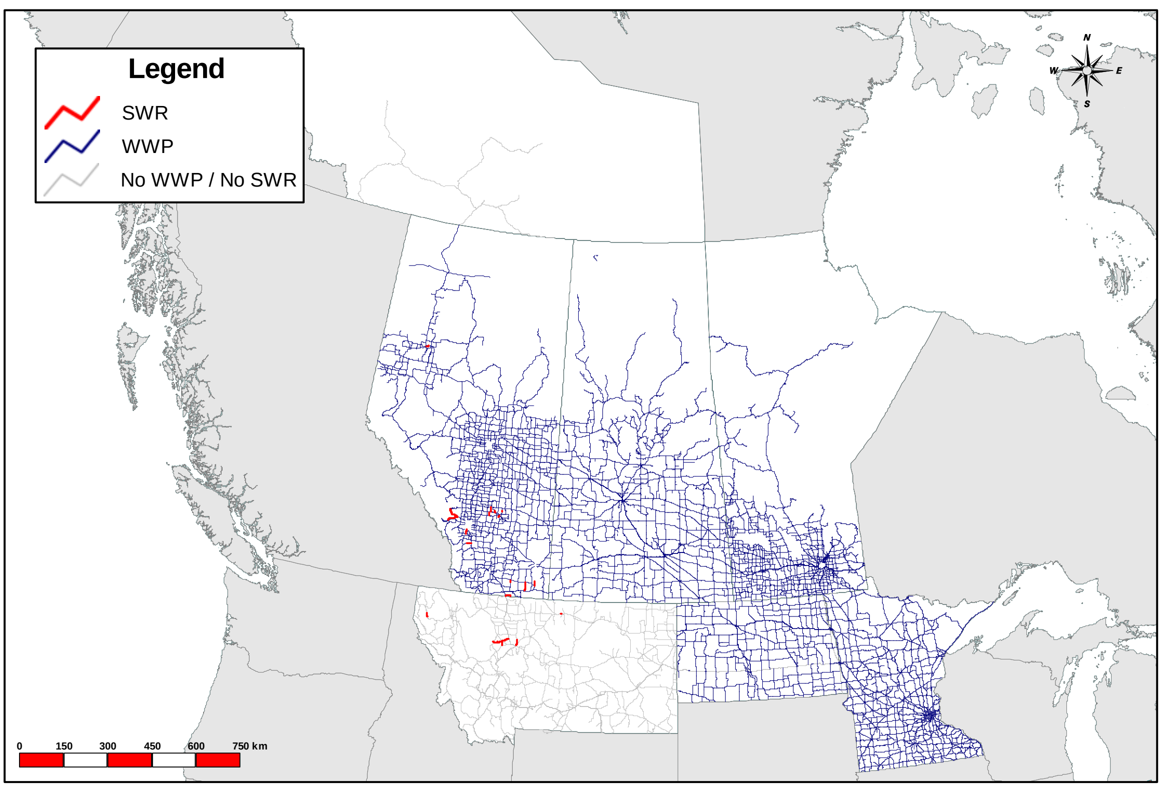

Figure 3-5b: Regional Winter Weight Premiums and Spring Weight Restrictions (Feb 12 2004)
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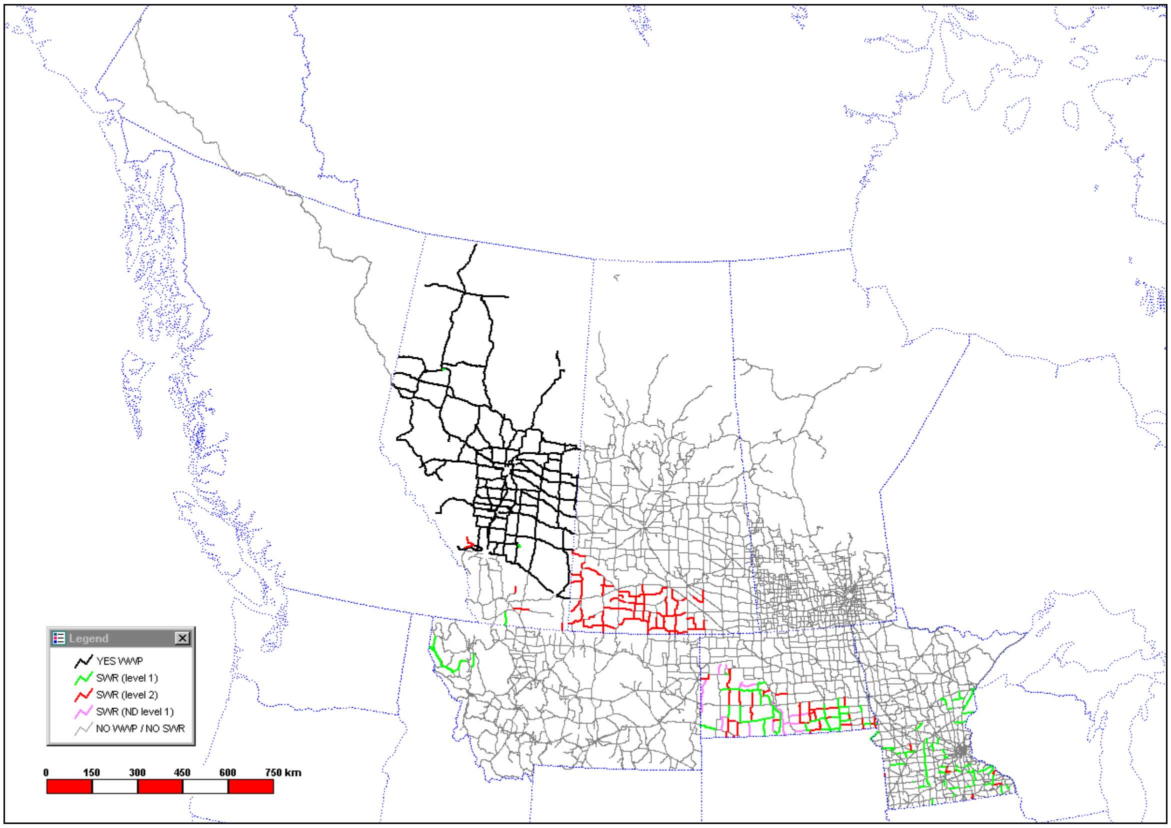

Figure 3-6a: Regional Winter Weight Premiums and Spring Weight Restrictions (Mar 11 1999)

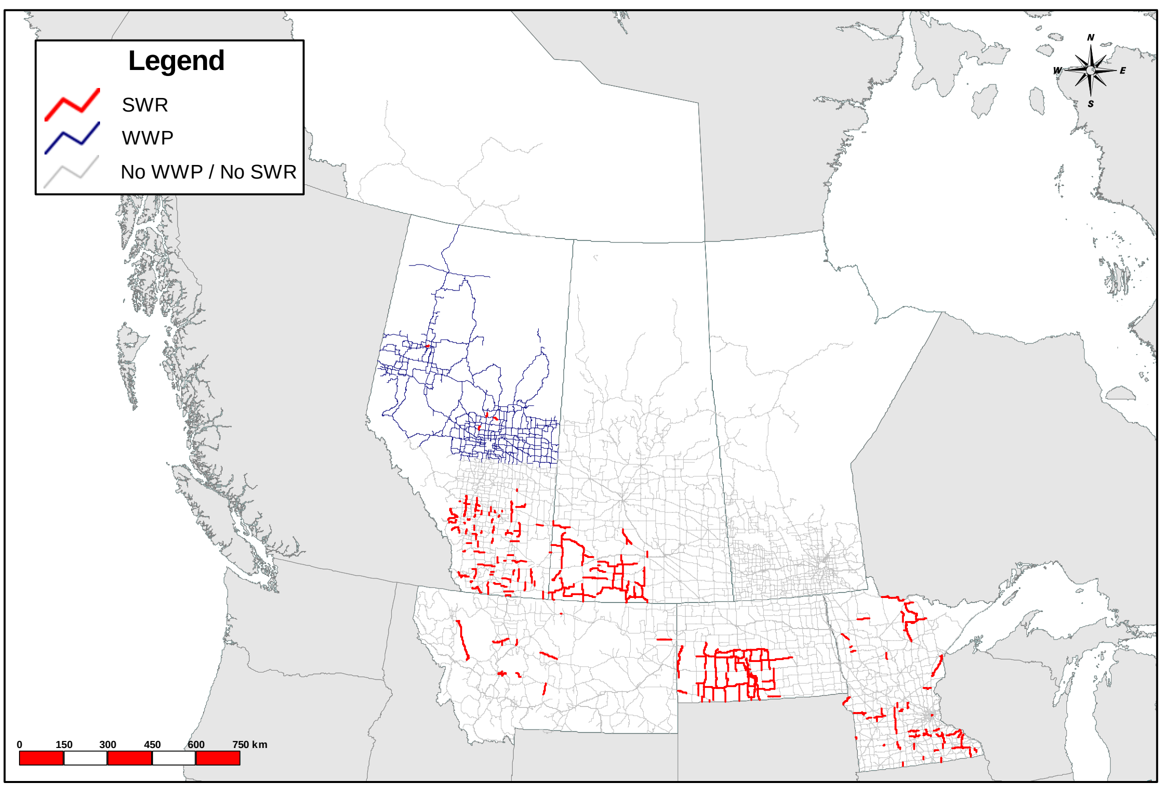

Figure 3-6b: Regional Winter Weight Premiums and Spring Weight Restrictions (Mar 11 2004)
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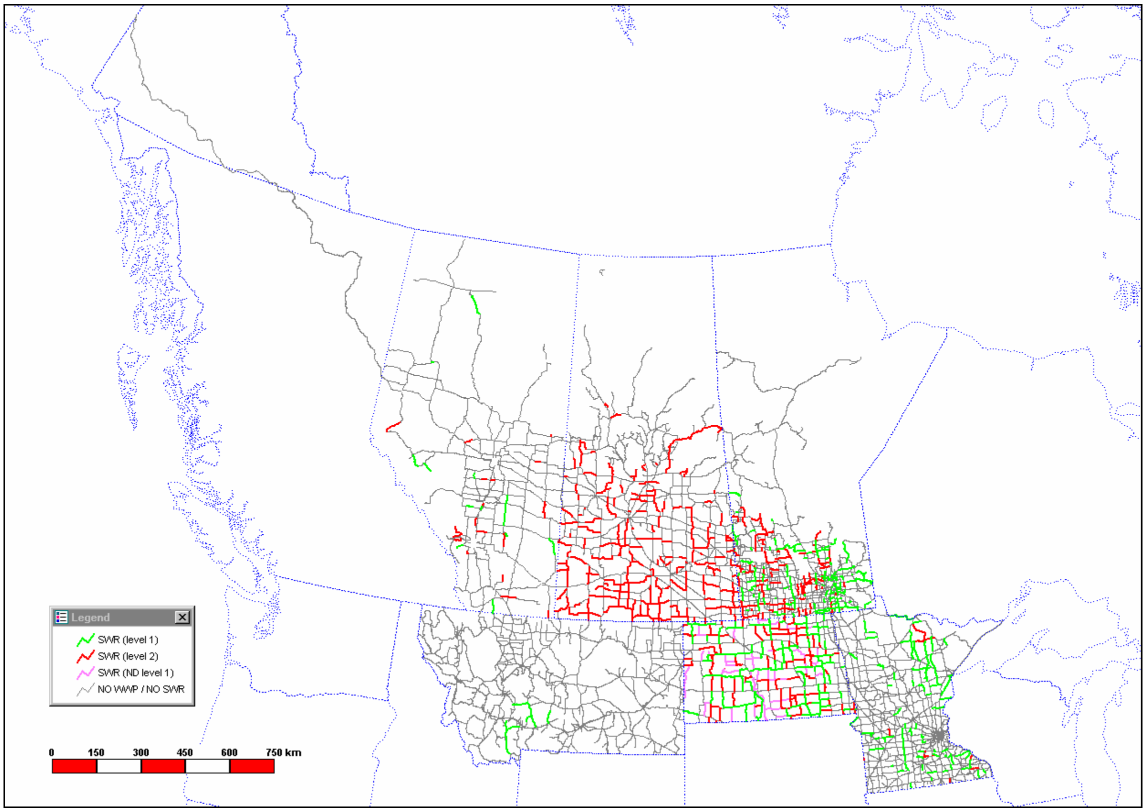

Figure 3-7a: Regional Winter Weight Premiums and Spring Weight Restrictions (Apr 8 1999)

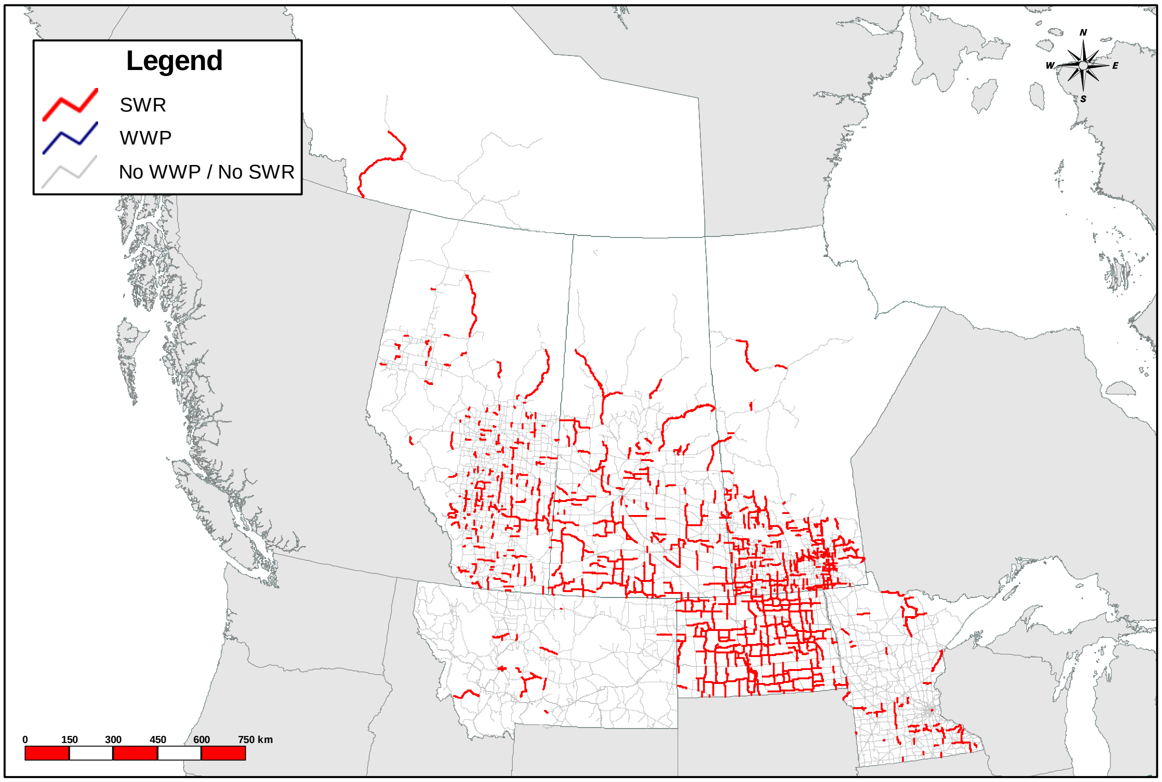

Figure 3-7b: Regional Winter Weight Premiums and Spring Weight Restrictions (Apr 8 2004)

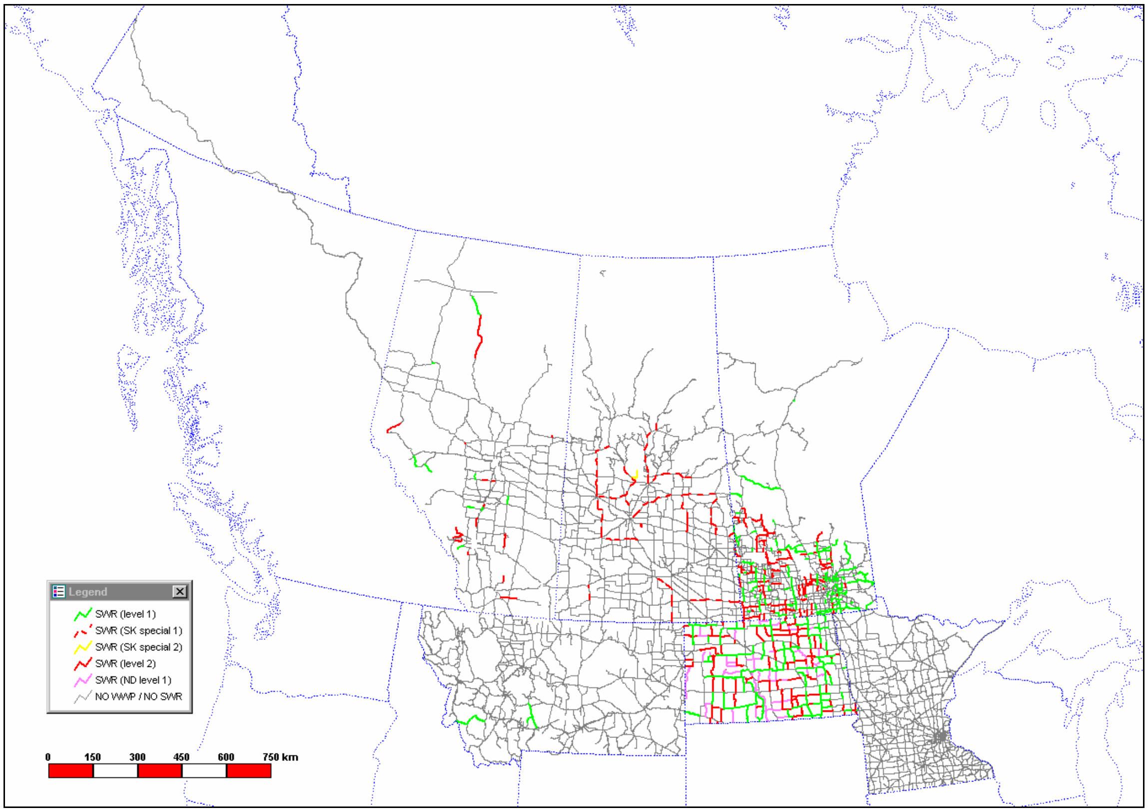

Figure 3-8a: Regional Winter Weight Premiums and Spring Weight Restrictions (May 13 1999)

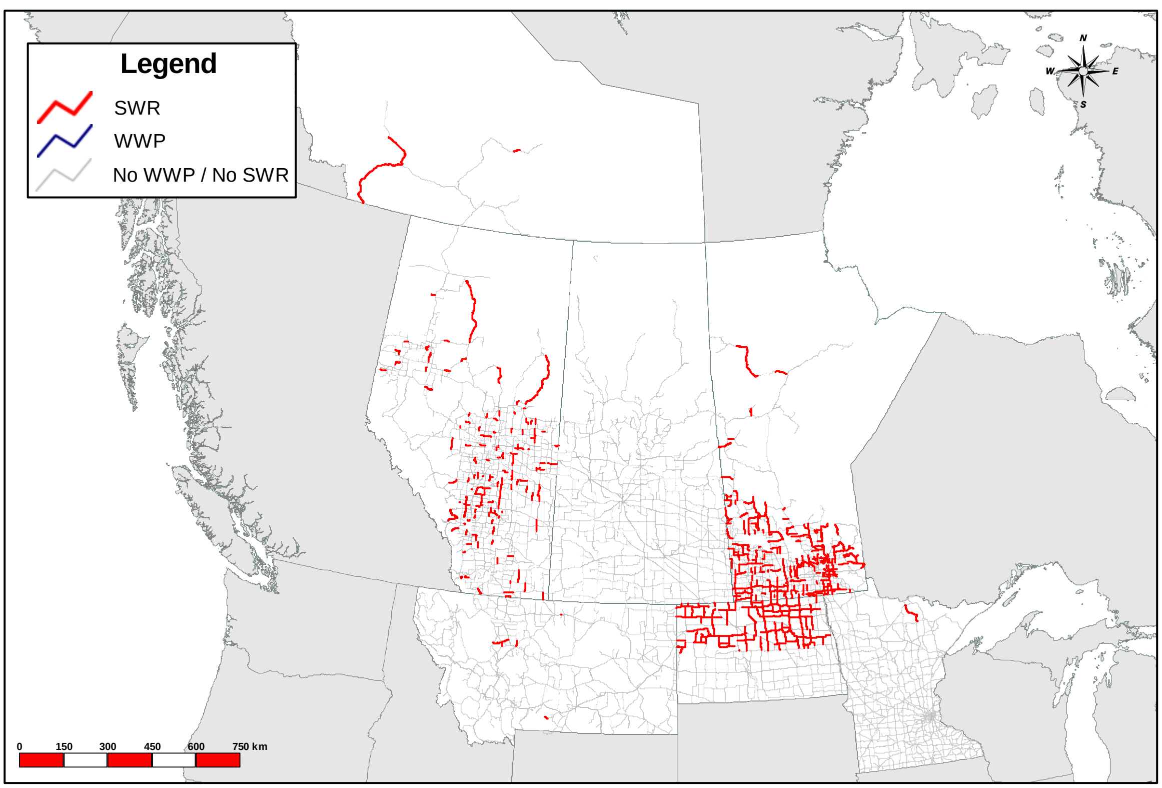

Figure 3-8b: Regional Winter Weight Premiums and Spring Weight Restrictions (May 13 2004)

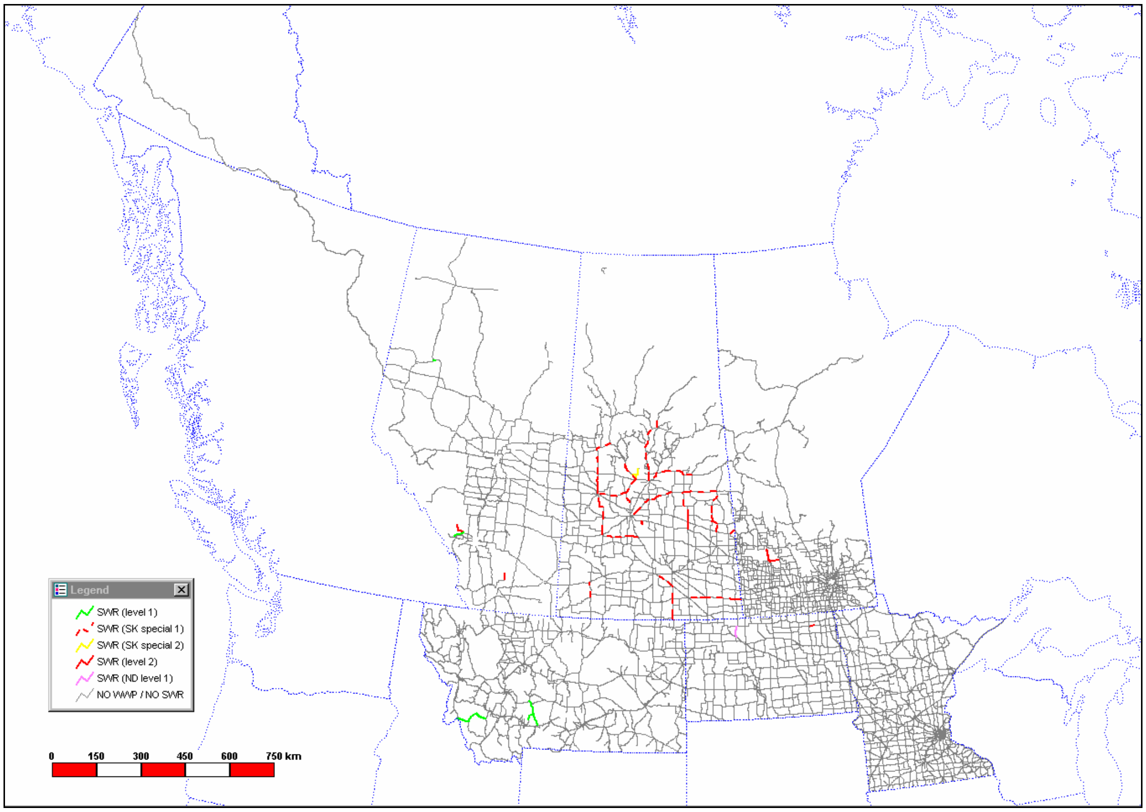

Figure 3-9a: Regional Winter Weight Premiums and Spring Weight Restrictions (Jun 10 1999)

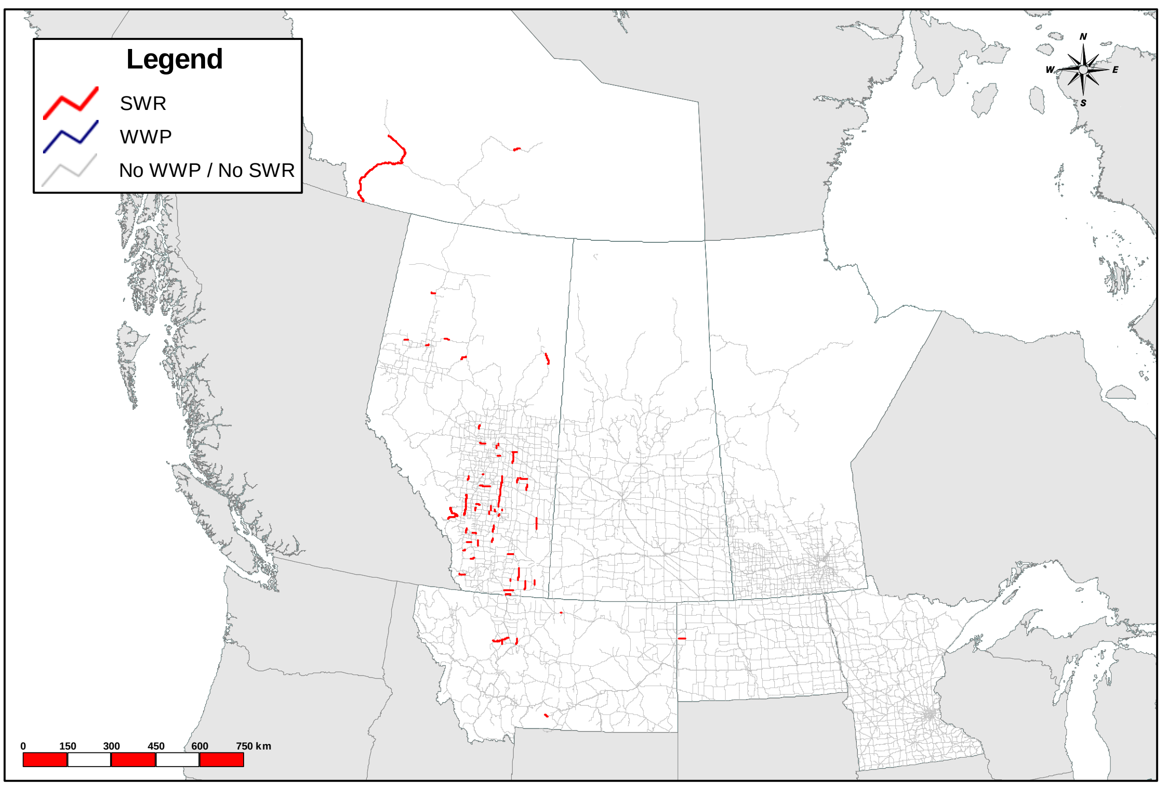

Figure 3-9b: Regional Winter Weight Premiums and Spring Weight Restrictions (Jun 10 2004)

4.0 DEFINITION OF CLIMATE CHANGE SCENARIOS

This chapter defines the climate change scenarios used in this research. These are plausible scenarios, related to temperature only, using different climate change models that apply to the region.

4.1 CLIMATE SCENARIOS

4.1.1 Definition

A climate scenario is a plausible future climate that is constructed for use in investigating the potential consequences of climate change. Climate scenarios should account for both human-induced climate change (anthropogenic) and natural climate variability. The term climate change scenario refers to the difference between a future climate and the present-day control climate. A climate change scenario is an interim step towards constructing a climate scenario (Houghton et al., 2001).

4.1.2 Criteria for Selecting Climate Scenarios

Smith and Hulme (1998) suggested four criteria to be used in the selection of climate scenarios for impact studies. These are outlined in the Intergovernmental Panel on Climate Change (IPCC) report *Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment* (1999), in addition to a fifth criterion proposed by the IPCC. The criteria are as follows:

- ***Consistency with global projections:*** Scenarios should be consistent with a broad range of global warming projections based on increased concentrations of greenhouse gases (GHG).

- ***Physical plausibility:*** Scenarios should not violate the basic laws of physics, meaning that changes in one region should be physically consistent with both regional and global changes. The combination of changes in different variables should also be physically consistent.

- ***Applicability in impact assessments:*** Scenarios should describe changes in the required number of variables on a spatial and temporal scale that allows for impact assessment.

- ***Representative:*** Scenarios should be representative of the potential range of future regional climate change.

- ***Accessibility:*** Scenarios should be straightforward to obtain, interpret, and apply for impact assessment.

The IPCC states, “simply defining a single climate future is insufficient and unsatisfactory” (Houghton et al., 2001). It is recommended that multiple scenarios be designed and applied to impact assessments. Rather than applying a single “best guess” scenario, the selected scenarios should span a range of possible future climates.

There are, however, limitations on the data that can be used in an impact study:

- Some data may not be archived in a form that is accessible to the public
- The variables that are required for the impact study may not be available
- The impact assessors may not be aware of the data sources that are available
- Resource limitations affecting the number of scenarios that can reasonably be run through the impact model.

In recognition of these limitations, the Canadian Institute for Climate Studies (CICS) suggests that a minimum of three scenarios of climate change be considered that cover the maximum, minimum and mid-range changes.

4.1.3 Climate Scenario Development

The three basic methods of climate scenario development outlined in Chapter 3 of *Climate Change 2001: Impacts, Adaptation and Vulnerability* (2001) and summarized in *Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment* (1999) will be discussed in the following sections.

4.1.3.1 Incremental

Incremental, or synthetic, scenarios are based on techniques where particular climatic elements are incrementally changed by realistic but arbitrary amounts. The imposed changes are often based on a qualitative interpretation of climate model simulations for a region. While these scenarios are easy to define and apply and capture a wide range of possible climate changes, the main disadvantage to their use is the potential for creating future climates that are not realistic or physically plausible.

4.1.3.2 Analogue

Analogue scenarios are developed from recorded climate regimes that resemble a possible future climate for a given region. Temporal analogues utilize climate records from the past while spatial analogues are based on information derived from another region that currently has a climate analogous to the proposed future climate. Appropriate analogue data may not be readily available for the region of interest and results are generally not based on GHG concentrations.

4.1.3.3 Climate Model-Based

According to the IPCC, General Circulation Models (GCMs) are the “only credible tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations.” GCMs, possibly in conjunction with nested regional models, are able to provide geographically and physically consistent results of regional climate change. Current GCM outputs are available through the IPCC Data Distribution Centre (DDC), the Canadian Climate Impacts and Scenarios (CCIS), and other climate modelling centres.

For this research, the climate model-based approach is used in the development of future climate scenarios. This method satisfies most of the key criteria listed in section 4.1.2, and has the advantage of accessibility to multiple data sources.

4.2 CLIMATE MODELS

4.2.1 Types of Climate Models

Global Climate Models or General Circulation Models (GCMs) are mathematical models that simulate the global climate system in three spatial dimensions and in time. They integrate the main physical processes in the earth-atmosphere system and calculate the adjustments and readjustments of the various elements in response to changes that occur. GCMs numerically simulate the state of the atmosphere at the earth's surface, as well as at various atmospheric levels above the surface (Hengeveld, 2000).

Coupled Atmosphere-Ocean General Circulation Models (AOGCMs) include an atmospheric GCM that is linked to a three-dimensional model of the ocean. Atmospheric models incorporate processes such as the greenhouse effect, thunderstorms, evapotranspiration, atmospheric pressure, wind, and precipitation. Ocean models include currents, temperature, salinity, and ice cover. The coupling of these two types of models enables AOGCMs to imitate the interactions between the atmosphere and the ocean, thus producing more realistic climate projections (CICS, 2004).

AOGCMs are generally used to generate coarse resolution projections of global climate change. These projections have a horizontal resolution in the order of 300 to 500 km. Since regional climate is often affected by factors that occur at the sub-AOGCM horizontal grid scale, it is difficult to extract fine-scale regional information from coarse resolution AOGCMs (Houghton et. al., 2001).

A number of "regionalisation" techniques have been developed to enhance AOGCMs and provide fine-scale climate information. The following techniques are outlined in Chapter 10 of the IPCC report *Climate Change 2001: The Scientific Basis (2001)*.

- ***High Resolution and Variable Resolution Atmosphere General Circulation Models (AGCM)***

  This procedure involves utilizing selected time periods within AOGCM transient simulations and modeling these with a high resolution or variable resolution AGCM. Since the time period is shorter (several decades as opposed to centuries), simulations at a spatial resolution of 100 km globally or 50 km locally are possible. This provides additional spatial detail in the regions of interest for the selected time-scale.

- ***Regional Climate Models (RCM)***

  The nested regional modeling technique uses initial conditions, time-dependent lateral meteorological conditions, and surface boundary conditions derived from GCMs to drive high-resolution RCMs. The RCM is used to account for sub-GCM grid scale factors and to enhance the simulation of atmospheric circulations and climatic variables at fine-scale. RCMs are constructed for limited areas and are run for shorter periods of time to reduce the computational output required to obtain data.

- ***Empirical/Statistical and Statistical/Dynamical Methods***

  Regional climate information is derived by establishing a statistical model that relates large-scale climate variables (predictors) from AOGCM simulations to regional variables (predictands). An AOGCM simulation provides the required input data for the statistical model, which is used to estimate regional climate characteristics.

Despite the enhanced spatial resolution and fine-scale climate data provided by regionalisation, there are a number of reasons why the use of AOGCMs for impact studies is still a viable and advantageous option:

- Analysis of AOGCM simulations conducted by the IPCC indicates that while the surface climate factors vary across regions and models, the recent experimental results are generally improved compared to previous generation models. This “implies increased confidence in simulated climatic changes” (Houghton et al., 2001).

- AOGCMs are the fundamental models used to simulate climate change and have been used as a data source for the majority of impact studies to date (Houghton et al., 2001).

- In general, AOGCMs provide “credible simulations of climate, at least down to sub-continental scales and over temporal scales from seasonal to decadal“ (Houghton et al., 2001).

- Regionalisation techniques are a maturing research area and the uncertainties related to these models are poorly understood (Houghton et al., 2001).

- AOGCM output data is readily available from a number of different modeling centers.

4.2.2 Criteria for Selecting Climate Change Models

The IPCC report *Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment* (1999) cites four criteria, originally proposed by Smith and Hulme (1998), that should be used in selecting a GCM.

- ***Vintage:*** In general, the most recent GCMs should be selected, since they are likely to be more reliable than earlier models. Many of the developments in climate modeling have occurred in the past 20 years. Recent model simulations will be based on current knowledge, incorporate more processes and feedbacks, and have a higher spatial resolution.

- ***Resolution:*** The spatial resolution of GCMs has increased over time as computing power has improved. Current models operate at approximately 300 km resolution with up to 20 vertical levels, compared to earlier models with 1000 km horizontal resolution and 2-10 vertical levels. A GCM with higher resolution will have more spatial detail, but this does not necessarily imply superior model performance.

- ***Validity:*** Validity refers to the ability of a GCM to simulate the present climate at both global and regional scales. If a model is able to accurately represent the current climate of a region, it is assumed that it will be able to more accurately represent the future regional climate. This is a stronger selection criterion than either vintage or resolution.

- ***Representativeness of Results:*** Given the uncertainties associated with GCMs, it is recommended that more than one model be applied to an impact assessment. It is also advisable to select scenarios that represent the potential range of regional climate change. In order to obtain results that are representative of the entire range, GCMs that produce average results, as well as those that represent the low and high end of the results, should be selected.

4.2.3 Model Descriptions

The IPCC Data Distribution Center (DDC) currently contains data that meets the above criteria from seven modelling centres. Of these, three have been selected to form the basis of the climate change scenarios for analyzing the impacts of climate change on the seasonal weight restrictions within the defined study area.

4.2.3.1 UK Hadley Centre for Climate Prediction and Research (HadCM2/HadCM3)

HadCM2 is a coupled atmosphere-ocean general circulation model developed at the Hadley Centre (United Kingdom) in 1994. Its successor, HadCM3 was developed in 1998.

These models have a spatial resolution of 2.5^o latitude by 3.75^o longitude, which produces a grid box resolution of 96 x 73 grid cells. The atmospheric component of HadCM2 has 19 vertical levels and the ocean component has 20 levels.

4.2.3.2 Canadian Centre for Climate Modeling and Analysis (CGCM2)

CGCM2 is the second generation Coupled Global Climate Model developed by the Canadian Centre for Climate Modelling and Analysis (CCCma). It is based on the same atmospheric component as the first generation model (CGCM1), but improvements have been made to address shortcomings of the ocean component. Specifically, the ocean mixing parameterization has been modified to produce more realistic results and more sophisticated sea-ice dynamics have been incorporated into the model.

The atmospheric component has a surface grid resolution of approximately 3.7^o by 3.7^o with 10 vertical levels. The ocean component has 29 vertical levels with a horizontal resolution of 1.8^0 by 1.8^0.

4.2.3.3 Australian Commonwealth Scientific and Industrial Research Organization (CSIRO-Mk2)

The Australian Commonwealth of Scientific and Industrial Research Organization developed the CSIRO Atmospheric Research Mark 2b climate model.

The atmosphere component of CSIRO-Mk2 has a horizontal resolution of approximately 5.6^o by 3.2^o with 9 vertical levels. The ocean model has the same horizontal resolution with 21 vertical levels.

4.3 NON-CLIMATE SCENARIOS

Demographic, economic, and technical driving forces are some of the underlying causes of climate change. It is therefore important to understand how concentrations of greenhouse gases and aerosols may change as a result of human activity. The development of non-climactic emissions scenarios is dependent on socioeconomic assumptions relating to population growth, economic activity, energy use, and land use changes.

There are currently two main emissions scenario sets. The first set of six IS92 scenarios was developed in 1992 for the IPCC First Assessment Report. More recently, a new set of emissions scenarios (SRES) was commissioned for the IPCC Third Assessment Report.

4.3.1 IS92 Emissions Scenarios

The IS92 scenarios were developed in 1992 as a supplement to the IPCC First Assessment Report. The scenarios consider the large uncertainty associated with population and economic growth, environmental, economic and institutional constraints, technological advances, and technology transfer. The future worlds described by the six IS92 scenarios represent a wide range of possible greenhouse gas futures.

4.3.1.1 IS92a

This represents the middle of the range scenario where population rises to 11.3 billion by 2100 with average economic growth of 2.3% per year. Both conventional and renewable energy sources are used, but no new emissions control policies are implemented.

4.3.1.2 IS92b

This scenario projects population growth similar to that of the IS92a scenario. Current emissions control policies are more inclusive and world-wide ratification and compliance with the amended Montreal Protocol is assumed.

4.3.1.3 IS92c

The IS92c scenario assumes that population first grows and then declines by the middle of the next century, that economic growth is low, and that there are severe constraints on oil and gas resource availability.

4.3.1.4 IS92d

The IS92d scenario is even more optimistic than the IS92c scenario. The trends represented in this scenario are increasing environmental protection relating to concerns about air pollution and waste disposal, low fossil fuel supply, and slower population growth. A 30% environmental surcharge is placed on fossil energy use to meet the costs of more stringent environmental control.

4.3.1.5 IS92e

This scenario produces the highest greenhouse gas emissions. The IS92e scenario is based on the assumptions of moderate population growth, high economic growth, high fossil fuel availability, and the eventual phase-out of nuclear power.

4.3.1.6 IS92f

The IS92f scenario has high population growth, high fossil fuel resource availability, increasing costs of nuclear power and less improvement in renewable energy technologies and costs.

4.3.2 SRES Emissions Scenarios

In total, there are 40 SRES scenarios. To reduce the number of scenarios used in climate studies, 6 marker scenarios have been defined, based on the consensus opinion of modelling teams. These marker scenarios attempt to capture the range of uncertainties associated with driving forces and emissions. The 6 marker scenarios are categorized into 4 storyline families, each describing a different world evolving through the 21^{st} century. A detailed description of the scenario development is provided in the IPCC *Special Report on Emissions Scenarios* (2001).

4.3.2.1 A1 Family

The A1 family represents a future world with rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. An underlying theme in this scenario family is the convergence of regional per capita income. Due to rapid technical progress, which reduces the resources required to create a given level of output and increases economically recoverable resources, energy and mineral resources are abundant.

Three distinct scenario groups are considered in the A1 family, each describing an alternative direction in the development of energy resources. The A1FI group describes a fossil-fuel intensive group, the A1T group is representative of non-fossil energy sources and the A1B group is based on a balance across all energy sources.

4.3.2.2 A2 Family

The A2 family describes a heterogeneous world with an emphasis on strengthening regional and local culture. The underlying themes are self reliance and preservation of local identities. Economic and technical changes are regionally oriented with rapid change in some regions and slow in others. Environmental concerns are relatively weak. Overall economic growth and technological change are more fragmented than other scenario families.

4.3.2.3 B1 Family

The emphasis of the B1 family is on global solutions to social, environmental, and economic sustainability. This family describes a world with a high level of environmental consciousness and institutional effectiveness. The global population is similar to the A1 family. There is rapid change in the economic structures toward service and information economy, accompanied by reductions in material intensity and the introduction of clean and resource-efficient technologies.

4.3.2.4 B2 Family

The B2 family represents a world with increased concern for environmental and social sustainability, with the solutions to sustainability being sought on a local and regional basis. Environmental protection is one of the only remaining international priorities. The world described by the B2 family is one of increasing global population, intermediate levels of economic development and less rapid and more diverse technological change than the B1 and A1 families.

The A1 and A2 families have a more economic focus, while the B1 and B2 families are environmentally focused. The A1 and B1 scenarios are more global compared to the more regional focus of the A2 and B2 scenarios. This is shown schematically in Figure 4-1.

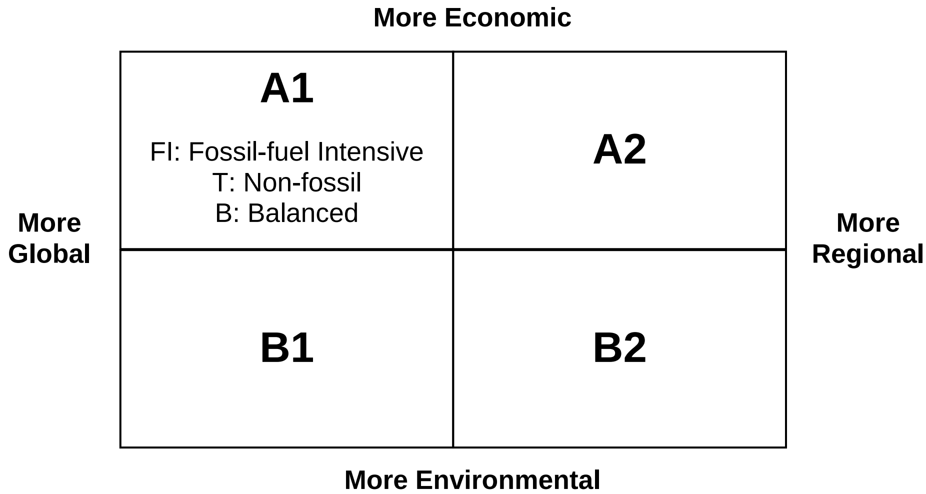

Figure 4-1: SRES Scenario Family
Source: http://www.cics.uvic.ca/scenarios/index.cgi?More_Info-Emissions

4.4 METHODOLOGY FOR CLIMATE SCENARIO DEVELOPMENT

Temperature change projections obtained from the three climate models described in Section 4.2.3 were used to form the basis of the climate scenario development for this research. These models were chosen because they meet the IPCC selection criteria for GCMs and they appear to give general results that cover a range of potential temperature changes.

Table 4.1 shows the emissions scenarios that were used to produce the climate change projections for each model. A total of 15 combinations of GCMs and emissions scenarios were selected for the final analysis.

Table 4.1: GCM and Emissions Scenario Combinations

	IS92a		SRES			
	gg[1]	ga[2]	A1	A2	B1	B2
HadCM2/3	✓	✓	✓	✓	✓	✓
CGCM2		✓		✓		✓
CISRO-Mk2	✓	✓	✓	✓	✓	✓

[1] *includes greenhouse gases*
[2] *includes greenhouse gases and aerosols*

The study area was divided into a series of climate scenario grid boxes, each representing a zone in which the projected temperature change is homogeneous. Each grid box in the study area is defined by the centroid of the corresponding box in the CGCM2 output grid. Since each GCM is based on a different grid system, data was collected for grid points nearest to the CGCM2 centroid location for the remaining two models.

4.5 BASELINE PERIOD

A baseline period is used as a reference point in climate change studies to characterize the present day climate in a region. The baseline is generally established for a time period for which good quality, observed climatological data is available (IPCC-TGCIA, 1999).

A 30-year “normal” period, as defined by the World Meteorological Organization (WMO), is commonly used as a climatological baseline period. Currently, the WMO normal period is 1961-1990. The climate change data presented in this research represents the change between the 1961-1990 baseline period and the future 30-year mean period from 2010 to 2039. This time period has been selected since it represents a practical engineering time horizon. The data change fields output by the GCMs are centered on the time slice 2020.

Baseline climate data was obtained from the IPCC Data Distribution Center for the study area. The grid for the baseline climate is finer than the grid used by the selected GCMs to project future climate scenarios (i.e., each climate scenario grid box contains more than one data point for baseline climate). To resolve this difference and allow for comparison between the baseline and the future climate, a spatial intersection was conducted using GIS software. The spatial intersection selected all of the baseline climate points that are contained by each of the climate scenario grid boxes. The monthly baseline temperatures were then averaged within each cell.

Figure 4-2 shows the variation in baseline temperature across the study area for the months of December through June. Figure 4-3 shows the average baseline temperature averaged over the entire study area.

4.6 NORTH AMERICAN CLIMATE CHANGE PROJECTIONS

A climate projection is defined by IPCC as a “description of the response of the climate system to a scenario of greenhouse gas and aerosol emissions as simulated by a climate model.” Climate projections are often used in conjunction with observed climate data as inputs to impact models (Houghton et al., 2001).

Two general temperature change scenarios were developed from the climate change projections for the study area. One represents the warmest temperatures projected by the climate models and the other represents the coldest projected temperatures. These scenarios were created by selecting the maximum and minimum change values for each grid box from the 15 combinations of GCMs and emissions scenarios. Grid box values correspond to the predicted temperature change for the 2010-2039 time frame.

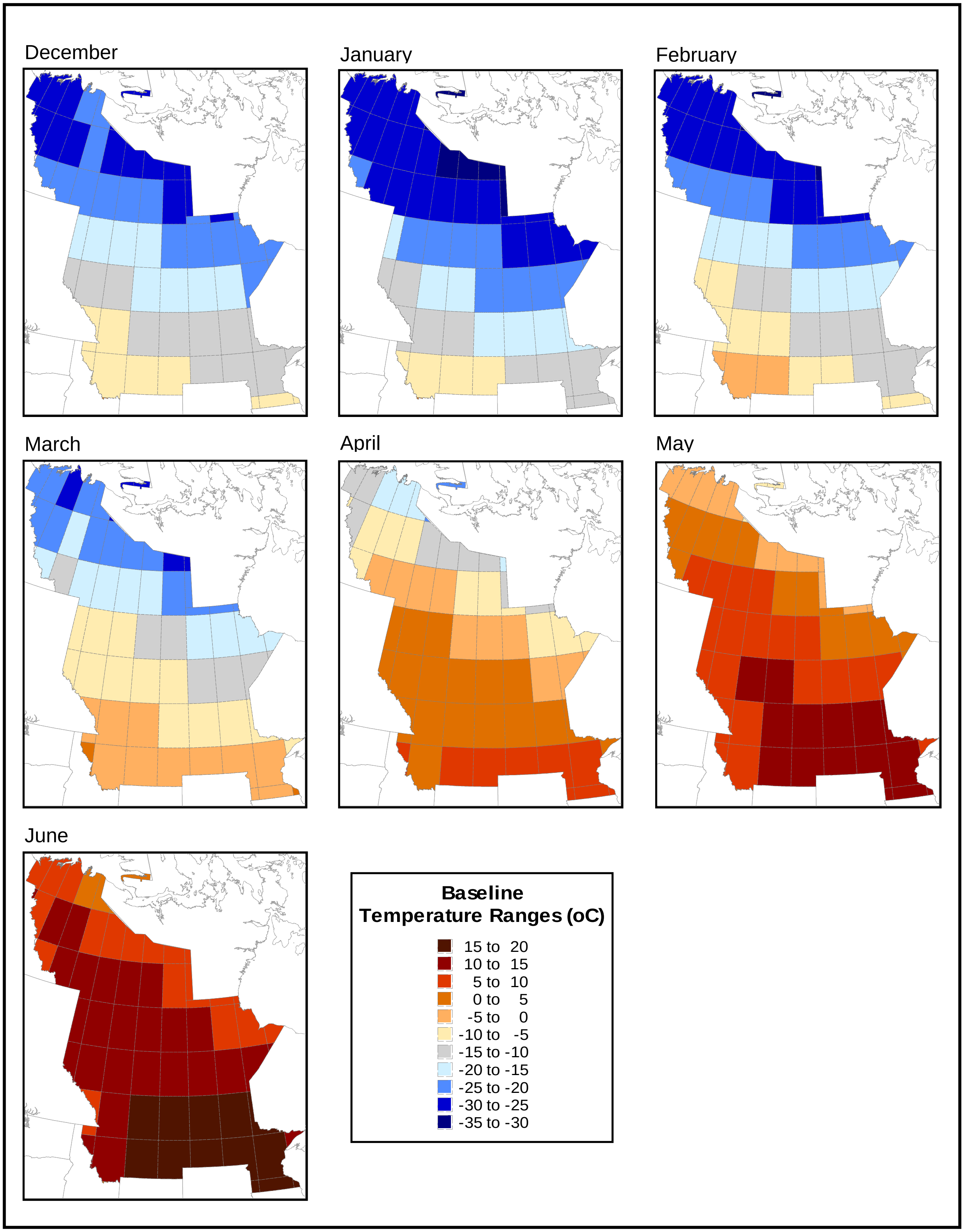

Figure 4-2: Monthly Variation in Baseline Temperature within the Study Area

Source: Raw data obtained from IPCC DDC; Analysis and map production by UMTIG

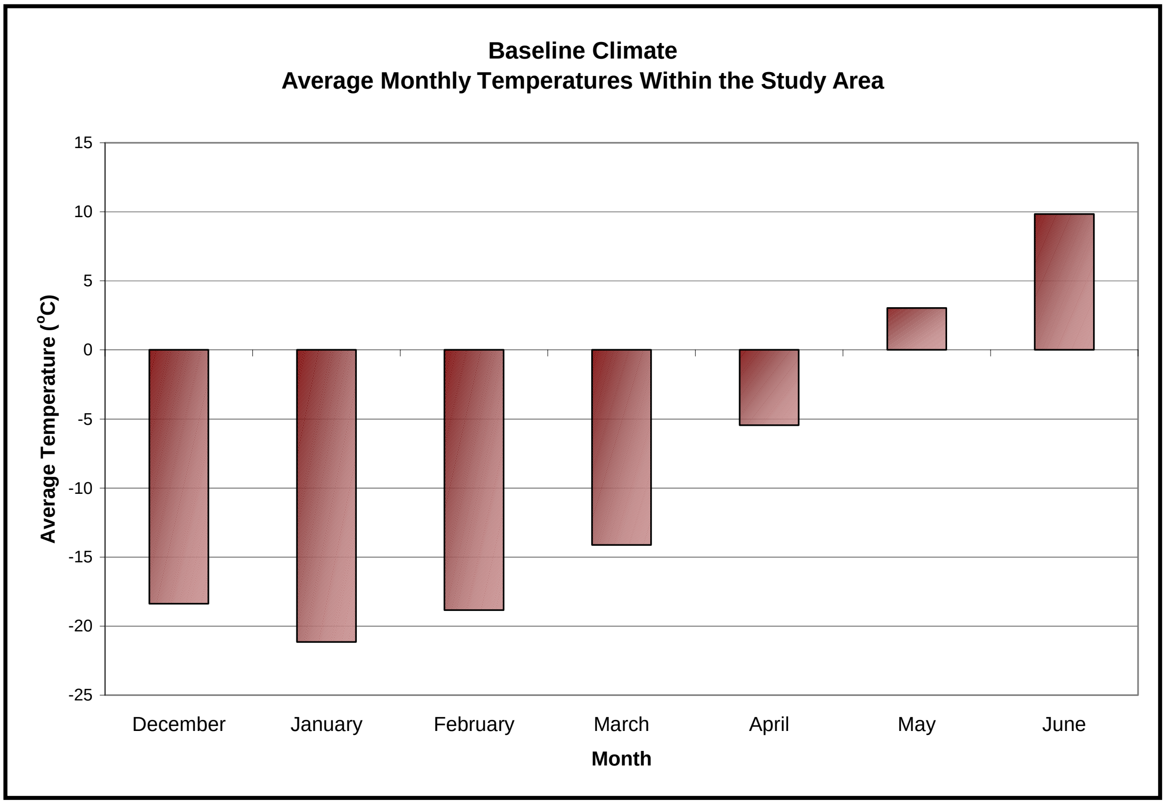

Figure 4-3: Average Baseline Temperature
Source: Raw data obtained from IPCC DDC; Analysis by UMTIG

The results of this analysis are presented graphically in Figure 4-4 for the months of December through June. The projected temperature changes averaged over the entire study area are shown in Figure 4-5 for both the maximum warming and minimum warming scenarios.

The figures show that over the next 25 years, there is no cooling expected in the region. In addition, the region could experience a minimum of ½ to one ^{o}C warming trend in winter and spring.

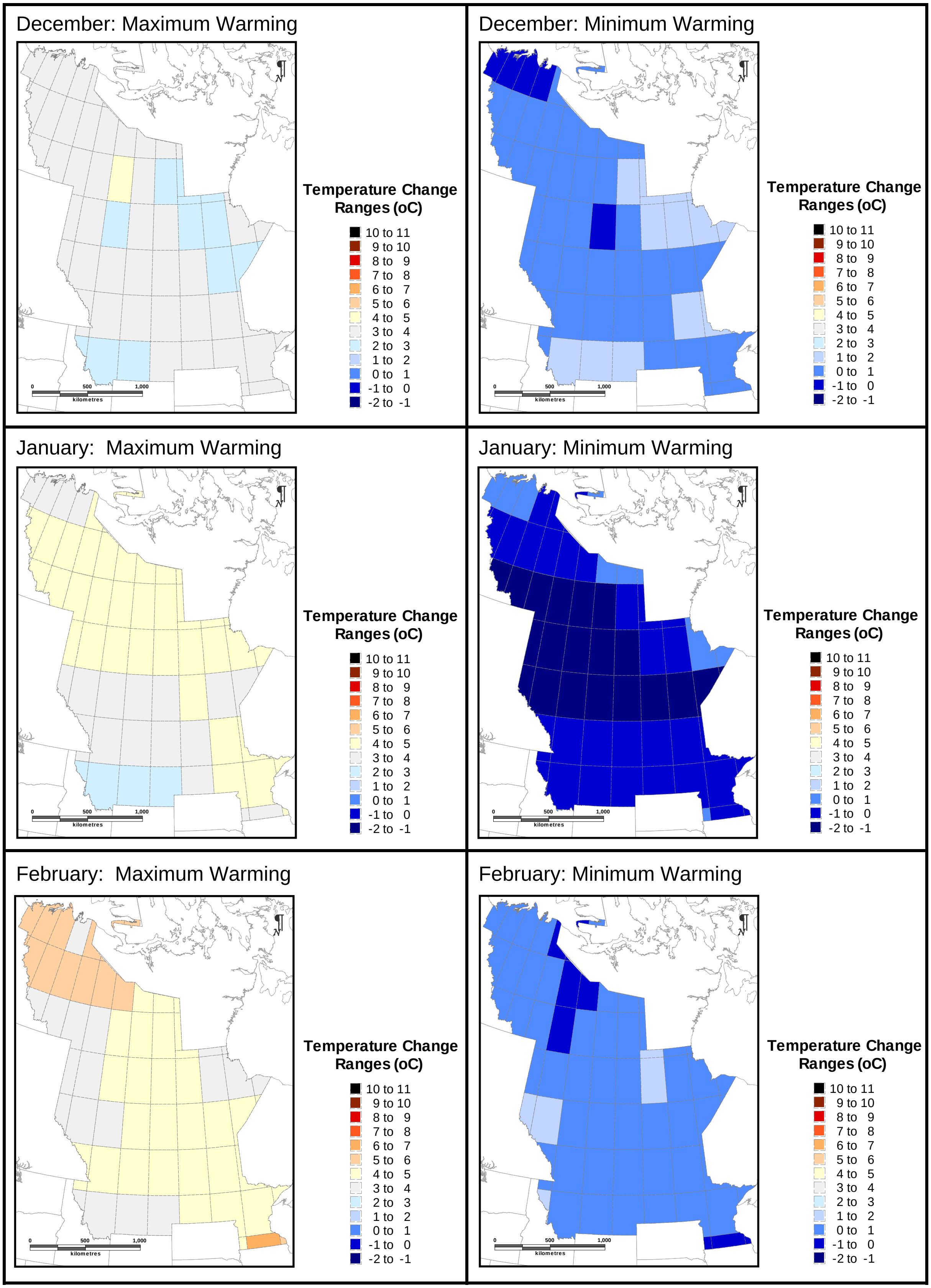

Figure 4-4: Projected Temperature Changes 2010-2039

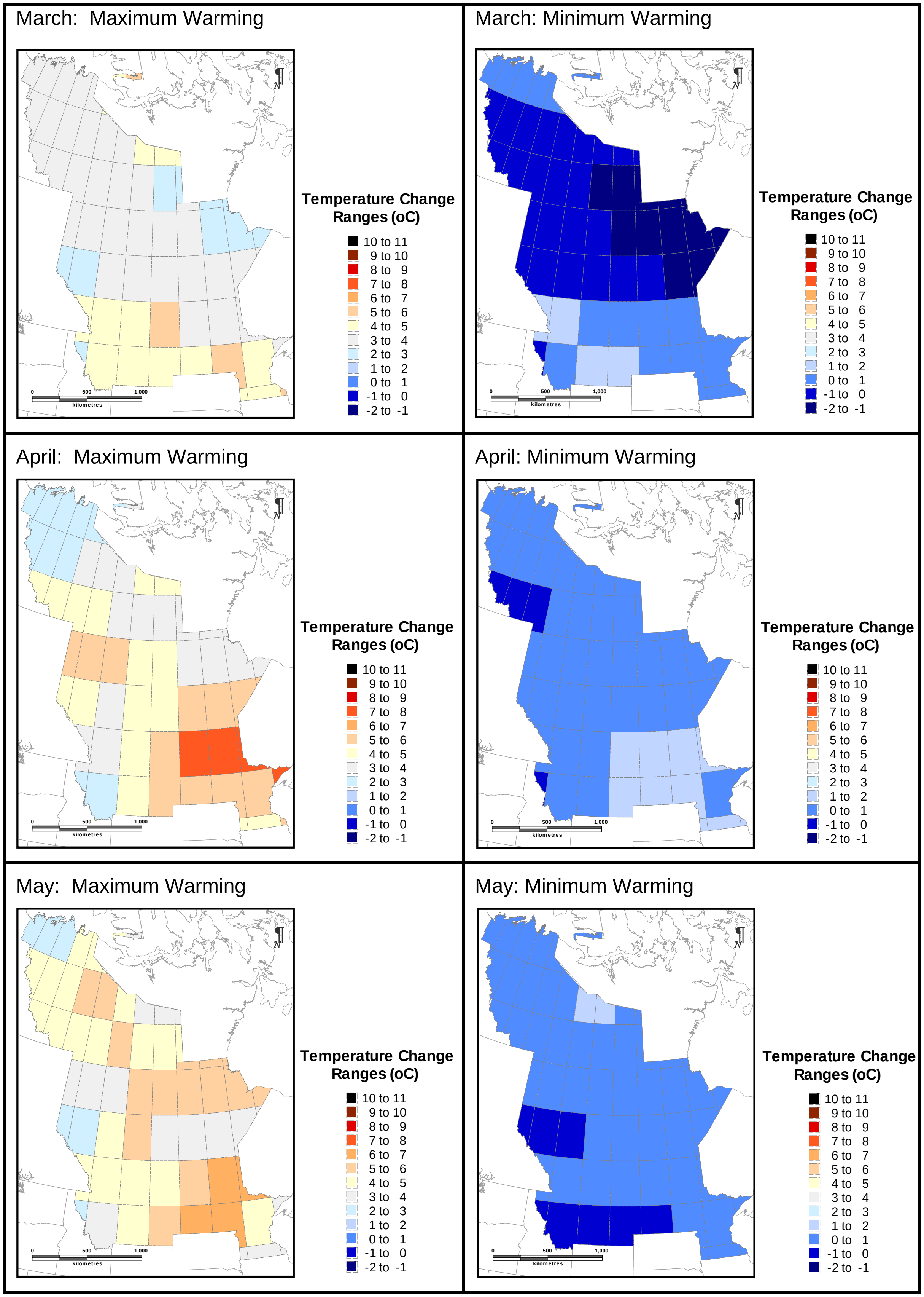

Figure 4-4 Cont'd: Projected Temperature Changes 2010-2039

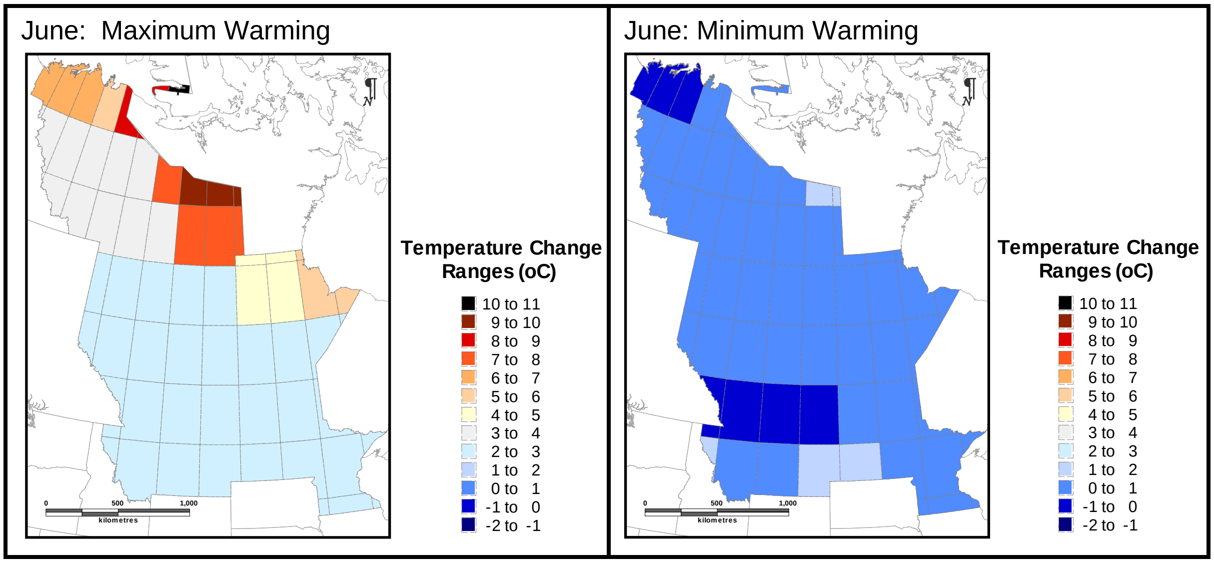

Figure 4-4 Cont'd: Projected Temperature Changes 2010-2039

Source: Raw data obtained from CICS; Analysis and map production by UMTIG

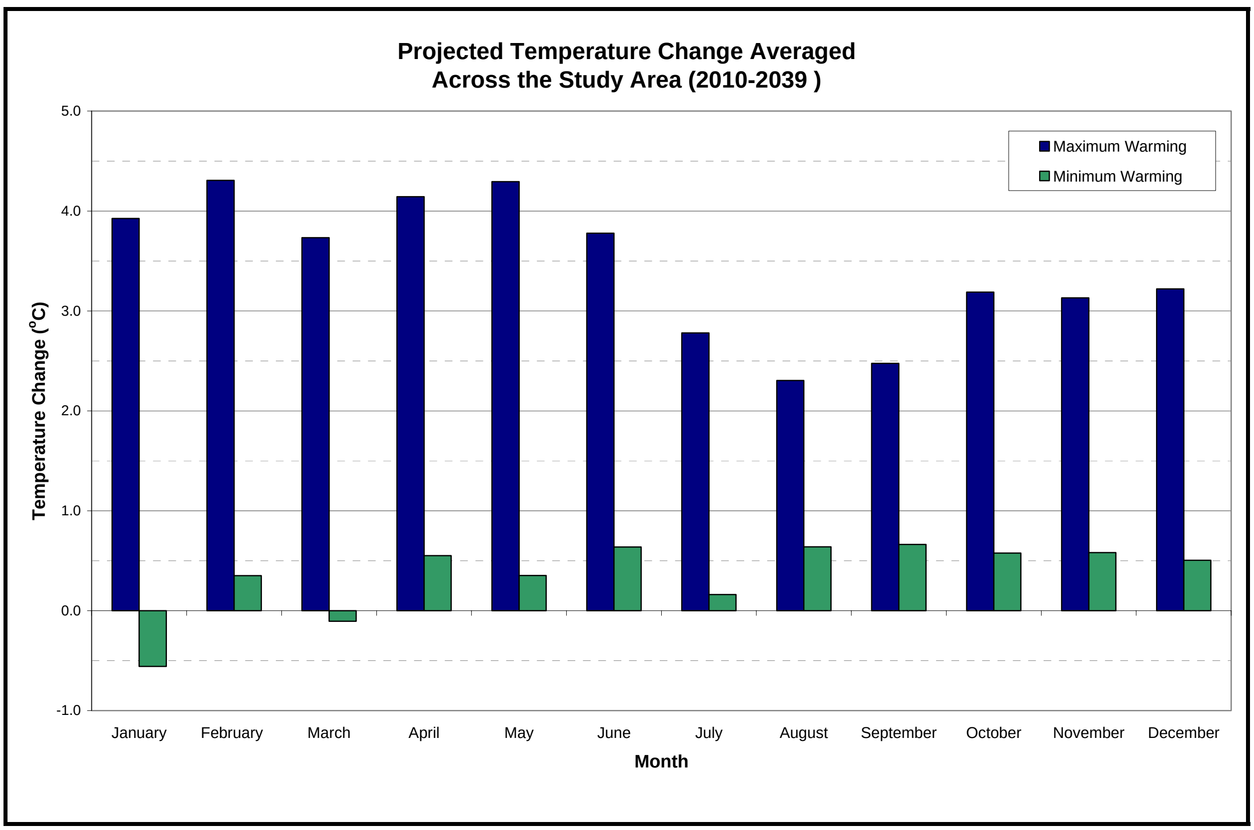

Figure 4-5: Average Projected Temperature Change (2010-2039)

Source: Raw data obtained from CICS; Analysis by UMTIG

5.0 TRUCK OPERATING COST MODEL

This chapter describes the development of the methodology to estimate truck cost impacts of seasonal weight limits in the prairie region. Changes in seasonal weight limits will affect truck payloads and hence productivity and truck operating costs. Truck cost impacts are developed using the "Operating Costs of Trucks in Canada – 2001" model, produced by Trimac Logistics Ltd. for Transport Canada.

5.1 MODEL DESCRIPTION

The Trimac model provides total truck operating costs per kilometer by province, truck configuration, body type, annual utilization, and profit margin. The model assumes that trucks are part of a fleet and that there is one origin-destination per trip. The following are cost components of the total truck operating costs (Trimac Logistics Ltd., 2001):

- Tractor variable costs (driver, fuel, repairs, cleaning, transport, tires)
- Tractor fixed costs (depreciation, licenses)
- Trailer variable costs (repairs, cleaning, transport, tires)
- Trailer fixed costs (depreciation, licenses)
- Insurance costs
- Administration and interest on working capital
- Interest financing equipment purchase
- Pickup and delivery
- Profit margin allowance

The approach to the development of the basic truck operating cost model for this research is to retain costs by truck configuration (i.e., five-axle tractor semitrailer or 3-S2, six-axle tractor semitrailer or 3-S3, and eight-axle tractor double trailer combination or 3-S3-S2) and annual utilization (i.e., 80,000 km, 160,000 km, or 240,000 km). Average or 'middle-of-the-road' cases are chosen for the remainder of the variables as described below:

- *Province* – Operating costs per kilometer for trucks in Manitoba generally represent a 'middle-of-the-road' value for the three Prairie Provinces, and are therefore used in the cost model. Costs in Saskatchewan are generally similar to costs in Manitoba, while costs in Alberta tend to be slightly higher. Discrepancies between the provinces are within 3 percent, regardless of the configuration or annual utilization. Manitoba truck operating costs are assumed to apply in Minnesota, North Dakota, and Montana.

- *Body type* – The Trimac model provides operating costs for the following body types:
  - 3-S2 (van, flat deck, liquid tanker, bulk dry tanker)
  - 3-S3 (van, flat deck)
  - 3-S3-S2 (van, flat deck, liquid tanker, bulk dry tanker)

For each configuration, operating costs per kilometer are averaged across body types.

- *Profit margin* – The Trimac model provides operating costs for three different operator profit margins:
    - 2.5 percent
    - 5 percent
    - 10 percent

  This research utilizes costs assuming a 5 percent profit margin. Increasing the profit margin to 10 percent roughly corresponds to a 5 percent increase in operating costs. Decreasing the profit margin to 2.5 percent roughly corresponds to a 2.5 percent decrease in operating costs.

Table 5.1 shows the basic truck operating cost model used in this research.

Table 5.1: Basic Truck Operating Cost Model (cents per km)

	Annual Utilization (km)		
Configuration	80000	160000	240000
3-S2	159.7	133.5	124.7
3-S3	179.9	154.9	146.5
3-S3-S2	208.0	170.2	157.7

5.2 ANALYTICAL FRAMEWORK

The analysis in this section extends previous research conducted by Montufar et al. (2000). Seasonal weight limit policies impact maximum GVWs, payload opportunities, and operating costs for each of the three truck configurations—by annual utilization, jurisdiction, road class, and season.

From the shipper/trucker perspectives, the payload and productivity effects of seasonal weight limits are key to the importance of a particular policy. If the seasonal effect on payloads and productivity is minimal (i.e., little increase/decrease in maximum payload and associated productivity), then the effect of a particular policy on trucking activity is probably also minimal. On the other hand, if the payload and productivity effects are large, then trucking activity can be substantially altered.

To help provide some perspective on the effects of the seasonal weight limit policies used in the region, a set of tables has been produced summarizing their effects on GVWs, payloads, and truck productivity. The tables are structured as follows:

- by truck configuration
- effective maximum GVW/payload (kg) by:
    - jurisdiction
    - road class
    - season

- annual utilization

Table 5.2 shows the maximum practicable (or effective) allowable GVW for each of the three truck configurations—by jurisdiction, road class, and season.

Table 5.3 shows how the maximum practicable GVW limits of Table 5.2 translate into typical maximum (practicable) payloads—by truck configuration jurisdiction, road class, and season. The typical maximum payload is the difference between the maximum effective GVW limit and the tare weight of the vehicle. The following assumptions about vehicle tare weights were made:

- 3-S2 tare weight 14,000 kg
- 3-S3 tare weight 17,000 kg
- 3-S3-S2 tare weight 20,500 kg

Tables 5.4 to 5.6 show the operating costs (per payload tonne-kilometer) of fully-loaded trucks—by configuration, jurisdiction, road class, and season—for three different annual utilizations (80,000 km, 160,000 km, and 240,000 km). These costs are calculated using the basic model shown in Table 5.1 and the typical maximum payloads shown in Table 5.3. The tables also show the percent change in costs for trucks operating under WWP and SWR. Note that the percent change values are constant for the three annual utilization cases.

5.3 EFFECTS OF WWP ON TRUCK OPERATING COSTS

5.3.1 Small Decrease in Truck Operating Costs Caused by WWP

The black cells in Table 5.7 indicate where WWPs effect only small decreases in truck operating costs per payload tonne-kilometer. For the purposes of this analysis, “small” is defined as an operating cost decrease of less than 5 percent. There is little incentive for truckers and shippers to change trucking activity much (e.g. shift the haulage from a basic period to a WWP period) where the operating cost savings are small. Examples of this type of effect/consequence are:

- Canadian primary highways for all trucks (except 3-S2s on Saskatchewan primary highways)
- All Canadian highways for 3-S3-S2s (except on Manitoba up-class highways)
- Interstate highways in North Dakota for all trucks
- State highways in North Dakota for 3-S3-S2s
- All highways in Montana for all trucks

5.3.2 Large Decrease in Truck Operating Costs Caused by WWP

The black cells in Table 5.8 indicate where WWPs effect large decreases in truck operating costs per payload tonne-kilometer. For the purposes of this analysis, “large” is defined as an operating cost decrease of greater than 20 percent. This type of effect provides truckers and shippers with large incentives to change trucking activity (e.g.

shift the haulage from a basic period to a WWP period). Examples of this type of effect/consequence are:

- Secondary highways in Saskatchewan for 3-S2s and 3-S3s
- Up-class (in winter) Manitoba B1 highways for all trucks

5.4 EFFECTS OF SWRs ON TRUCK OPERATING COSTS

5.4.1 Small Increase in Truck Operating Costs Caused by SWR

The black cells in Table 5.9 indicate situations where SWRs effect small (less than 5 percent) increases in truck operating costs per payload tonne-kilometer. Examples of this type of effect/consequence are:

- Spring 1 loading restrictions on non-Interstate highways in Montana for 3-S3s
- Spring 1 loading restrictions on non-RTAC highways in Manitoba for 3-S3-S2s
- Spring 1 loading restrictions on State highways in North Dakota for 3-S3-S2s
- Spring 1 loading restrictions on 10-ton highways in Minnesota for 3-S3-S2s

5.4.2 Large Increase in Truck Operating Costs Caused by SWR

The black cells in Table 5.10 indicate situations where SWRs effect large (greater than 20 percent) increases in truck operating costs per payload tonne-kilometer. Examples of this type of effect/consequence are:

- Down-class (in spring) Saskatchewan primary highways for 3-S3s and 3-S3-S2s
- Spring 1 and Spring 2 loading restrictions on 10-ton highways in Minnesota for all trucks except Spring 1 loading restrictions for 3-S3-S2s
- Spring 2 loading restrictions on non-RTAC highways in Manitoba for all trucks
- Spring 2 and Spring 3 loading restrictions on State highways in North Dakota for 3-S3s and 3-S3-S2s
- Spring 2 loading restrictions on Alberta primary highways for all trucks

Table 5.2: Maximum Practicable Allowable GVW

Truck Type: 3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter GVW	40500	41500	41500	41500	40700	40700	37400	40700	40700	40700	39428	N/A	39428	N/A	N/A	N/A
Basic GVW	39500	39500	34500	39500	39500	37500	34500	37500	34500	34500	36344	36344	36287	36287	36287	36287
Spring-1 GVW	36100	N/A	31900	34500	N/A	34300	33050	34300	33050	33050	34530	N/A	29489	N/A	34530	34530
Spring-2 GVW	31000	N/A	N/A	N/A	N/A	25545	23595	25545	23595	23595	32714	N/A	21672	N/A	N/A	N/A
Spring-3 GVW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	27215	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter GVW	47500	N/A	46500	N/A	47100	46100	41450	47100	46100	47100	46413	N/A	39917	N/A	N/A	N/A
Basic GVW	46500	46500	40000	46500	46500	44500	40000	44500	40000	40000	42694	40426	36287	40426	40426	40426
Spring-1 GVW	42400	N/A	38500	40000	N/A	40600	38275	40600	38275	38275	39065	N/A	32664	N/A	39493	39493
Spring-2 GVW	36250	N/A	N/A	N/A	N/A	30095	27170	30095	27170	27170	35436	N/A	23940	N/A	N/A	N/A
Spring-3 GVW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	29484	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter GVW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	62500	56500	62500	N/A	N/A	39917	N/A	N/A	N/A
Basic GVW	63500	62500	54500	62500	62500	56500	47630	56500	47630	47630	47854	47854	36287	55848	55848	55848
Spring-1 GVW	57700	N/A	51700	54500	N/A	55000	47630	55000	47630	47630	47854	N/A	36287	N/A	54034	54034
Spring-2 GVW	49000	N/A	N/A	N/A	N/A	40495	36595	40495	36595	36595	36287	N/A	32508	N/A	N/A	N/A
Spring-3 GVW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	29484	N/A	N/A	N/A	N/A	N/A

Table 5.3: Typical Maximum Payloads

Truck Type: 3-S2 (Assumed Tare Weight = 14000 kg)

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter Payload	26500	27500	27500	27500	26700	26700	23400	26700	26700	26700	25428	N/A	25428	N/A	N/A	N/A
Basic Payload	25500	25500	20500	25500	25500	23500	20500	23500	20500	20500	22344	22344	22287	22287	22287	22287
Spring-1 Payload	22100	N/A	17900	20500	N/A	20300	19050	20300	19050	19050	20530	N/A	15489	N/A	20530	20530
Spring-2 Payload	17000	N/A	N/A	N/A	N/A	11545	9595	11545	9595	9595	18714	N/A	7672	N/A	N/A	N/A
Spring-3 Payload	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	13215	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3 (Assumed Tare Weight = 17000 kg)

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter Payload	30500	N/A	29500	N/A	30100	29100	24450	30100	29100	30100	29413	N/A	22917	N/A	N/A	N/A
Basic Payload	29500	29500	23000	29500	29500	27500	23000	27500	23000	23000	25694	23426	19287	23426	23426	23426
Spring-1 Payload	25400	N/A	21500	23000	N/A	23600	21275	23600	21275	21275	22065	N/A	15664	N/A	22493	22493
Spring-2 Payload	19250	N/A	N/A	N/A	N/A	13095	10170	13095	10170	10170	18436	N/A	6940	N/A	N/A	N/A
Spring-3 Payload	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12484	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3-S2 (Assumed Tare Weight = 20500 kg)

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter Payload	N/A	N/A	N/A	N/A	N/A	N/A	N/A	42000	36000	42000	N/A	N/A	19417	N/A	N/A	N/A
Basic Payload	43000	42000	34000	42000	42000	36000	27130	36000	27130	27130	27354	27354	15787	35348	35348	35348
Spring-1 Payload	37200	N/A	31200	34000	N/A	34500	27130	34500	27130	27130	27354	N/A	15787	N/A	33534	33534
Spring-2 Payload	28500	N/A	N/A	N/A	N/A	19995	16095	19995	16095	16095	15787	N/A	12008	N/A	N/A	N/A
Spring-3 Payload	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8984	N/A	N/A	N/A	N/A	N/A

Table 5.4: Operating Cost per Payload Tonne-Kilometer and Percent Change for 80,000 km Annual Utilization

Truck Type: 3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter Cost	6.03	5.81	5.81	5.81	5.98	5.98	6.83	5.98	5.98	5.98	6.28	N/A	6.28	N/A	N/A	N/A
Basic Cost	6.26	6.26	7.79	6.26	6.26	6.80	7.79	6.80	7.79	7.79	7.15	7.15	7.17	7.17	7.17	7.17
Spring-1 Cost	7.23	N/A	8.92	7.79	N/A	7.87	8.38	7.87	8.38	8.38	7.78	N/A	10.31	N/A	7.78	7.78
Spring-2 Cost	9.40	N/A	N/A	N/A	N/A	13.83	16.65	13.83	16.65	16.65	8.54	N/A	20.82	N/A	N/A	N/A
Spring-3 Cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12.09	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter Cost	5.90	N/A	6.10	N/A	5.98	6.18	7.36	5.98	6.18	5.98	6.11	N/A	7.85	N/A	N/A	N/A
Basic Cost	6.10	6.10	7.82	6.10	6.10	6.54	7.82	6.54	7.82	7.82	7.00	7.68	9.32	7.68	7.68	7.68
Spring-1 Cost	7.08	N/A	8.37	7.82	N/A	7.62	8.45	7.62	8.45	8.45	8.15	N/A	11.48	N/A	8.00	8.00
Spring-2 Cost	9.34	N/A	N/A	N/A	N/A	13.73	17.68	13.73	17.68	17.68	9.76	N/A	25.91	N/A	N/A	N/A
Spring-3 Cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	14.41	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter Cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4.95	5.78	4.95	N/A	N/A	10.71	N/A	N/A	N/A
Basic Cost	4.84	4.95	6.12	4.95	4.95	5.78	7.67	5.78	7.67	7.67	7.60	7.60	13.18	5.88	5.88	5.88
Spring-1 Cost	5.59	N/A	6.67	6.12	N/A	6.03	7.67	6.03	7.67	7.67	7.60	N/A	13.18	N/A	6.20	6.20
Spring-2 Cost	7.30	N/A	N/A	N/A	N/A	10.40	12.92	10.40	12.92	12.92	13.18	N/A	17.32	N/A	N/A	N/A
Spring-3 Cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	23.15	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	-3.8	-7.3	-25.5	-7.3	-4.5	-12.0	-12.4	-12.0	-23.2	-23.2	-12.1	N/A	-12.4	N/A	N/A	N/A
Basic Cost	6.26	6.26	7.79	6.26	6.26	6.80	7.79	6.80	7.79	7.79	7.15	7.15	7.17	7.17	7.17	7.17
Spring-1 %	15.4	N/A	14.5	24.4	N/A	15.8	7.6	15.8	7.6	7.6	8.8	N/A	43.9	N/A	8.6	8.6
Spring-2 %	50.0	N/A	N/A	N/A	N/A	103.6	113.7	103.6	113.7	113.7	19.4	N/A	190.5	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	69.1	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	-3.3	N/A	-22.0	N/A	-2.0	-5.5	-5.9	-8.6	-21.0	-23.6	-12.6	N/A	-15.8	N/A	N/A	N/A
Basic Cost	6.10	6.10	7.82	6.10	6.10	6.54	7.82	6.54	7.82	7.82	7.00	7.68	9.32	7.68	7.68	7.68
Spring-1 %	16.1	N/A	7.0	28.3	N/A	16.5	8.1	16.5	8.1	8.1	16.4	N/A	23.1	N/A	4.1	4.1
Spring-2 %	53.2	N/A	N/A	N/A	N/A	110.0	126.2	110.0	126.2	126.2	39.4	N/A	177.9	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	105.8	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-14.3	-24.6	-35.4	N/A	N/A	-18.7	N/A	N/A	N/A
Basic Cost	4.84	4.95	6.12	4.95	4.95	5.78	7.67	5.78	7.67	7.67	7.60	7.60	13.18	5.88	5.88	5.88
Spring-1 %	15.6	N/A	9.0	23.5	N/A	4.3	0.0	4.3	0.0	0.0	0.0	N/A	0.0	N/A	5.4	5.4
Spring-2 %	50.9	N/A	N/A	N/A	N/A	80.0	68.6	80.0	68.6	68.6	73.3	N/A	31.5	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	204.5	N/A	N/A	N/A	N/A	N/A

Table 5.5: Operating Cost per Payload Tonne-Kilometer and Percent Change for 160,000 km Annual Utilization

Truck Type: 3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter Cost	5.04	4.85	4.85	4.85	5.00	5.00	5.71	5.00	5.00	5.00	5.25	N/A	5.25	N/A	N/A	N/A
Basic Cost	5.24	5.24	6.51	5.24	5.24	5.68	6.51	5.68	6.51	6.51	5.97	5.97	5.99	5.99	5.99	5.99
Spring-1 Cost	6.04	N/A	7.46	6.51	N/A	6.58	7.01	6.58	7.01	7.01	6.50	N/A	8.62	N/A	6.50	6.50
Spring-2 Cost	7.85	N/A	N/A	N/A	N/A	11.56	13.91	11.56	13.91	13.91	7.13	N/A	17.40	N/A	N/A	N/A
Spring-3 Cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10.10	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter Cost	5.08	N/A	5.25	N/A	5.15	5.32	6.34	5.15	5.32	5.15	5.27	N/A	6.76	N/A	N/A	N/A
Basic Cost	5.25	5.25	6.73	5.25	5.25	5.63	6.73	5.63	6.73	6.73	6.03	6.61	8.03	6.61	6.61	6.61
Spring-1 Cost	6.10	N/A	7.20	6.73	N/A	6.56	7.28	6.56	7.28	7.28	7.02	N/A	9.89	N/A	6.89	6.89
Spring-2 Cost	8.05	N/A	N/A	N/A	N/A	11.83	15.23	11.83	15.23	15.23	8.40	N/A	22.32	N/A	N/A	N/A
Spring-3 Cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12.41	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter Cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4.05	4.73	4.05	N/A	N/A	8.77	N/A	N/A	N/A
Basic Cost	3.96	4.05	5.01	4.05	4.05	4.73	6.27	4.73	6.27	6.27	6.22	6.22	10.78	4.81	4.81	4.81
Spring-1 Cost	4.58	N/A	5.46	5.01	N/A	4.93	6.27	4.93	6.27	6.27	6.22	N/A	10.78	N/A	5.08	5.08
Spring-2 Cost	5.97	N/A	N/A	N/A	N/A	8.51	10.57	8.51	10.57	10.57	10.78	N/A	14.17	N/A	N/A	N/A
Spring-3 Cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	18.94	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	-3.8	-7.3	-25.5	-7.3	-4.5	-12.0	-12.4	-12.0	-23.2	-23.2	-12.1	N/A	-12.4	N/A	N/A	N/A
Basic Cost	5.24	5.24	6.51	5.24	5.24	5.68	6.51	5.68	6.51	6.51	5.97	5.97	5.99	5.99	5.99	5.99
Spring-1 %	15.4	N/A	14.5	24.4	N/A	15.8	7.6	15.8	7.6	7.6	8.8	N/A	43.9	N/A	8.6	8.6
Spring-2 %	50.0	N/A	N/A	N/A	N/A	103.6	113.7	103.6	113.7	113.7	19.4	N/A	190.5	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	69.1	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	-3.3	N/A	-22.0	N/A	-2.0	-5.5	-5.9	-8.6	-21.0	-23.6	-12.6	N/A	-15.8	N/A	N/A	N/A
Basic Cost	5.25	5.25	6.73	5.25	5.25	5.63	6.73	5.63	6.73	6.73	6.03	6.61	8.03	6.61	6.61	6.61
Spring-1 %	16.1	N/A	7.0	28.3	N/A	16.5	8.1	16.5	8.1	8.1	16.4	N/A	23.1	N/A	4.1	4.1
Spring-2 %	53.2	N/A	N/A	N/A	N/A	110.0	126.2	110.0	126.2	126.2	39.4	N/A	177.9	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	105.8	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-14.3	-24.6	-35.4	N/A	N/A	-18.7	N/A	N/A	N/A
Basic Cost	3.96	4.05	5.01	4.05	4.05	4.73	6.27	4.73	6.27	6.27	6.22	6.22	10.78	4.81	4.81	4.81
Spring-1 %	15.6	N/A	9.0	23.5	N/A	4.3	0.0	4.3	0.0	0.0	0.0	N/A	0.0	N/A	5.4	5.4
Spring-2 %	50.9	N/A	N/A	N/A	N/A	80.0	68.6	80.0	68.6	68.6	73.3	N/A	31.5	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	204.5	N/A	N/A	N/A	N/A	N/A

Table 5.6: Operating Cost per Payload Tonne-Kilometer and Percent Change for 240,000 km Annual Utilization

Truck Type: 3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter Cost	4.71	4.53	4.53	4.53	4.67	4.67	5.33	4.67	4.67	4.67	4.90	N/A	4.90	N/A	N/A	N/A
Basic Cost	4.89	4.89	6.08	4.89	4.89	5.31	6.08	5.31	6.08	6.08	5.58	5.58	5.60	5.60	5.60	5.60
Spring-1 Cost	5.64	N/A	6.97	6.08	N/A	6.14	6.55	6.14	6.55	6.55	6.07	N/A	8.05	N/A	6.07	6.07
Spring-2 Cost	7.34	N/A	N/A	N/A	N/A	10.80	13.00	10.80	13.00	13.00	6.66	N/A	16.25	N/A	N/A	N/A
Spring-3 Cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9.44	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter Cost	4.80	N/A	4.96	N/A	4.87	5.03	5.99	4.87	5.03	4.87	4.98	N/A	6.39	N/A	N/A	N/A
Basic Cost	4.96	4.96	6.37	4.96	4.96	5.33	6.37	5.33	6.37	6.37	5.70	6.25	7.59	6.25	6.25	6.25
Spring-1 Cost	5.77	N/A	6.81	6.37	N/A	6.21	6.88	6.21	6.88	6.88	6.64	N/A	9.35	N/A	6.51	6.51
Spring-2 Cost	7.61	N/A	N/A	N/A	N/A	11.18	14.40	11.18	14.40	14.40	7.94	N/A	21.10	N/A	N/A	N/A
Spring-3 Cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	11.73	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter Cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.75	4.38	3.75	N/A	N/A	8.12	N/A	N/A	N/A
Basic Cost	3.67	3.75	4.64	3.75	3.75	4.38	5.81	4.38	5.81	5.81	5.76	5.76	9.99	4.46	4.46	4.46
Spring-1 Cost	4.24	N/A	5.05	4.64	N/A	4.57	5.81	4.57	5.81	5.81	5.76	N/A	9.99	N/A	4.70	4.70
Spring-2 Cost	5.53	N/A	N/A	N/A	N/A	7.88	9.79	7.88	9.79	9.79	9.99	N/A	13.13	N/A	N/A	N/A
Spring-3 Cost	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	17.55	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	-3.8	-7.3	-25.5	-7.3	-4.5	-12.0	-12.4	-12.0	-23.2	-23.2	-12.1	N/A	-12.4	N/A	N/A	N/A
Basic Cost	4.89	4.89	6.08	4.89	4.89	5.31	6.08	5.31	6.08	6.08	5.58	5.58	5.60	5.60	5.60	5.60
Spring-1 %	15.4	N/A	14.5	24.4	N/A	15.8	7.6	15.8	7.6	7.6	8.8	N/A	43.9	N/A	8.6	8.6
Spring-2 %	50.0	N/A	N/A	N/A	N/A	103.6	113.7	103.6	113.7	113.7	19.4	N/A	190.5	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	69.1	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	-3.3	N/A	-22.0	N/A	-2.0	-5.5	-5.9	-8.6	-21.0	-23.6	-12.6	N/A	-15.8	N/A	N/A	N/A
Basic Cost	4.96	4.96	6.37	4.96	4.96	5.33	6.37	5.33	6.37	6.37	5.70	6.25	7.59	6.25	6.25	6.25
Spring-1 %	16.1	N/A	7.0	28.3	N/A	16.5	8.1	16.5	8.1	8.1	16.4	N/A	23.1	N/A	4.1	4.1
Spring-2 %	53.2	N/A	N/A	N/A	N/A	110.0	126.2	110.0	126.2	126.2	39.4	N/A	177.9	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	105.8	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-14.3	-24.6	-35.4	N/A	N/A	-18.7	N/A	N/A	N/A
Basic Cost	3.67	3.75	4.64	3.75	3.75	4.38	5.81	4.38	5.81	5.81	5.76	5.76	9.99	4.46	4.46	4.46
Spring-1 %	15.6	N/A	9.0	23.5	N/A	4.3	0.0	4.3	0.0	0.0	0.0	N/A	0.0	N/A	5.4	5.4
Spring-2 %	-64.5	N/A	N/A	N/A	N/A	80.0	68.6	80.0	68.6	68.6	73.3	N/A	31.5	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	204.5	N/A	N/A	N/A	N/A	N/A

Table 5.7: Analysis of Small Decrease (< 5%) in Operating Cost per Payload Tonne-Kilometer Caused by WWP

Truck Type: 3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	[redacted]	-7.3	-25.5	-7.3	[redacted]	-12.0	-12.4	-12.0	-23.2	-23.2	-12.1	[redacted]	-12.4	[redacted]	[redacted]	[redacted]
Spring-1 %	15.4	N/A	14.5	24.4	N/A	15.8	7.6	15.8	7.6	7.6	8.8	N/A	43.9	N/A	8.6	8.6
Spring-2 %	50.0	N/A	N/A	N/A	N/A	103.6	113.7	103.6	113.7	113.7	19.4	N/A	190.5	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	69.1	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	[redacted]	[redacted]	-22.0	[redacted]	[redacted]	-5.5	-5.9	-8.6	-21.0	-23.6	-12.6	[redacted]	-15.8	[redacted]	[redacted]	[redacted]
Spring-1 %	16.1	N/A	7.0	28.3	N/A	16.5	8.1	16.5	8.1	8.1	16.4	N/A	23.1	N/A	4.1	4.1
Spring-2 %	53.2	N/A	N/A	N/A	N/A	110.0	126.2	110.0	126.2	126.2	39.4	N/A	177.9	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	105.8	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	-14.3	-24.6	-35.4	[redacted]	[redacted]	-18.7	[redacted]	[redacted]	[redacted]
Spring-1 %	15.6	N/A	9.0	23.5	N/A	4.3	0.0	4.3	0.0	0.0	0.0	N/A	0.0	N/A	5.4	5.4
Spring-2 %	50.9	N/A	N/A	N/A	N/A	80.0	68.6	80.0	68.6	68.6	73.3	N/A	54.1	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	204.5	N/A	N/A	N/A	N/A	N/A

Table 5.8: Analysis of Large Decrease (> 20%) in Operating Cost per Payload Tonne-Kilometer Caused by WWP

Truck Type: 3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	-3.8	-7.3	[redacted]	-7.3	-4.5	-12.0	-12.4	-12.0	[redacted]	[redacted]	-12.1	N/A	-12.4	N/A	N/A	N/A
Spring-1 %	15.4	N/A	14.5	24.4	N/A	15.8	7.6	15.8	7.6	7.6	8.8	N/A	43.9	N/A	8.6	8.6
Spring-2 %	50.0	N/A	N/A	N/A	N/A	103.6	113.7	103.6	113.7	113.7	19.4	N/A	190.5	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	69.1	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	-3.3	N/A	[redacted]	N/A	-2.0	-5.5	-5.9	-8.6	[redacted]	[redacted]	-12.6	N/A	-15.8	N/A	N/A	N/A
Spring-1 %	16.1	N/A	7.0	28.3	N/A	16.5	8.1	16.5	8.1	8.1	16.4	N/A	23.1	N/A	4.1	4.1
Spring-2 %	53.2	N/A	N/A	N/A	N/A	110.0	126.2	110.0	126.2	126.2	39.4	N/A	177.9	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	105.8	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-14.3	[redacted]	[redacted]	N/A	N/A	-18.7	N/A	N/A	N/A
Spring-1 %	15.6	N/A	9.0	23.5	N/A	4.3	0.0	4.3	0.0	0.0	0.0	N/A	0.0	N/A	5.4	5.4
Spring-2 %	50.9	N/A	N/A	N/A	N/A	80.0	68.6	80.0	68.6	68.6	73.3	N/A	54.1	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	204.5	N/A	N/A	N/A	N/A	N/A

Table 5.9: Analysis of Small Increase (< 5%) in Operating Cost per Payload Tonne-Kilometer Caused by SWR

Truck Type: 3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	-3.8	-7.3	-25.5	-7.3	-4.5	-12.0	-12.4	-12.0	-23.2	-23.2	-12.1	N/A	-12.4	N/A	N/A	N/A
Spring-1 %	15.4	N/A	14.5	24.4	N/A	15.8	7.6	15.8	7.6	7.6	8.8	N/A	43.9	N/A	8.6	8.6
Spring-2 %	50.0	N/A	N/A	N/A	N/A	103.6	113.7	103.6	113.7	113.7	19.4	N/A	190.5	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	69.1	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	-3.3	N/A	-22.0	N/A	-2.0	-5.5	-5.9	-8.6	-21.0	-23.6	-12.6	N/A	-15.8	N/A	N/A	N/A
Spring-1 %	16.1	N/A	7.0	28.3	N/A	16.5	8.1	16.5	8.1	8.1	16.4	N/A	23.1	N/A	[redacted]	[redacted]
Spring-2 %	53.2	N/A	N/A	N/A	N/A	110.0	126.2	110.0	126.2	126.2	39.4	N/A	177.9	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	105.8	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-14.3	-24.6	-35.4	N/A	N/A	-18.7	N/A	N/A	N/A
Spring-1 %	15.6	N/A	9.0	23.5	N/A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	N/A	[redacted]	N/A	5.4	5.4
Spring-2 %	50.9	N/A	N/A	N/A	N/A	80.0	68.6	80.0	68.6	68.6	73.3	N/A	54.1	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	204.5	N/A	N/A	N/A	N/A	N/A

Table 5.10: Analysis of Large Increase (> 20%) in Operating Cost per Payload Tonne-Kilometer Caused by SWR

Truck Type: 3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	-3.8	-7.3	-25.5	-7.3	-4.5	-12.0	-12.4	-12.0	-23.2	-23.2	-12.1	N/A	-12.4	N/A	N/A	N/A
Spring-1 %	15.4	N/A	14.5	24.4	N/A	15.8	7.6	15.8	7.6	7.6	8.8	N/A	[redacted]	N/A	8.6	8.6
Spring-2 %	[redacted]	N/A	N/A	N/A	N/A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	19.4	N/A	[redacted]	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	69.1	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	-3.3	N/A	-22.0	N/A	-2.0	-5.5	-5.9	-8.6	-21.0	-23.6	-12.6	N/A	-15.8	N/A	N/A	N/A
Spring-1 %	16.1	N/A	7.0	[redacted]	N/A	16.5	8.1	16.5	8.1	8.1	16.4	N/A	[redacted]	N/A	4.1	4.1
Spring-2 %	[redacted]	N/A	N/A	N/A	N/A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	N/A	[redacted]	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	[redacted]	N/A	N/A	N/A	N/A	N/A

Truck Type: 3-S3-S2

Jurisdiction	AB	SK			MB						ND		MN	MT		
Road Class	Primary	Primary	Secondary	*Prim-Sec in Spring*	RTAC	A1	B1	*A1-RTAC in Winter*	*B1-A1 in Winter*	*B1-RTAC in Winter*	State	Interstate	10-ton	Interstate	Primary	Secondary
Winter %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	-14.3	-24.6	-35.4	N/A	N/A	-18.7	N/A	N/A	N/A
Spring-1 %	15.6	N/A	9.0	[redacted]	N/A	4.3	0.0	4.3	0.0	0.0	0.0	N/A	0.0	N/A	5.4	5.4
Spring-2 %	[redacted]	N/A	N/A	N/A	N/A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	N/A	[redacted]	N/A	N/A	N/A
Spring-3 %	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	[redacted]	N/A	N/A	N/A	N/A	N/A

6.0 CLIMATE CHANGE IMPACTS ON SEASONAL WEIGHT REGULATIONS IN THE PRAIRIE REGION

This chapter synthesizes the results of earlier chapters for the purpose of characterizing issues that decision makers should consider in deliberations about seasonal weight limit regulation and how it might be affected by climate change over the next 25 years in the prairie region. It also provides illustrative examples of possible effects. The chapter is sub-divided into three sections: (1) the time dimension of seasonal weight limits; (2) highway routing and network questions; and (3) commodity considerations.

6.1 THE TIME DIMENSION OF SEASONAL WEIGHT LIMITS

This research concludes that within the foreseeable future for the prairie region, the principal material effects of the warming trend anticipated by the climate change models investigated could be:

(a) A possible shortening of the WWP period—maybe by starting later and/or ending earlier. There is no indication that as a result of climate change, the WWP period would not take place, nor that the impacted geographical scope of the network would be materially altered.

(b) A bringing-forward of the SWR periods. There is already evidence of this, but it appears to reflect more rational condition-based regulatory practices than climate change impacts. Bringing bans forward in time will not necessarily shorten them. As with WWPs, there is no indication of a material change in the geographical scope of the road network requiring SWRs.

Taking these two effects together means that in the 25-year time line of interest to this research, the most important effect of warming could be a shortening of the time period over which WWPs apply, a speeding-up of when SWRs are applied, and an increasing of the total time period when seasonal weight limits do not apply at all (i.e., later and/or shorter periods of WWPs, and earlier periods of SWRs). In other words, the principal effect of change on seasonal weight limits would not be the termination of their occurrence, but a change of their timing and duration (for WWPs, probably detrimental to certain groups, and for SWRs, probably beneficial to certain groups).

In addition, some literature suggests that a warming trend could lead to an increase in the frequency of freeze-thaw cycles in the region. Depending on the significance of this phenomenon, seasonal weight limits could also be impacted by it.

Irrespective of these possibilities, the rapid adoption and implementation of advanced technologies and analytical procedures by all agencies in the region are facilitating more rational, condition-based approaches to regulating seasonal weight limits. These technological improvements seem to be masking any possibility of minor climate change impacts which may be experienced in the short term.

6.2 HIGHWAY ROUTING AND NETWORK ISSUES

Except for Montana and interstate highways in North Dakota, all regional highways are subject to WWPs of varying levels, types, start times, end times, and durations—with differing impacts on different vehicles and their payloads. These are discussed in detail in Chapter 3 and Chapter 5.

It is unlikely that this very wide geographical scope of coverage of WWPs will decrease due to any feasible climate change-induced warming trend identified in this research. What is likely and indeed is already happening in most jurisdictions in the region is that the regulation of WWPs is increasingly "smart" (e.g., condition-based). In as little as the past 5 years, major applications of advanced technologies have been developed and introduced to monitor/sense freezing/frozen road conditions, advise decision-makers in real-time about the onslaught/decline of the frozen state, evaluate appropriate regulation changes (i.e. add/subtract particular roads or areas from a WWP state, place/remove WWPs earlier), and share this information with the trucking industry users of the highway network (through internet-based information systems). These technological developments and the smart regulation they have permitted will be the driving forces behind changes in WWP policy--much more than any trend in warming which might be experienced over the forseeable future in the region.

As illustrated in Figure 3-2, there is also a very wide and extensive network of regional highways subject to SWRs. Spring weight restrictions are particularly prevalent on secondary highways. Few major RTAC routes in Canada or major state or interstate routes in the U.S. are subject to spring bans. This is because the need for banning has been "designed out" of the road, or the lack of bans has been generally accepted as “the cost of doing business”.

As with WWPs, it is the temporal nature of SWRs rather than their geographical scope of coverage that is potentially more vulnerable to the effects of climate change. But also as with WWPs, the region's SWR regulation systems are becoming rapidly smarter with the application of advanced technologies and analytical tools—and this increasing smartness will no doubt suppress any foreseeable climate change impact.

In the consideration of vulnerable routes to climate change effects on seasonal weight limits, it is also fact that throughout the region, the secondary highway network is becoming less and less (relatively) significant to regional trucking and related economic activities. This is caused by continuing trends towards centralization of population and economic activities at fewer major centers, and the ever-increasing size of rural farming activities with the related declining relevance of certain lower-class, weight-constrained highways. This is evident in stable or declining traffic volumes on certain secondary/tertiary highways. It is also evident on certain highways in some jurisdictions in the abandonment and/or downgrading of the riding surface to a gravel base capable of withstanding higher loads than thin pavements.

6.3 COMMODITY CONSIDERATIONS

Key to the understanding of the vulnerability of freight movements to seasonal weight restrictions is the question of commodity density. Conventional industrial wisdom indicates that at a commodity density value of between 250 to 333 kilograms per cubic meter (about 15 to 20 pounds per cubic foot), normal transportation operations including trucking shift from being a cubic payload to a weight payload. Thus for example, water—with a density of 1000 kilograms per cubic meter (62 pounds per cubic foot) is a weight-out commodity—and therefore potentially vulnerable to weight limits themselves, and of course seasonal variations in them. By contrast, feathers are a cubic commodity, and not vulnerable to either basic or seasonal weight limits.

Throughout the region, there is a demand to move large quantities of low-value, dense (weight-out) commodities associated with three key regional industries such as forestry, petroleum, and agriculture, both intra- and inter-jurisdictionally. The research indicates (see Table 2.2) that these three types of commodities comprise the majority of freight tonnage moved by truck in the region. The origin-destination characteristics of these freight movements are such that some portion of these shipments occurs on the primary highway network and some portion on the secondary highway network. The weight limits governing trucks hauling these commodities are fundamental determinants of trucking productivity and related payload handling costs for these products, and the regional economic prospects for their production and distribution. The research indicates (see Chapter 5) that the economic impacts of seasonal weight limits are particularly important on the secondary highway network in the region.

Movement of raw forest products in frozen winter periods is particularly significant to Minnesota, Manitoba, Saskatchewan and Alberta. Many of these products must be originally accessed in bush territory (largely serviced by secondary roadways) when it is either under a frozen condition (winter) or relatively dry (later summer, fall). Seldom can they be accessed during thawing periods. As such, they are not significantly impacted by SWRs. Coupled to the WWP issue has been the emergence of high weight, specially-permitted, and in some cases the use of advanced technology operations to raw forest product movements in the three prairie provinces.

Certain fertilizer movements are important to the agricultural industry in the region, and can be importantly impacted by SWRs. This is because these products are often moved in the spring period, probably starting on primary, non-banned routes, but in many cases destined for locations along secondary and even tertiary roads, which are often subject to SWRs.

7.0 CONCLUDING REMARKS

The purpose of this research was to characterize potentially significant impacts which could result from climate change-induced modifications to seasonal weight limits applied to commercial truck operations on prairie region highways. Its time horizon is 25 years, representing the pragmatic engineering life of most highway infrastructure in the region. Potential impacts of climate change on the very limited mileage of prairie region highways built in areas of intermittent permafrost are beyond the scope of this work, as are considerations involving winter/snow/ice roads. The research builds upon previous work conducted by the authors about 5 years ago, as reported in Montufar et al. (2000), and attempts to minimize duplication of that work

Five matters were addressed in the research: (1) what does the literature say about the subject?; (2) how has the seasonal weight regulatory situation in the region changed over the past 5 years?; (3) what climate change scenarios might the region face in the coming 25-year period?; (4) how, where, and to what extent do seasonal weight limit regulations impact truck operating costs?; and (5) how might prairie region trucking be vulnerable to changes in seasonal weight limits that might arise from climate change issues? This chapter synthesizes the findings of this work.

Principal conclusions and observations of the research are:

- The literature and related research concerning the subject matter is very limited.

- All highway agencies in the region have moved in a variety of ways to much more condition-based seasonal weight regulation over the past few years—using a wide range of monitoring and sensing technologies, and information sharing with the truck industry users of their respective highway systems. This movement is dominating the regulatory changes being experienced throughout the region in this recent time period. Indications are that this expansion and adoption of "smart" regulation is rapidly replacing "prescriptive command and control" regulatory practices—independent of climate change considerations.

- The analysis of climate change (temperature only) scenario models for the region over the next 25 years suggests that the study area will not experience cooling, but could experience a minimum of ½ to one degree centigrade warming (or more). It is reasonable to assume that this effect would occur over time, and in the next 10 or 15 or more years, nothing much of this would be noticed or influential on seasonal weight limit policies in the region.

- The analysis of truck operating costs in the region suggests that seasonal weight regulations have little effect on the productivity of large trucks operating on the primary highway network. Operating costs intensify for operations on secondary highways and smaller truck configurations. WWPs significantly affect large truck operations on secondary highways. The effects of SWRs are most significant for large trucks operating on secondary highways.

- The amount of possible warming due to climate change in the region and in the time period under consideration will not prevent the occurrence of freezing conditions (and therefore the application of winter weight premiums), nor the thawing of those conditions (and therefore the application of spring weight restrictions). However, the timing and duration of the freezing and thawing circumstances could change—principally in the direction of postponing the start of the winter, shortening its length, and bringing ahead in time the start of spring thaw, as well as its ending. These effects would most obviously impact those regional trucking activities which benefit from WWPs. For example, they might dictate that the movement of raw forest products would have to be conducted in a shorter time period, and that other movements that benefit from WWPs would either have to occur over a quicker time period, or lose the incremental benefit of the shorter period of WWP application. The spring thawing effect would appear principally to shift the time of the SWR impact, and not its scale of impact in any obviously negative way. Indeed, for some commodities, such as fertilizer, earlier spring banning could be beneficial to the region's economy by removing the bans sooner.

Smart, technology-driven approaches to seasonal weight regulation will have much greater and positive effects on regional trucking than any negative impacts that might arise from climate change-induced effects during the study period in the region. While these technological approaches are not onto themselves a climate change adaptation strategy per se, they act as such—and will be much more influential than climate change issues over regional truck productivity in the coming foreseeable time period.

As a final comment, based on discussions and insights gained by the team in this and related projects, three other factors are at work in the prairie region counteracting potentially negative implications of climate change on seasonal weight limits. These are: (1) greater concern for freight and trucking information systems to facilitate more rational highway planning, design, operations, asset management, and compliance assurance; (2) testing, evaluation and introduction of new, more road-friendly trucking equipment; and (3) increasing concern for rationalized road pricing systems. All of these together result in a more technologically-sound approach to regulating truck weights and dimensions, including seasonal weight limits.

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