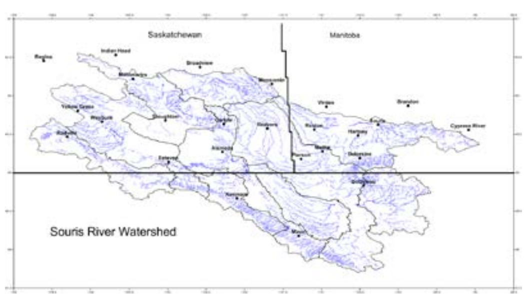
# Climatic Extremes and the Energy Sector's Vulnerability: Now and in the Future - Focus on the Canadian Portion of the Souris River Watershed: A Literature Review

Prepared for Environmental Systems Assessment Canada Ltd as part of the Natural Resources Canada Adaptation Platform Energy Working Group

By V. Wittrock
Saskatchewan Research Council
Environment Division

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Oil Pump Jack surrounded by water in Souris River Watershed. 28 May 2015 (Photo by: I. Radchenko, Saskatchewan Research Council)

Boundary Dam Power Generating Station. 15 May 2010 (Photo by: T. Welter, SaskPower)

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## Summary

The electrical power and oil and gas sectors are an important component of the Saskatchewan and Canadian economies but the overall impact of extreme climate changes to these industries is not well understood or documented. The purpose of this report is to determine what possible future adaptation actions the energy sector can do both locally and nationally to capitalize on the potential opportunities and reduce their risks for a changing climate.

The Canadian side of Souris River watershed was chosen to be the case study region because it contains both of these industries and has had numerous climatic extremes in the past. While past events assist with determining what possible impacts will occur in the industries, developing adaptation actions based on historic climatic and hydrologic averages does not necessarily equate to what will occur in the future. This is due to the climates' uncertainty and variability as well as the industries' requirement for long-term assets and planning.

This reports utilizes previously published literature to examine future climate and projected extremes. In the Souris River watershed, on average, the region will be warmer for all seasons with more precipitation. In terms of projected extremes, the number of hot days, those with temperatures greater than 30°C, will increase. On the precipitation side, the number of 1, 3 and 7-day precipitation extremes will also increase. It should be noted that climate change models and value-added data keep evolving and it is imperative that the most up-to-date information is utilized, when possible.

The historic weather and climate events tended to be the motivators of change in both industries. For example, the flooding that occurred in the 2010 to 2015 period resulted in negative impacts to the oil rigs and equipment. This posed potential risks to the workforce, potential public health and safety concerns and resulted in the oil companies examining alternative procedures and making modifications to their risk management plans. An example of a lesson learned by electrical power industry relates to a past drought event in the 1980s when the adaptation strategy implemented a non-traditional water source for usage in electrical production because the traditional source of water was not sufficient.

In general, the oil and gas industry believes they are fairly well situated to adapt to the changing climate with some modifications to their future development such as developing future oil rigs above the flood prone region. The provincial electrical power industry also in general believes it is able to deal with future climatic issues at the power plants. The main source of concern is the infrastructure to supply power to the customers after the power has been generated.

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## Acronyms:

% - Percentage
°C – Degrees Celsius
°F – Degrees Fahrenheit
AR4 – IPCC Fourth Assessment Report
AR5 – IPCC Fifth Assessment Report
CAPP – Canadian Association of Petroleum Producers
CGCM3 - Canadian Global Climate Models
CMIP5 - Coupled Model Inter-comparison Project, 5$^{th}$ phase
CRCM - Canadian Regional Climate Model
DEM – Drought & Excessive Moisture
DJF – December, January, February
GCMs – General Circulation Models
GFDL - Geophysical Fluid Dynamics Laboratory
GHG – Greenhouse Gas Emissions
GRI – Global Reporting Initiatives
HADCM3 - Hadley Centre for Climate Prediction and Research
IJC – International Joint Commission
IPCC – Intergovernmental Panel on Climate Change
JJA – June, July, August
MAM – March. April, May
MB – Manitoba
ND – No Date
NRTEE – National Round Table of the Environment and the Economy
PCIC – Pacific Climate Impacts Consortium
RCM – Regional Climate Model
RCP – Representative Concentration Pathway
RF – Radiative Forcing
RSI – Risk Sciences International
SK – Saskatchewan
SON – September, October, November
SRES – Special Report on Emission Scenarios of the IPCC
WECC – Western Electricity Coordinating Council
WMO – World Meteorological Organization
WSA – Water Security Agency (Saskatchewan)

# Introduction, Objective and Methods

The energy sector is an important component of the Saskatchewan and Canadian economy. The Souris River Watershed (Figure 1) contains many industries associated with the energy sector including oil and gas, and coal-fired electrical generation plants. Each of these industries has varying degrees of susceptibility to extreme climatic events including drought and excessive moisture situations.

Climate extremes can result in both increasing risks and opportunities for the oil and gas and electrical generation industries. These climate-related risks are associated with extreme weather events, changes in seasonal temperatures, and changes to water availability (PRI Project 2009). Extreme drought and excessive moisture (DEM) conditions are frequent in the Canadian Prairies. It is also not uncommon for the Prairies to have both of these events in the same year and in close proximity to each other. DEM events can be multi-year occurrences which can add to the impacts they have on the industries as they adapt to the impacts of the DEM occurrences (Wittrock 2012).

## Objectives, Study Area and Methods

The objectives of this report are to:

- Analyze future extreme climatic events including drought and excessive moisture conditions
- Determine and analyze risk and adaptation actions taken by the oil and gas industry and regarding thermal power generating stations in relation to extreme climatic events including extreme wet and dry periods.
- Explore the drivers or motivators of these adaption actions
- Describe the risks and opportunities resulting from the adaptation actions taken
- Document the lessons learned from actions undertaken and assess what could have been done differently.

The study area chosen for this project is the Canadian side of the Souris River Watershed (Figure 1). This area contains two major energy sectors: oil production in the region which has been expanding recently with large scale development of the Bakken Formation (Figure 6) and two major power generating stations (Figure 11).

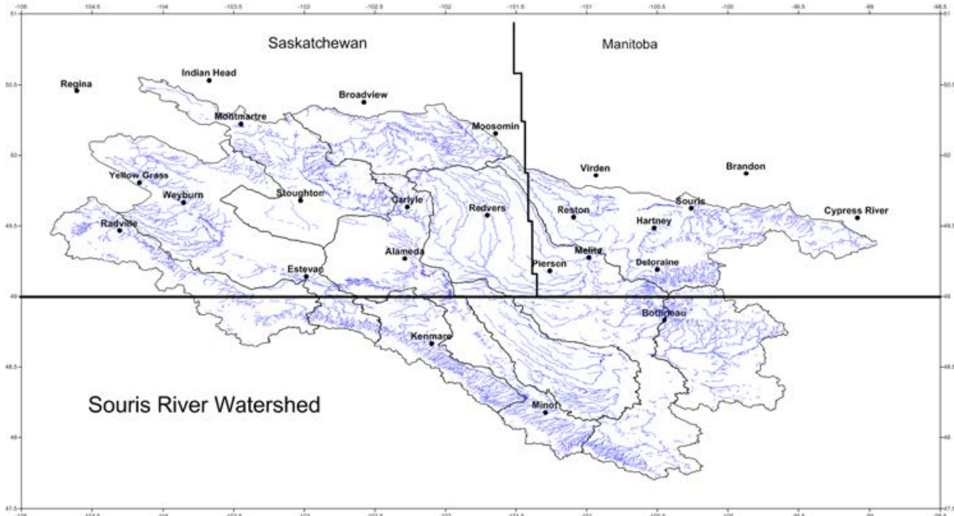


**Figure 1 Souris River Watershed (base map and stream flow data provided by Natural Resources Canada (NRCan) and International Joint Commission (IJC) (p. comm. 2015)).**

This report utilizes information attained in Wittrock (2016) and Terton and Parry (2016). Wittrock (2016) examines the historic climate of the Souris River watershed over the 1901-2014 period. Terton and Parry (2016) used an interview process of representatives from the energy sector and local and provincial governments to understand how extreme weather events impact their operations, what actions were taken to reduce the impacts and the risk or opportunities that resulted from these actions. The survey also examined the motivations or drivers for actions taken to reduce current and projected risks plus any lessons that were learned thus increasing the capacity of both industry and governments to plan for and manage future extreme events. This report also utilized journal articles, industry reports, government reports, and other sources including personal communication with industry experts. It was discovered that much of the available information is only available on either the national or international scale therefore relating it to a smaller watershed such as the Souris River watershed was a challenge. Where possible, information applicable to the Souris River watershed was gleaned out of the national database. In addition, the Souris River watershed is an international watershed, therefore information from the United States was incorporated. Usage of Global Reporting Initiatives (GRI) was suggested as a possible resource for this project. Currently, GRIs deal mainly with greenhouse gas emissions (GHG) and GHG is beyond the scope of this project. An advisory committee consisting of industry and government personnel was established for this project to assist with targeting experts in the industry for specific information in the study area

## Overview of the Souris River Watershed

The Souris River watershed is 61,100 km$^2$ in size and is located in two Canadian provinces (Saskatchewan and Manitoba) and one US State (North Dakota). The water in this watershed flows from Saskatchewan south to North Dakota and then northwards into Manitoba and eventually joins with the Assiniboine System and ultimately flows into Lake Winnipeg. The Souris River valley is relatively flat and shallow with extensive cultivation (US Corp of Engineers 2012) and is classified as semi-arid prairie (West Souris River Watershed Planning Authority ND).

Water availability in the Souris River watershed can be considered at risk as shown by Environment Canada based on the year 2009. The water availability indicator (Figure 2) is calculated by dividing water demand by water supply and does not include water withdrawn from lakes and groundwater (Environment Canada 2013).

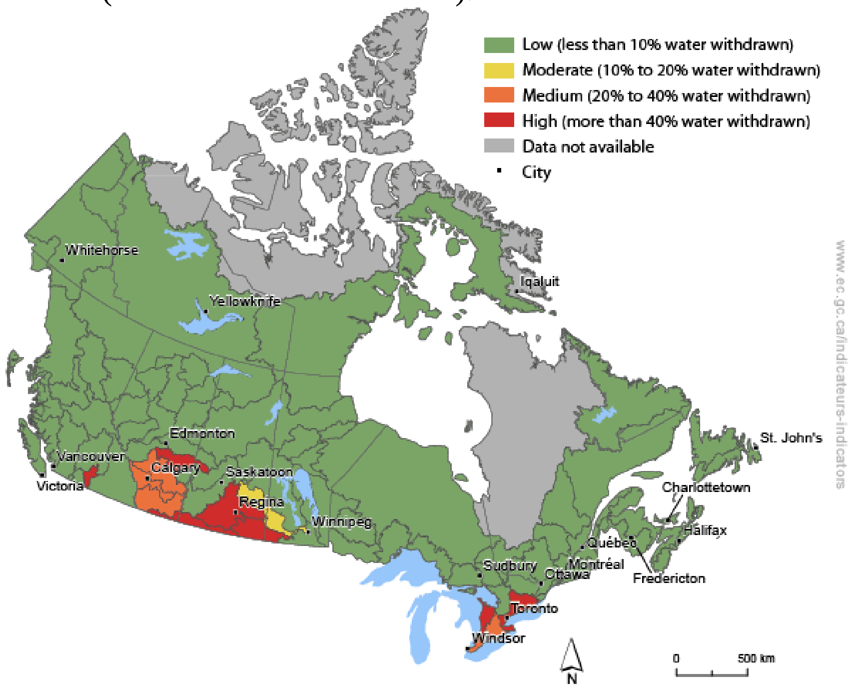


**Figure 2 Water Availability Indicator (Environment Canada 2013)**

The Souris River system has numerous dams and reservoirs (Figure 3). The Rafferty and Boundary Dams as well as the Alameda Dam are the largest. The dams have multiple uses including downstream flood control and assisting with low water years. The Rafferty and Boundary Reservoirs' other main use is the cooling water source for the electrical generation process at the Boundary Dam and Shand Power stations.

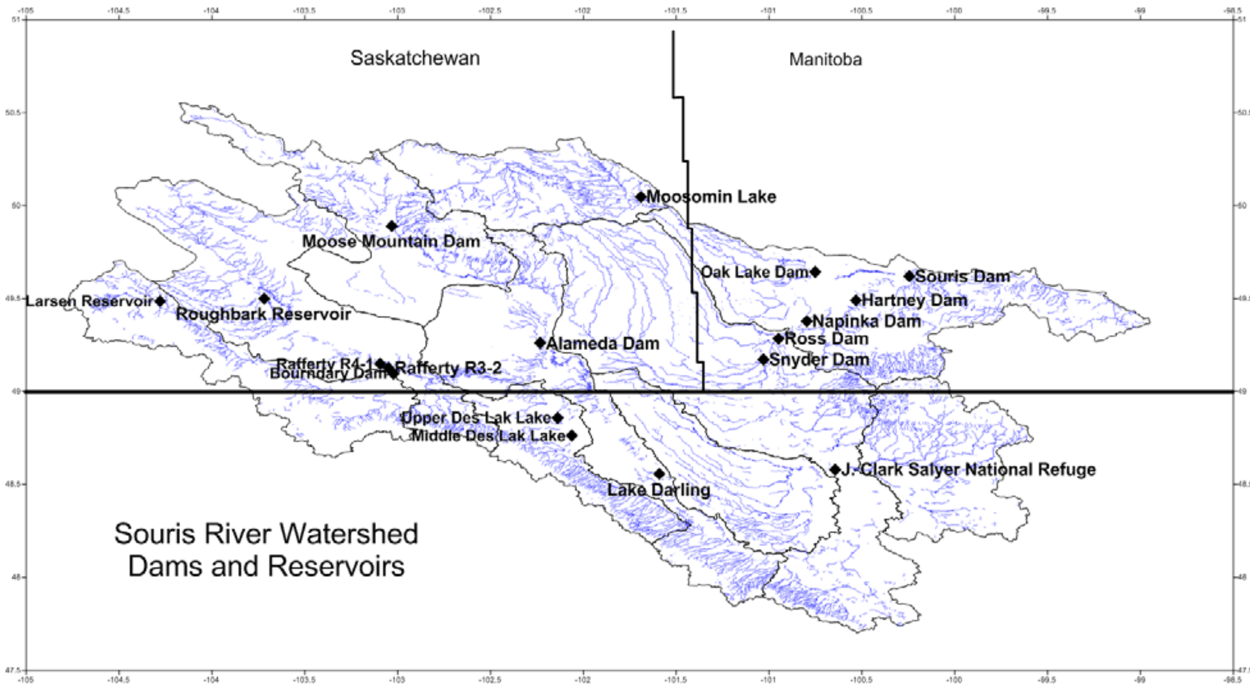


**Figure 3 Location of Major Dams and Reservoirs along the Souris River (base map and stream flow data provided by Natural Resources Canada (NRCan) and International Joint Commission (IJC) (p. comm. 2015) and Dam and Reservoir locations provided by West Souris River Watershed Planning Authority ND)**

The timing of spring snowmelt maximum floods in southern Manitoba during the 1974 to 2003 period has occurred earlier on some of the watersheds or has not changed on the statistically significant level. The magnitude of the spring snowmelt maximum floods in the same region has no statistically significant trend over the same 1974-2003 period (Cunderlik and Ouarda 2009). Continued changes in climatic conditions, like increased temperatures, will lead to further changes in snow cover and timing of spring snow melt which in turn may lead to a decline in winter snow storage (RSI 2012). These river flow changes may require modifications to infrastructure and flow strategies (RSI 2012).

River flows in the Souris River are highly variable ranging from near zero in the 1930s, early 60s, 80s and 2000s to peak flows in the 1950s, 70s, 90s and 2010s. The long term historic peak river flow near Sherwood, North Dakota, located just south of the Canada/US border (48° 59' 24" N 101° 57' 28"W (Environment Canada 2015)), occurred in the mid-1970s when an annual natural flow rate of over 600,000 dam$^3$ was recorded (Figure 4). This peak flow was exceeded in 2011 when over 1,550,000 dam$^3$ was measured. The latest peak flow was different from previous years because in 2011 it was mainly due to multiple extreme rainfall events in late May and June (Wittrock 2016; Hopkinson 2011) (Figure 5) causing the river to exceed its full supply level.

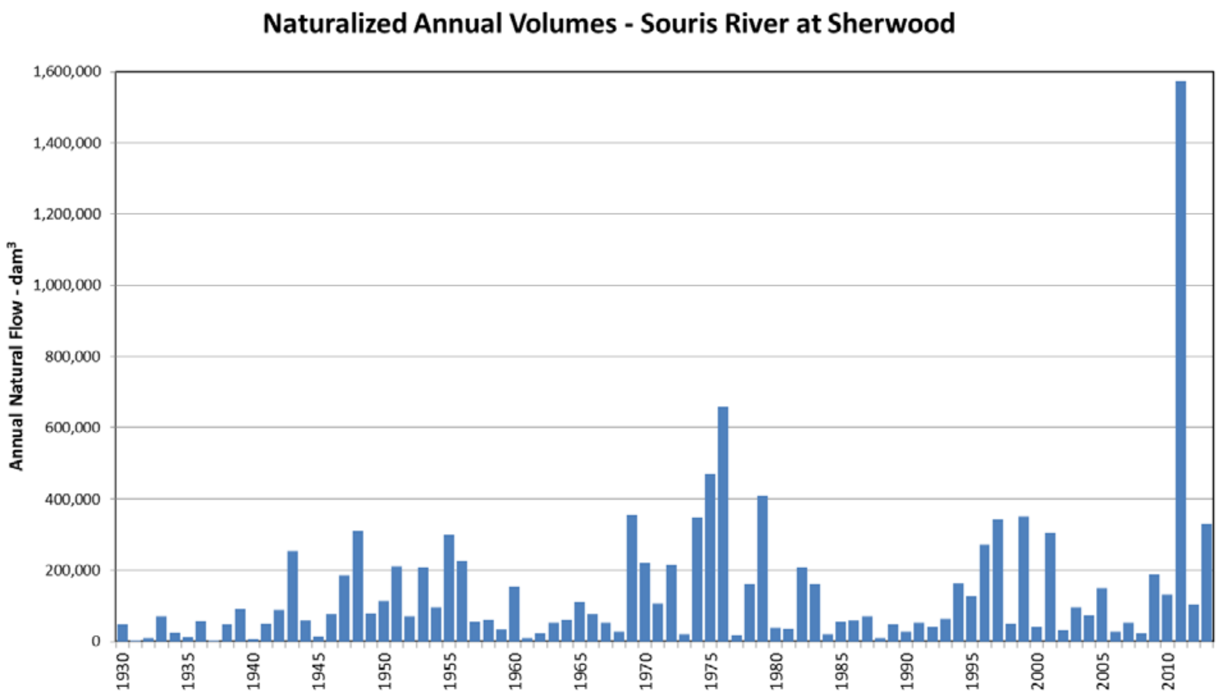


**Figure 4 Naturalized Annual Flow Volume of the Souris River (1930-2013) at Sherwood (WSA p. comm. 2015).**

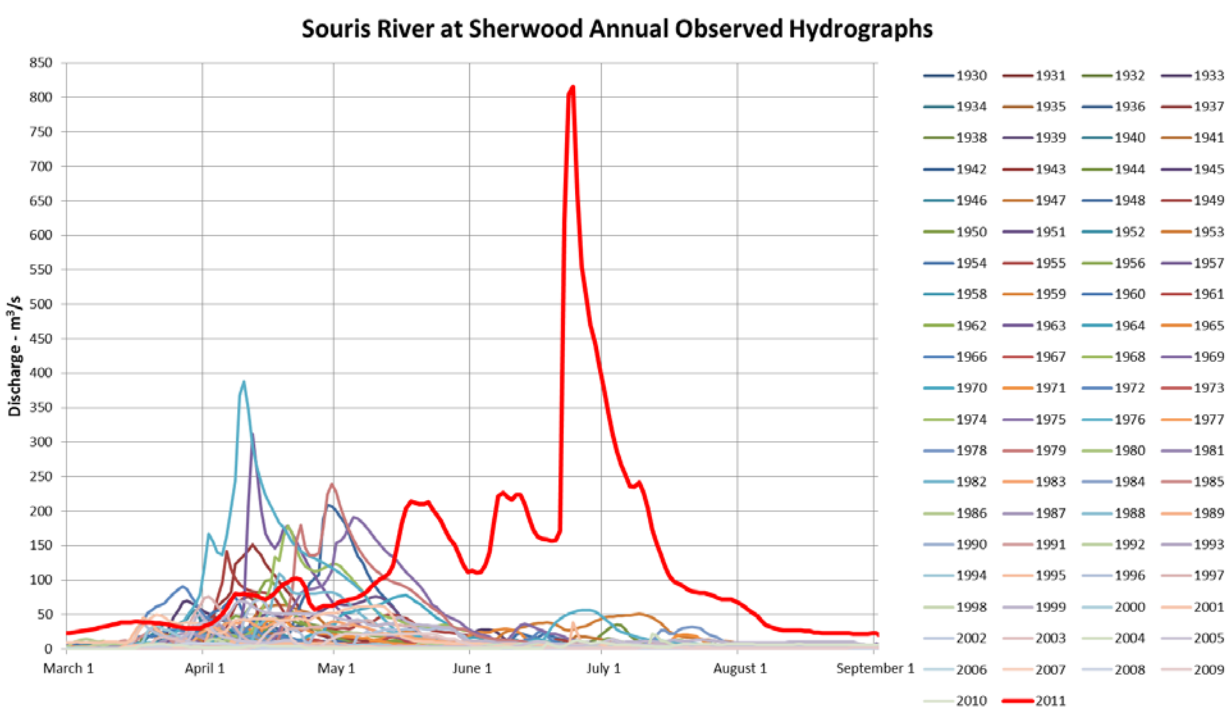


**Figure 5 Discharge on Souris River for March to September (1930-2011) (WSA p. comm. 2015)**

The three major reservoirs inflow volume in 2011 (Appendix 2) was double to nearly triple the 1:500 volume levels. In addition the 2011 volume of water more than eight times its maximum storage level (Boundary Reservoir). This further shows that the extreme rainfall occurrence in 2011 is unprecedented.

Cohen et al. (2015) documented what others had found in potential changes in annual runoff levels for the Lake Winnipeg watershed for the 2050s compared with 1961-1990 baseline period. The Assiniboine River is just north of the Souris River and the Morris River is to the east of the Souris River watershed. Annual runoff levels in the Assiniboine River could be anywhere between + 9 to + 90% above average while the Morris River was projected to range from -6 to +66% above average. These were calculated using the SWAT hydrologic model and three different SRES scenarios (CGCM3-CRCM; GFDL-RCM2 AND HadCM3-HRM3).

Surface water drainage is considered to be an adaptive practice to assist farmland, communities and road infrastructure from being negatively impacted by high water levels. While drainage can provide benefits, negative impacts can also occur. Drainage in an average year can increase flood peaks and water volumes because water stored in sloughs and wetlands, for example, does not normally reach a stream or outlet channel. As events get larger, generally those at a one in 10 year frequency, drainage has less impact on the level of flooding. As runoff events increase, the area contributing runoff downstream increases resulting in higher peak flows and volumes. In addition, the higher the runoff events, the fill and spill of wetlands are generally at capacity going into the runoff event making them ineffective at buffering high flow events (MacKenzie and Lieslar 2013). People along the West Souris River in Manitoba are concerned about Saskatchewan's drainage licensing and permitting system. They have recommended Saskatchewan's system be reviewed because they feel that due to drainage in Saskatchewan portion of the Souris River, the river flows in their area have increased (West Souris River Watershed Planning Authority 2012). It is recommended that more areas be assessed for flood hazards and flood prone regions using detailed digital elevation information as well as information on location on transportation infrastructure and associated drainage structures. Currently, only portions of the Souris River watershed have undergone flood hazard mapping including the communities of Weyburn, Estevan, Roche Percee and Oxbow on the Saskatchewan side (Hallborg, p. comm. 2016). Appendix 3 contains aerial views of Roche Percee and Estevan illustrates how the extreme precipitation 2011 overwhelmed previous adaptations such as dyking in Roche Percee.

June 2014 had widespread flooding to the Souris River watershed with many rural municipalities declaring a state of emergency in both southeastern Saskatchewan and southwestern Manitoba with multiple roads and bridges closed (Graham and Puxley 2014). Preliminary analysis showed the June 28 to 30$^{th}$ event had precipitation levels greater than 900 mm over the three day period along the Saskatchewan Manitoba border (Hopkinson 2014). In addition, the antecedent conditions to this event show that southeastern Saskatchewan and southwestern Manitoba, between April 1 to June 23$^{rd}$ 2014, had precipitation totals between 150 and 200% above normal (Hopkinson 2014) thus likely resulting in most of the available storage areas such as sloughs being filled to capacity resulting in the June 28 to 30$^{th}$ event flowing downstream.

# Overview of Oil & Gas and Thermal Power Generating Stations Industries in the Souris River Watershed

The energy sector is large and complex with a wide variety of financial and management resources (Wilbanks et al. 2012). In the USA, on a national scale, the energy sector has strategy development and operation in place to adapt to uncertainties and risks, both environmental and political (Wilbanks et al. 2012). In Canada, the level of resilience to climatic and weather stressors depends on the type of energy industry and its location in the country.

## Oil & Gas Industry

Saskatchewan is the second largest oil producing province in Canada, while Manitoba accounts for four percent of the total conventional production in western Canada (CAPP 2015). Conventional light oil production has increased since 2011 (CAPP 2015) due in part to increased production in the Bakken Formation. The Souris River watershed is over portions of the Bakken Formation (Figure 6). This formation consists of the lower layer composed of organic-rich shale, a middle siltstone and sandstone unit and an overlying organic-rich shale (Bickford 2013). This region had limited production since the 1950s but since 2005, technological innovation led to increased production (Yukowski 2015). Specialized technology was required to access the oil located in impermeable shale beds resulting in this oil field not being fully accessible until the mid-2000s with the use of hydraulic fracturing technology (National Energy Board 2013, Yukowski 2015) (Figure 7). Manitoba's oil fields in the Bakken formation was 18.46 million barrels, equivalent to less than 5% of the province's total oil production in 2012 (Manitoba Innovation, Energy and Mines ND) while Saskatchewan's total production from the Bakken Formation in 2014 was approximately 20.5 million barrels or approximately 12% of the oil produced in the province in 2014 (Yukowski 2015).

**Figure 6 Williston Basin Bakken-Torquay Formations (Fox and Nicolas 2012) Red dashed line denotes general location of Bakken Formation.**

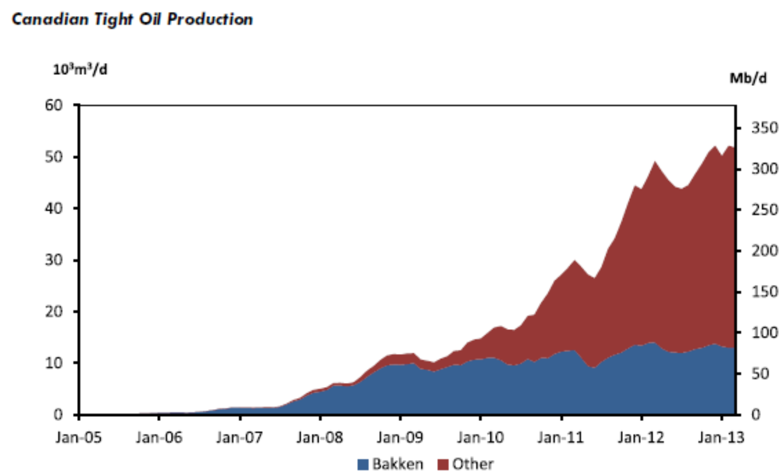


**Figure 7 Tight Oil Production in Canada including Bakken Formation (2005-2013) (National Energy Board 2013)**

As of mid-September 2015, Saskatchewan has over 18,000 active oil wells and over 2,500 support wells[1] that are active in the Souris River watershed and the majority of these wells are non-fracture stimulated (West p. comm. 30 Sept. 2015). As of August 2015, Manitoba has 3,385 active oil wells and 354 support wells that are active within the Souris River watershed (Lowdon p. comm. 29 Sept 2015). Wells in the Bakken formation generally have a production lifespan of between 30 and 40 years (Foster, 9 Feb 2015, North Dakota Petroleum Council 2012). Figure 8 is a collage of maps from the Governments of Saskatchewan and Manitoba indicating locations of these wells.

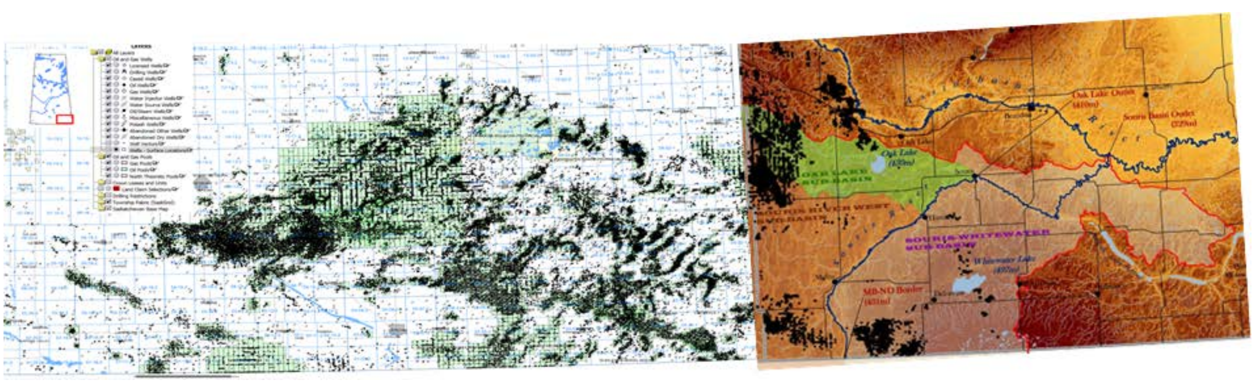

**Figure 8 Locations of Oil and Gas Wells in the Souris Rivers Watershed (left: adapted from SK Ministry of the Economy 2015; right: MB Mineral Resources 2015) Black dots indicate oil drilling locatiions.**

Nationally, in 2005, the oil and gas sector used small volumes (0.6%) of the total water used in comparison to other sectors such as manufacturing (7.8%), pulp and paper (7.2%) and mining (1.3%), leading to water quantity concerns being localized (Canada NRTEE 2011). Unfortunately, a comparable breakdown for the Souris River watershed is unavailable but if the watershed is in a drought situation, even small amounts of water usage may be a concern. One of the water issues for the oil and gas sector centers on water quality and ecosystem integrity on a regional and

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[1] Support wells are injection and salt water disposal wells (Manitoba Innovation Energy and Mines ND)

watershed basis and their interactions are not fully understood (Canada NRTEE 2011). Water used in the oil and gas industry is considered to be 'consumed' and therefore not available for other potential users (Kulshreshtha et al. 2012a). However, new technology is allowing at least some of this water to be recycled (Terton and Parry 2016) by the oil and gas industry and used again in the drilling process, although the percentage level is currently unknown. In Manitoba, an average hydraulic fracturing[2] well uses 400 to 700 cubic metres of water (Fox and Nicolas 2012). On the Saskatchewan side of the watershed, it is estimated that the volume of water used is approximately 300 to 500 cubic metres per oil well but each well is different (West, p. comm. 30 Sept. 2015) and the amount used depends on the method of extraction (Hovdebo, p. comm. 30 Sept. 2015). As noted above, oil wells in the Souris River watershed have a life span of 30 to 40 years (Foster, 9 Feb 2015, North Dakota Petroleum Council 2012), therefore these wells will have years when there is an abundance of available water including years with limited water supply for usage.

Water used by the oil and gas industry in the Souris watershed is obtained from a variety of sources. They can include water from local land owners (e.g., dugouts[3], wells, small dams) or municipal water wells (Hovdebo, p. comm. 30 Sept 2015). Between 2002 and 2014, water usage by the oil and gas industry in the Saskatchewan portion of the Souris River has varied between a low of 3,279 $dam^3$ in 2002 to a high of 6,227 $dam^3$ in 2009 (Figure 9) (Hovdebo, p. comm. 30 Sept 2015). The increase in water usage is likely due to the increase in number of wells. For example, in 2004, there were 75 producing wells on the Saskatchewan side of the Bakken formation while 2015 the number of producing wells increased to more than 2500 (Yurkowski 2015).

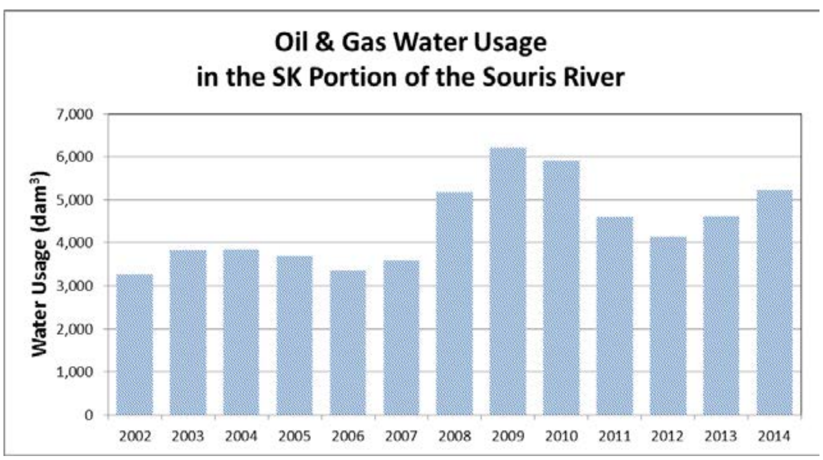


**Figure 9 Oil and Gas Water Usage in the SK Portion of the Souris River Watershed (data: WSA 2015)**

## Thermal Electrical Power Generating Stations

The electrical power generating sector is a significant water user in Canada with fossil fuel electricity accounting for 64% of the gross water use across the country (Canada NRTEE 2011).

[2] Shale gas and shale oil development expanded since 2005 because of technological advances in horizontal drilling and hydraulic fracturing (or fracing). The fracturing process involves injecting a fluid at high pressure into a well, which creates small fractures in the rock. The injected substance props open the fracture and allows the gas or oil to move and flow out of the formation (Zamuda et al. 2013).

[3] A dugout is a constructed water storage structure for surface water and generally has a storage capacity of approximately 1,800 $m^3$ to over 7,000 $m^3$ (Saskatchewan Ministry of Agriculture 2015, SASCC 1984).

Fossil electric power generating stations are located across the country with many located near rivers and lakes (Figure 10).


**Figure 10 Fossil Electric Power Generating Stations across the Canadian Prairies (modified from Canada NRTEE 2010). The red dots indicate station location and the blue circle denotes general location of the Souris River watershed.**

Water usage in thermal electric power generation is mainly for cooling. This water is either re-circulated or discharged. In 2005, in Canada, approximately 2.5% of the thermal electric power generation water intake was consumed primarily from the loss through steam produced in the cooling process (Canada NRTEE 2011). In 2005, the economic value of this sector was $15.6 billion across Canada or 3.1% of total national economic output (Canada NRTEE 2011).

There are three power generating stations located in the Souris River watershed, all on the Saskatchewan side (Figure 11). Two coal-fired stations, Boundary Dam and Shand Power Stations, are located near Estevan and together provide 948 MW of net capacity (SaskPower 2015). The life span of these facilities ranges from over 50 years (Shand) to almost 60 years (Boundary) (SaskPower 2015). The third station is a Heat Recover Facility located near Alameda and provide a net capacity of 5 MW of power (SaskPower 2015). The primary focus is on the two coal-fired electrical power generating stations. Boundary Dam Power Station obtains cooling water from the Boundary Reservoir. The Shand Power Station's cooling water is obtained from the Rafferty Reservoir. Water for the two coal-fired generating stations is usually obtained from the Souris River. Between 2002 and 2014, water usage fluctated from a low of 9,096 $dam^3$ in 2014 to a high of 15,546 $dam^3$ in 2008 (Figure 12) (Hovdebo, p. comm. 30 Sept 2015). The amount of water used for thermal electrical generation is based on generation. Therefore, the high water usage in 2008 is due to high amount of power generation (Hovdebo, p. comm. 9 Oct 2015).

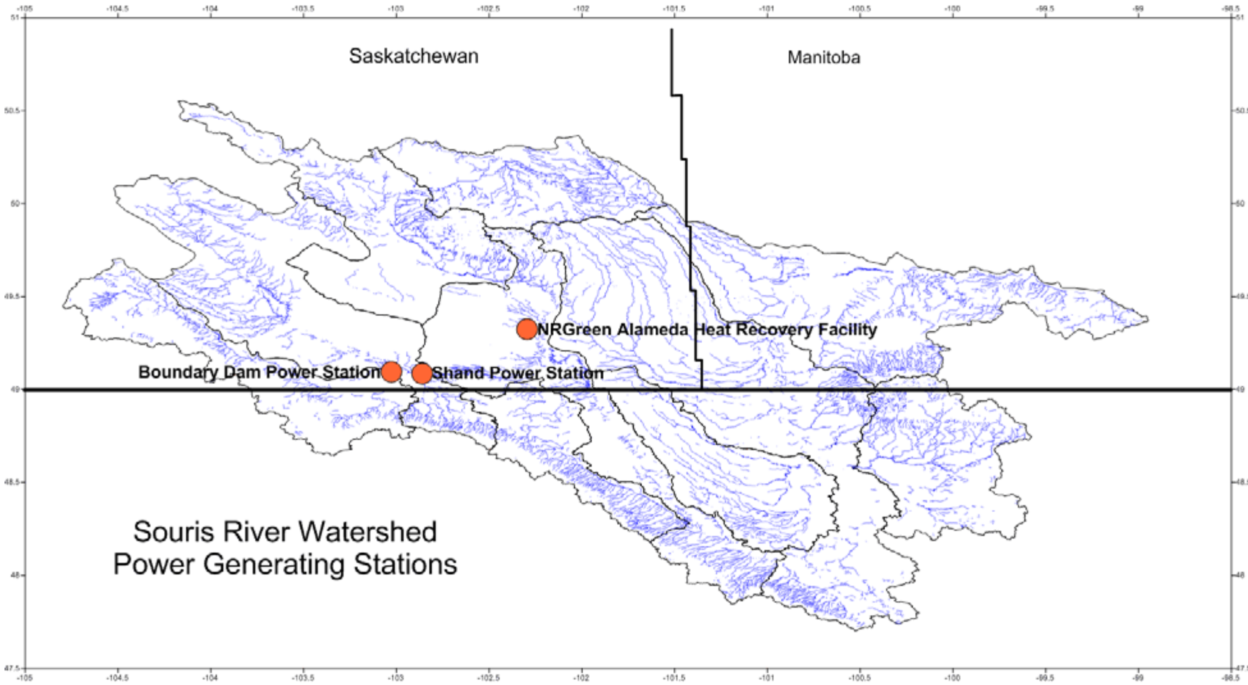


**Figure 11 Power Generating Stations located in the Souris River Watershed**

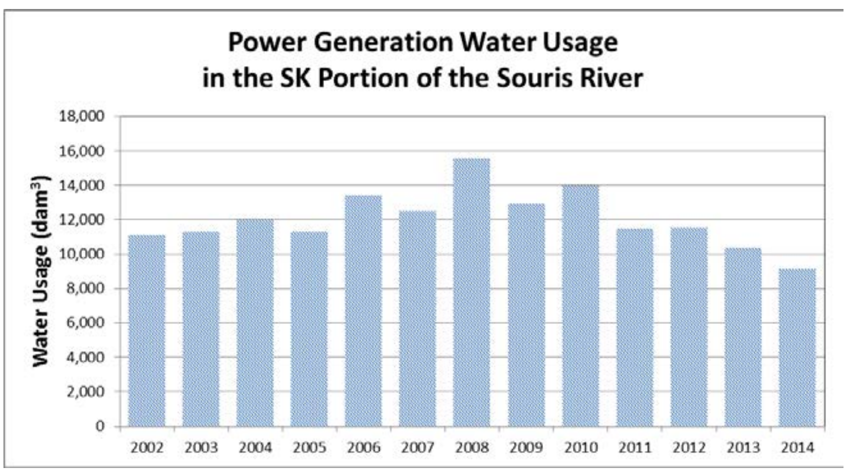


**Figure 12 Power Generation Water Usage in the Saskatchewan Portion of the Souris River Watershed (data: WSA 2015)**

Based on current government regulations and infrastructure hardware, the two coal-fired power generating units have various life spans. These range from approximately 15 (late 2020s) to 30 (mid 2040s) years resulting in different weather and climate impacts depending on the types, duration and intensities of the extreme weather events and changing climatic parameters over those time periods (Hanly p. comm. 17 Nov 2015, Halliday 2013). The two coal-fired power stations depend on adequate prairie water supplies both in terms of quantity and quality. The power stations can be subject to derating if cooling water temperatures increases above a certain level (Halliday 2013). Boundary Dam and Shand Power Stations can be impacted by drought conditions at certain points in time but histroically yearly power production has been equal or higher during drought years as coal units are dispatched at higher levels to offset lower hydropower production in other regions of the province (Hanly p. comm. 19 Jan 2016). The drought year of 1988 resulted in low water levels, reduced water quality and high temperatures of the reservoir water reducing the availability of cooling water and thus requiring the plant to reduce power generation capacity (Arthur and Chorney 1992). The Boundary Dam Power Station utilized water supplied from groundwater during the drought of the 1980s to offset shortages of surface water but this was found to be not sustainable for the long-term (Halliday 2013). Substantial additional surface water reservoir capacity on the Souris River was added with the completion of Rafferty and Alameda[4] dams in 1995 (Hanly p. comm. 19 Jan 2016).

# Past and Future Climate in Souris River Watershed

## Overview of Past Climate

Canada with its large northern landmass has experienced rapid warming, with nationwide annual mean surface temperature increasing 1.5°C between 1950 and 2010 (Vincent et al. 2012). This increasing temperature has been associated with changes in other climatic conditions such as increasing precipitation (Mekis and Vincent 2011), changes in the duration of snow cover (Brown and Braaten 1998, Brown and Mote 2009, Byrne et al. 2010, Rupp et al. 2013) and changes in volume of streamflow and timing of runoff (Zhang et al. 2001, Fang and Pomeroy 2008 and Byrne et al.2010) across the country.

The Canadian Prairies has one of the most variable climates in the world (Sauchyn 2010). Western Canada's temperature trends indicate the minimum temperatures are increasing the most resulting in the Prairies becoming less cold (Sauchyn 2010). Wittrock (2016) also found this for the Estevan region with the winter season in general becoming less cold when compared to the 1981-2010 averaging period since the mid-1980s compared to the previous years. The increasing temperature has a domino effect on other environmental parameters such as changes in the timing of spring runoff and changes to the timing of ground temperatures going above and below freezing. As shown in Wittrock (2016), the Souris River watershed is susceptible to both extreme weather and climate events such as drought and excessive moisture conditions, some lasting a limited amount of time while others occasionally last for years.

The region has an annual average temperature ranging from less than 3.0°C on the north side of the watershed to over 4.5°C on the south side. The winter (December, January, February) average minimum temperatures are below -15°C across the watershed. The summer average maximum temperatures range from 24 to 27°C (Wittrock 2016).

The Souris River watershed region receives between 400 and 500mm of average annual precipitation. Spring (March April May) has precipitation amounts between 95 and 120mm and summer precipitation (June July August) amounts average from 180 to 230mm (Wittrock 2016). Spring and summer are the seasons when the region, in general, receives the majority of its precipitation. Precipitation amounts are highly variable. For example, the Estevan region had a relatively dry decade in the 1980s with only the winter of 1989 having precipitation values greater than 50% above average. In contrast, starting in the spring of 2010 and continuing through the summer of 2011, above average precipitation levels were recorded. The spring of 2011 had five

[4] Water from the Alameda dam facilitates meeting minimum transboundary water transfer requirements on the Souris River (Hanly p. comm.19 Jan 2016).

rain extreme events ranging from one day to multiple days with totals from 49.4mm to 95.7mm with an overall total of 322mm of rain over a 32 day period (Wittrock 2016). In an average year, Estevan receives 427mm of precipitation (based on the 1981-2010 averaging period) (Wittrock 2016).

## Future Climate and Extreme Weather

Extreme weather events are considered to be rare for a particular place and time of year and the occurrence of this event would normally have a less than 1 in 10 chance (McBean et al. 2012). The frequency and intensity of certain types of extreme weather events are expected to change (Dell et al. 2014) and become the new normal (Gordon 2014) (Figure 13). Warmer global and local temperatures may lead to more violent weather patterns such as storms and resulting floods, and droughts (McBean et al. 2012). Within Canada, the Prairies are prone to drought mainly due to their location on the leeside of the western cordillera and distance from large moisture sources (Bonsal et al. 2013). Information about extreme weather is useful as energy demands can be affected by extremely high or low temperatures and by extremely dry or wet conditions (Tencer et al. 2014).

The Earth's warmer temperatures will have an influence on precipitation amounts and intensity. Increased warming leads to greater evaporation, surface drying and likelihood of increasing the intensity and duration of drought. However, with every 1°C of warming, atmospheric water holding capacity increases by about 7%, leading to increased water vapor in the atmosphere. This leads to the potential of more intense precipitation events (Trenberth 2011).

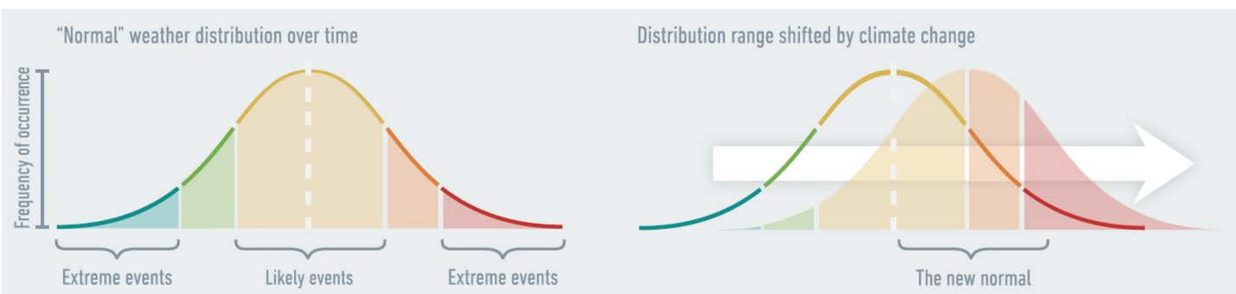


**Figure 13 Extreme weather events turn into normal events (Gordon 2014).**

Projected climate changes in the Souris River watershed will influence the severity of future droughts and floods. Global climate models utilizing various emissions scenarios are used to suggest future climate conditions. The most widely used models are the Special Report on Emission Scenarios (SRES) and the more recent IPCC AR5 Representative Concentration Pathway (RCPs). SRES models describe emissions scenario four storylines and corresponding scenario families. Each of these storylines have different assumptions on future greenhouse gas pollution, land use and other driving forces. RCPs are based on selected pathways from four modelling teams working on integrated assessment modelling, climate modelling and modelling and analysis impacts. Four RCPs were selected according to their total radiative forcing (WMO ND). Journal articles and grey literature have used both SRES and RCP over the past five years therefore information from both model types are utilized here.

Figure 14 and Table 1 illustrate the similarities and differences among the scenarios. The IPCC's fifth assessment report stated that in 2011, RCP 8.5 is the radiative forcing trajectory we are on with well-mixed greenhouse gases at a level of 2.83 $W/m^2$ (Stocker et al. 2013). Previous radiative forcing levels reported by the IPCC in its fourth assessment report was at 2.3 $W/m^2$ (IPCC 2007). The SRES scenarios most similar to RCP 8.5 are the SRES A1F1. RCP 4.5 is the level being hoped for with radiative forcing levels stabilizing at 4.2 W/m2 around 2100. The SRES scenario most similar to RCP 4.5 is SRES B1 (Table 1, Figure 14).

**Table 1 Similarities and difference in temperature projections for RCPs and SRES scenarios (Rogelj et al. 2012; WMO ND)**

| RCP | Closest SRES Model | Radiative Forcing expected level | Differences |
|---|---|---|---|
| RCP 4.5 | SRES B1 | Stabilize after 2100 at 4.2 $W/m^2$ | Median temperatures in RCP 4.5 rise faster than SRES B1 until mid-century and slower afterwards |
| RCP 6 | SRES 2 | Stabilize after 2100 at 6.0 $W/m^2$ | Median temperatures in RCP 6 rise slower in the $21^{st}$ century than SRES B2 except between 2060 and 2090 |
| RCP 8.5 | SRES A1F1 | Rising radiative forcing pathway leading to 8.5 $W/m^2$ in 2100<br>Known as "Business as usual" scenario | Median temperatures in RCP 8.5 rise slower than SRES A1F1 between 2035 but faster during other periods of the $21^{st}$ Century |

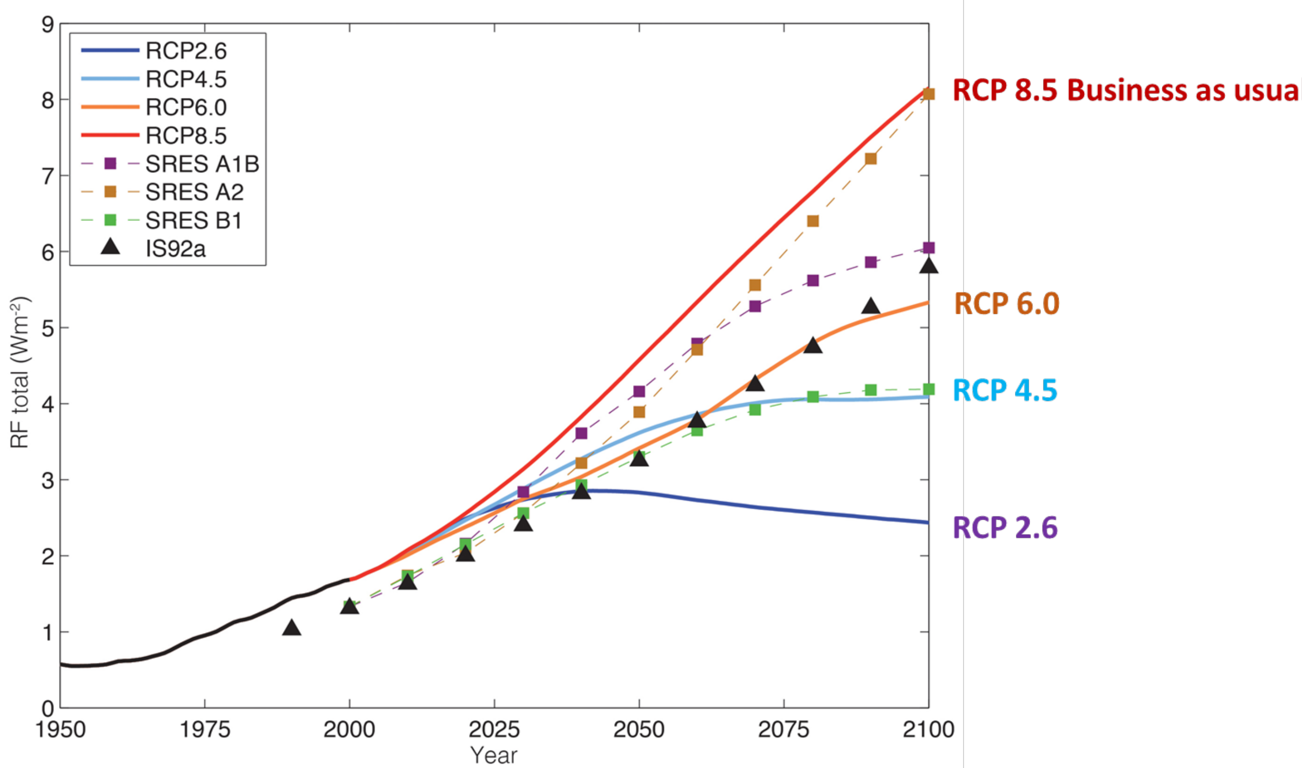


**Figure 14 Historical and projected total anthropogenic radiative forcing relative to preindustrial for the RCP, SRES and IS92a scenarios (modified from Cubasch et al. 2013).**

Scatter plots of seasonal temperature and precipitation projections for the 2021-2050 period compared to the 1981-2010 averaging period were developed for various locations on the Canadian prairies including Regina and Brandon (Figures 15 and 16). These plots are based on 12 CMIP5 GCMs (Coupled Model Intercomparison Project Global Circulation Model) and used two RCPs (4.5 and 8.5). The information used by Smith and Blair (2015DRAFT) was provided to them Pacific Climate Impacts Consortium (PCIC). PCIC produced bias-corrected, statically downscaled versions of the GCM output at a 10 km between data points output. PCIC chose models, based on location[5], that captured a range of projected values observed across all CMIP5 models. Smith and Blair (2015DRAFT) information is utilized in this report because much of their work was carried out in or within close proximity to the Souris River watershed.

All of the GCMs, regardless of whether they are RCP 8.5 or RCP 4.5 runs, show increasing temperatures for all seasons. The winter season (DJF) has most of the runs indicating temperature increases between two and four degrees Celsius greater than the 1981-2010 averaging period (Smith and Blair 2015DRAFT). For the other three seasons, all have warming temperature ranges

---

[5] PCIC chose models based on Georgi regions. The 12 model ensembles for southern Manitoba and south eastern Saskatchewan include MPI-ESM-LR-r3, inmcm4-r1, CanESM2-r1, CNRM-CM5-r1, ACCESS1-0-r1, CSIRO-Mk3-6-0-r1, HadGEM2-ES-r1, MIROC5-r3, HadGEM2-CC-r1, CCSM4-r2, MRI-CGCM3-r1 and GFDL-ESM2G-r1. More information is available regarding PCIC climate scenario methodology on their website: https://www.pacificclimate.org/data/statistically-downscaled-climate-scenarios

between zero and greater than three degrees Celcius, regardless of the RCP model (Figures 15 and 16).

Precipitation is highly variable regardless of the season as shown in the temporal graphs for Brandon in Appendix 1 and the future projections appear to be similar. The scatter plots (Figures 15 and 16) indicate the majority of the model runs show increasing levels of precipitation, for three seasons. However, summer (June, July and August) model results for precipitation are split equally between being below or above the 1981-2010 average (Smith and Blair 2015DRAFT).

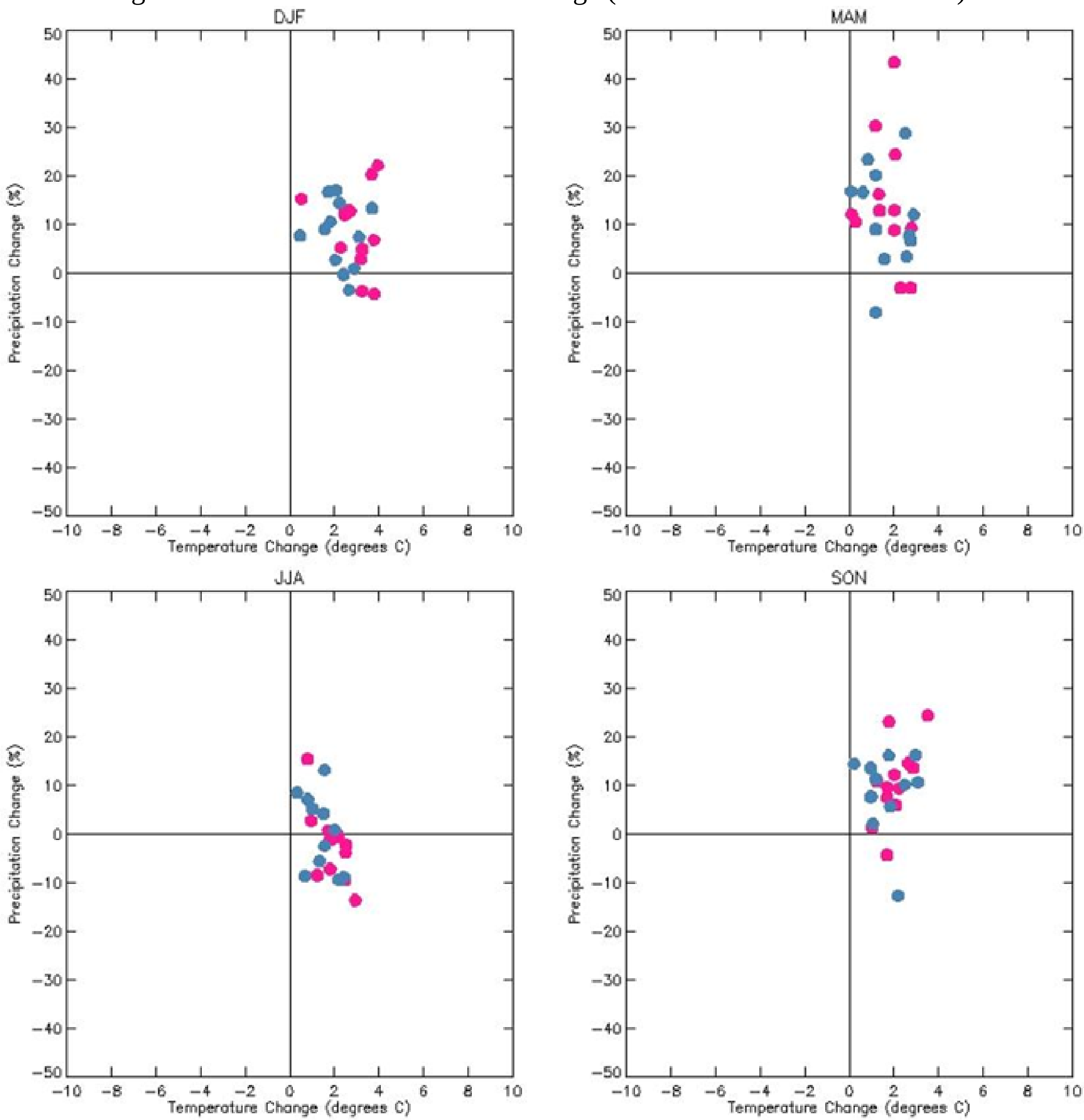


**Figure 15 Brandon, MB Seasonal Temperature and Precipitation changes (2021-2050) from the 1981-2010 baseline period (Blair 22 Oct 2015; Smith and Blair 2015DRAFT) Pink dots represent RCP 8.5; blue dots represent RCP 4.5.**

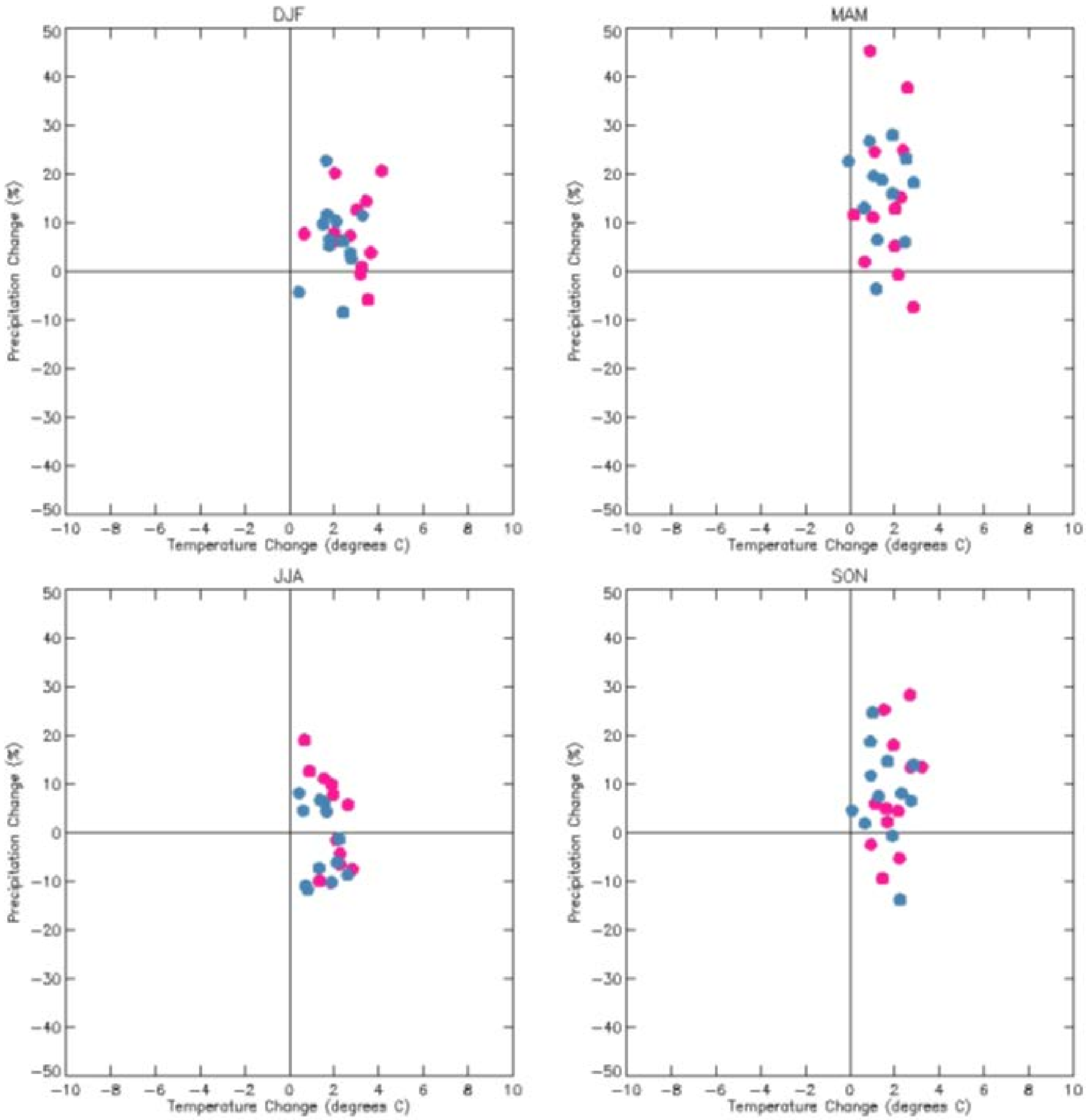


**Figure 16 Regina, SK Range of Seasonal Temperature and Precipitation changes (2021-2050) from the 1981-2010 baseline period (Blair 24 Nov 2015) for several GCMS. Pink dots represent RCP 8.5; blue dots represent RCP 4.5.**

Blair and Smith (2015) use the RCP 4.5 precipitation ensembles calculated by PCIC for the 2021-2050 period (Figure 17). The maps show the Souris River watershed will generally have an increase in precipitation levels with spring having the greatest increase, about 20%, compared to the 1981-2010 averaging period. Average summer precipitation for the 2021-2050 period is projected to stay similar to the amount of summer precipitation received in the 1981-2010 period. It should be noted that precipitation projections have more uncertainty than the temperature projections. The implications are that the temperature increases and temperature-based variables are much more dependable indicators of risk and of vulnerability.

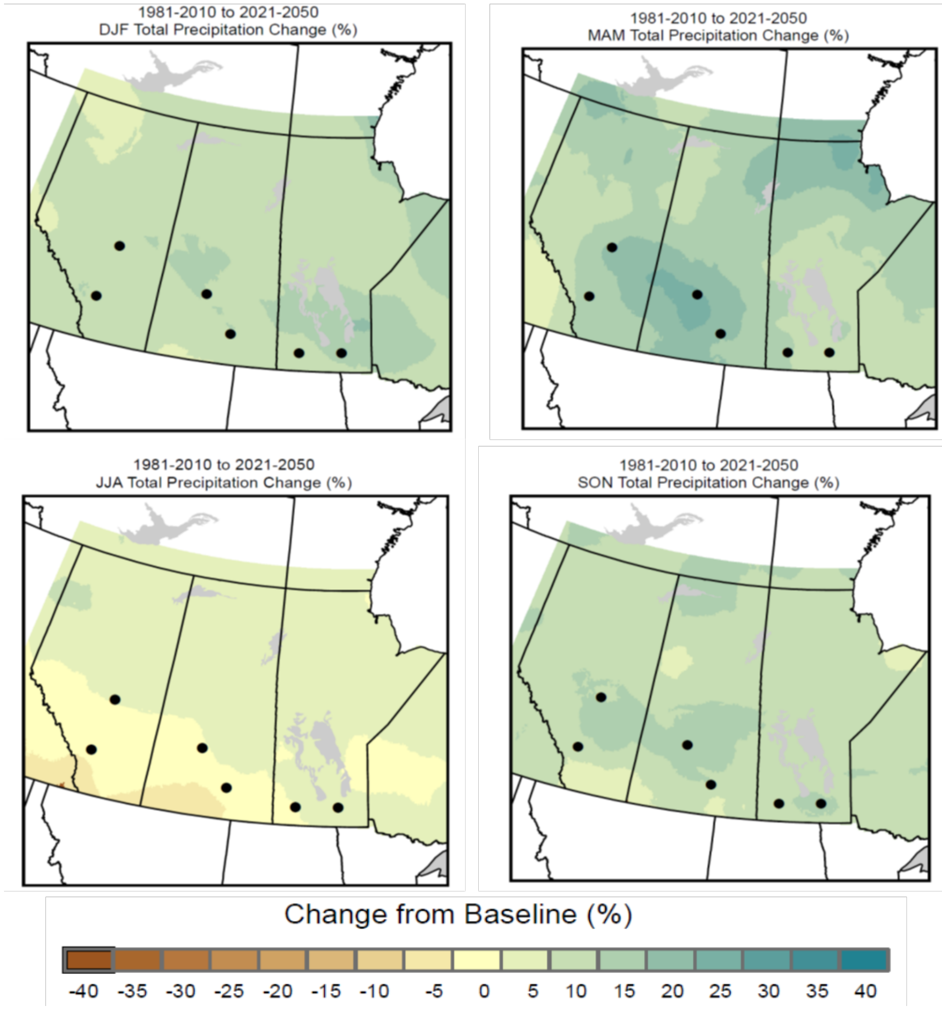


**Figure 17 1981-2010 (Baseline) to 2041-2070 (RCP 4.5 Ensemble) Precipitation Change (expressed as percent change from Baseline period) for the four seasons (Blair and Smith 2015)**

These projected increases in temperature and highly variable precipitation sets up a perfect scenario for increasing the number, intensity and duration of both droughts and excessive moisture events. The droughts in the 20th century are considered relatively mild when compared to pre-settlement droughts in the prairies. The projected changes to the climate will likely mean returning to those extreme drought conditions (Bonsal et al. 2013). In addition, with the warmer atmospheric temperatures, the atmosphere will be able to hold more moisture. With each 1°C of warming, atmospheric moisture-holding capacity increases by 7% and implies increases in intensity and frequency of extreme precipitation events in the middle latitudes (Trenberth et al. 2007).

## Future Possible Droughts

Droughts occur in a variety of forms including meteorologic, hydrologic, socio-economic and agricultural. The drought types that would have the greatest potential influence on the energy sector are the meteorologic, hydrologic and socio-economic. In addition, with the oil and gas sector utilizing the same water supply as the agricultural sector, an agricultural drought may impact the available water supply of the oil and gas sector. Meteorologic and hydrologic droughts would influence local site management and resultant risk management while socio-economic and agricultural drought would have a more over-arching influence on the amount of energy in demand influencing the energy sector's broader economic picture. Wheaton et al.(2013) did a detailed examination of future possible dry extremes in Saskatchewan. This section uses this information and augments it with current and readily available information including RCP 4.5 and 8.5 models. Where possible, the time frame is focused on the mid-21st Century as this is the projected life span for the current oil & gas wells and electrical power generating stations in the Souris River watershed.

Wheaton et al. (2013) completed a review of the literature regarding future drought in southern Saskatchewan and found a consensus for an expected increased intensity of dryness, driven by factors such as an increased evaporation potential. This is still valid with the RCP models. Even though the models project increased precipitation for most seasons (Figures 16, 16, Appendix 1 Figures 34-39). They also indicate temperatures will increase for all seasons. Summer has historically been the period when the Souris River watershed receives the greatest amount of precipitation (Wittrock 2016) but it is also the period when there is greater likelihood of drought events occurring due to increasing temperature and the potential for a future decline in mean levels of precipitation in this season (Figures 15 and 16). In addition, based on information from Blair (22 Oct 2015 and 24 Nov 2015), the number of days with temperatures greater than 30°C are projected to increase in both RCP 4.5 and 8.5 model runs as compared to the 1981-2010 baseline climate (Figures 18 and 19). The summer months see an increase in the number of these days, potentially by 140% (or more than 6 days) to more than 250% (or more than 15 days) compared to the 1981-2010 baseline of Brandon and Regina (Figure 20) (Smith and Blair 2015DRAFT).

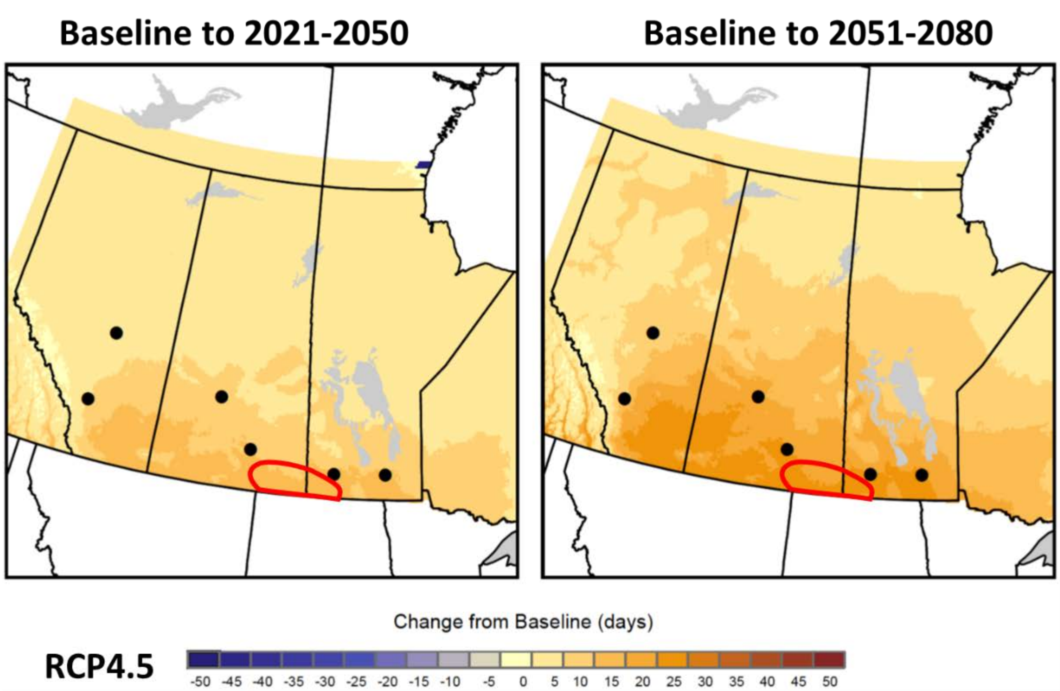


**Figure 18 Changes in Annual Number of Days ≥ 30°C for the RCP 4.5 scenario compared to the 1981-2010 baseline climate (modified from Blair 22 Oct 2015) Red oval approximately denotes location of Souris River Watershed.**

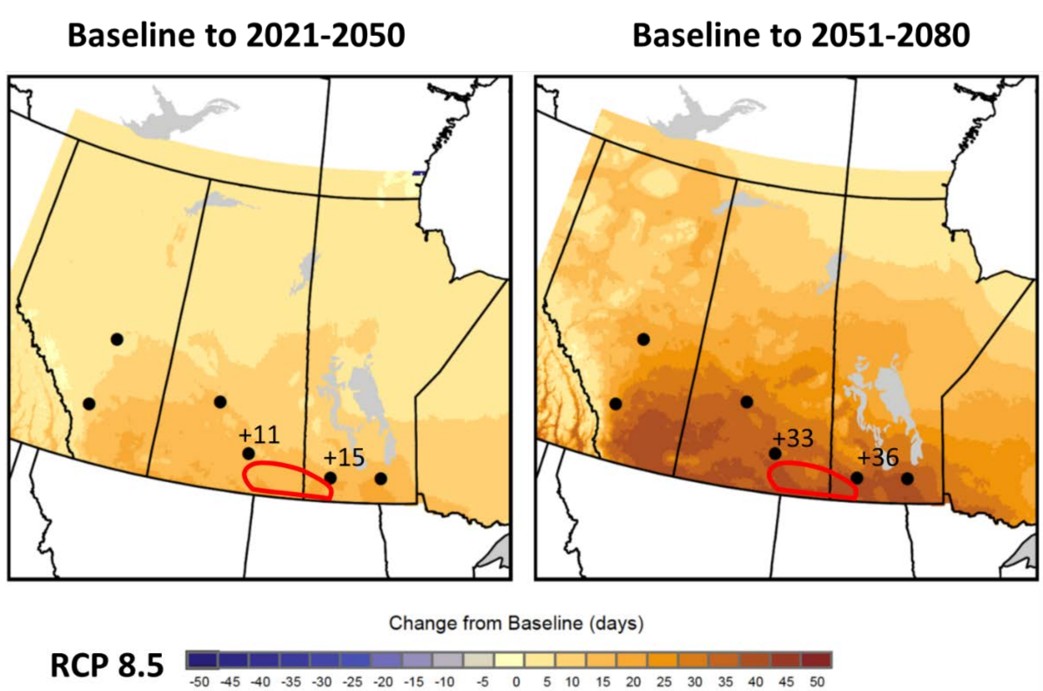


**Figure 19 Changes in Annual Number of Days ≥ 30°C for the RCP 8.5 compared to the 1981-2010 baseline climate (modified from Blair 24 Nov 2015) Red oval approximately denotes location of Souris River Watershed**

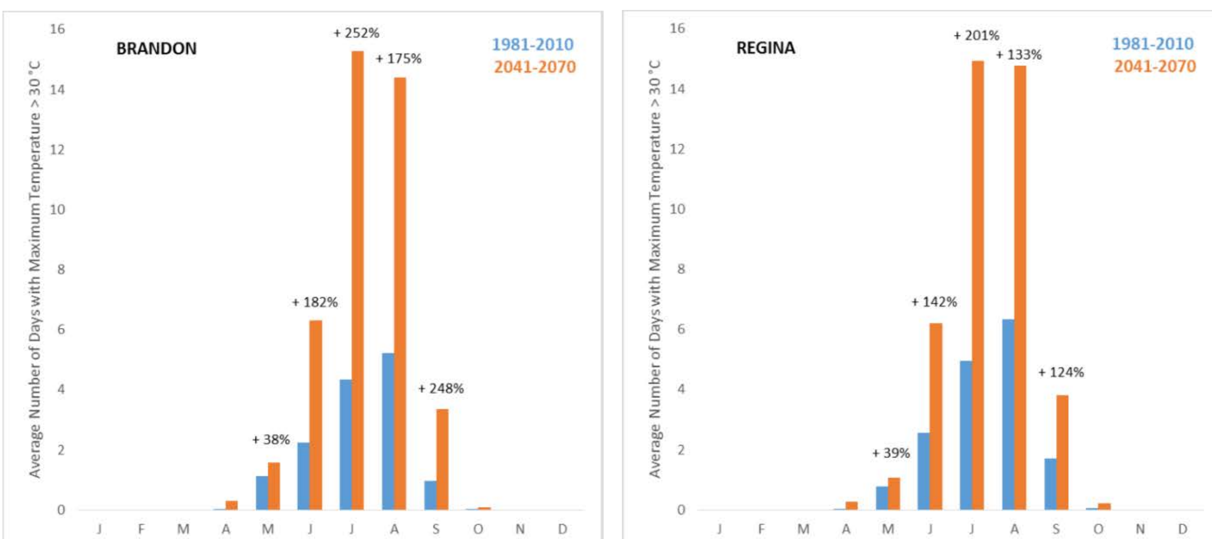


**Figure 20 Comparison of 1981-2010 and 2041-2070 Average number of days per month with maximum temperatures >30°C at Brandon and Regina (Smith and Blair 2015DRAFT). RCP 8.5 are the orange bars and observed averaging period are the blue bars. Percentage is the change from observed data period.**

Another influencing factor on increasing dryness is the number of days when temperatures do not cool off in the summer months. The RCP 8.5 model indicates the number of nights with temperatures greater than 20°C will increase throughout much of the Souris River watershed between 2021 and 2050 (Figure 21). Smith and Blair (2015Draft) found the number of >20°C nights during the summer months at Regina and Brandon will increase by one and four days (between 550 to more than 2000%) for the 2041-2070 period compared to the 1981-2010 base period (Figure 22).

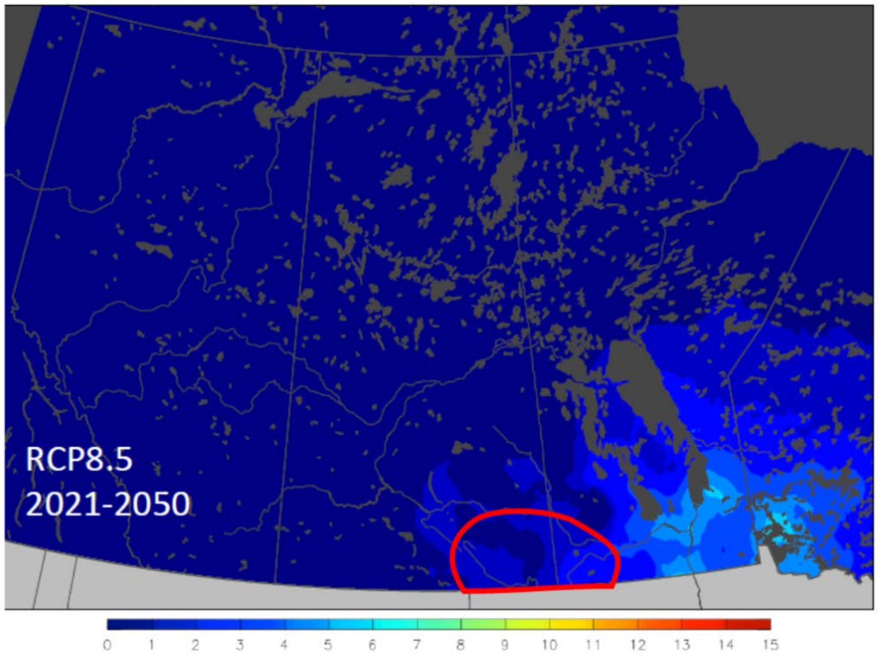


**Figure 21 Average annual number of tropical nights 2021-2050 (>20°C) for the RCP 8.5 (Blair 22 Oct 2015) Red oval approximately denotes location of Souris River Watershed**

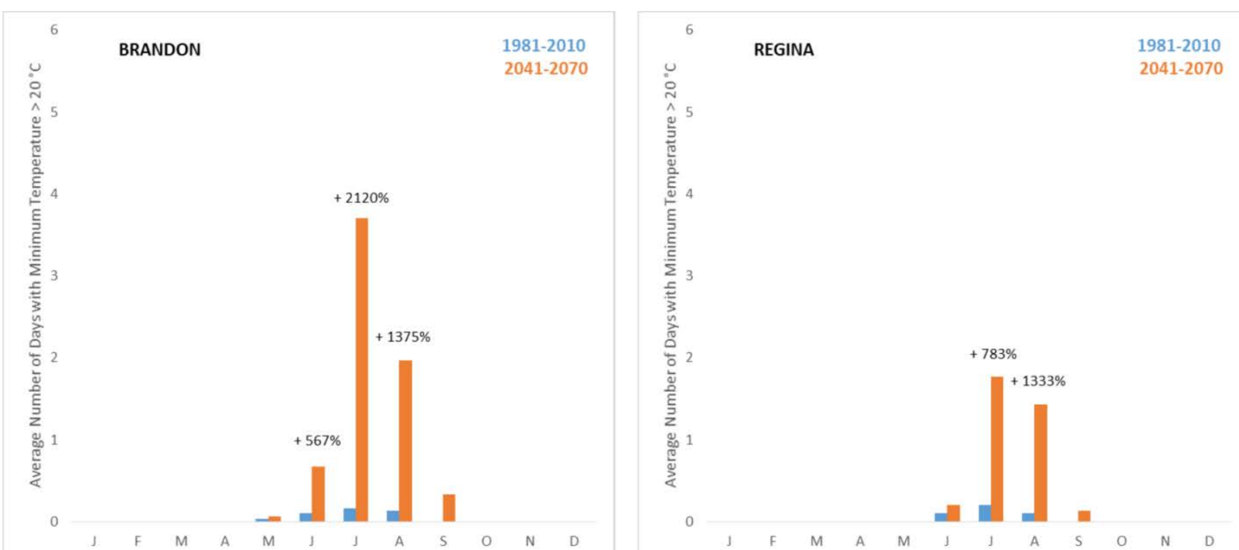


**Figure 22 Comparison of 1981-2010 and 2041-2070 Average number of days per month with minimum temperatures >20°C at Brandon and Regina (Smith and Blair 2015DRAFT). RCP 8.5 ensemble are the orange bars and observed data are the blue bars. Percentage is the change from observed data period.**

PaiMuzumber et al. (2013) also documented that droughts at least 6-10 months long could increase in frequency by an additional four events by the 2041-2070 period with respect to the 1971-2000 period. The frequency of droughts that last at least 10-months is projected to increase by up to four more events over the 1971-2000 number of between six to eight events. PaiMazumder et al. (2013) looked at projected changes to short and longer term drought characteristics on the Canadian Prairies using an ensemble of ten Canadian Regional Climate simulations corresponding to the 1971-2000 averaging period and the 2041-2070 projection period. For the Prairies as a whole, they found a decrease in the mean summer precipitation and an increase for other seasons. They also found that the severity, frequency and maximum duration of both short and longer term droughts are projected to increase over the southern prairies, with the largest projected changes being associated with drought events of longer duration. For the Souris River watershed (Figure 23), they project increases in precipitation for all seasons with summer being near the 1971-2000 averaging period. Winter was projected to have a 5 to 15% increase in precipitation, spring as much as 25% increase and fall has increases between 5 and 15%. Summer is likely to remain similar to the 1971-2000 averaging period ranging between a 5% increase to 10% decrease.

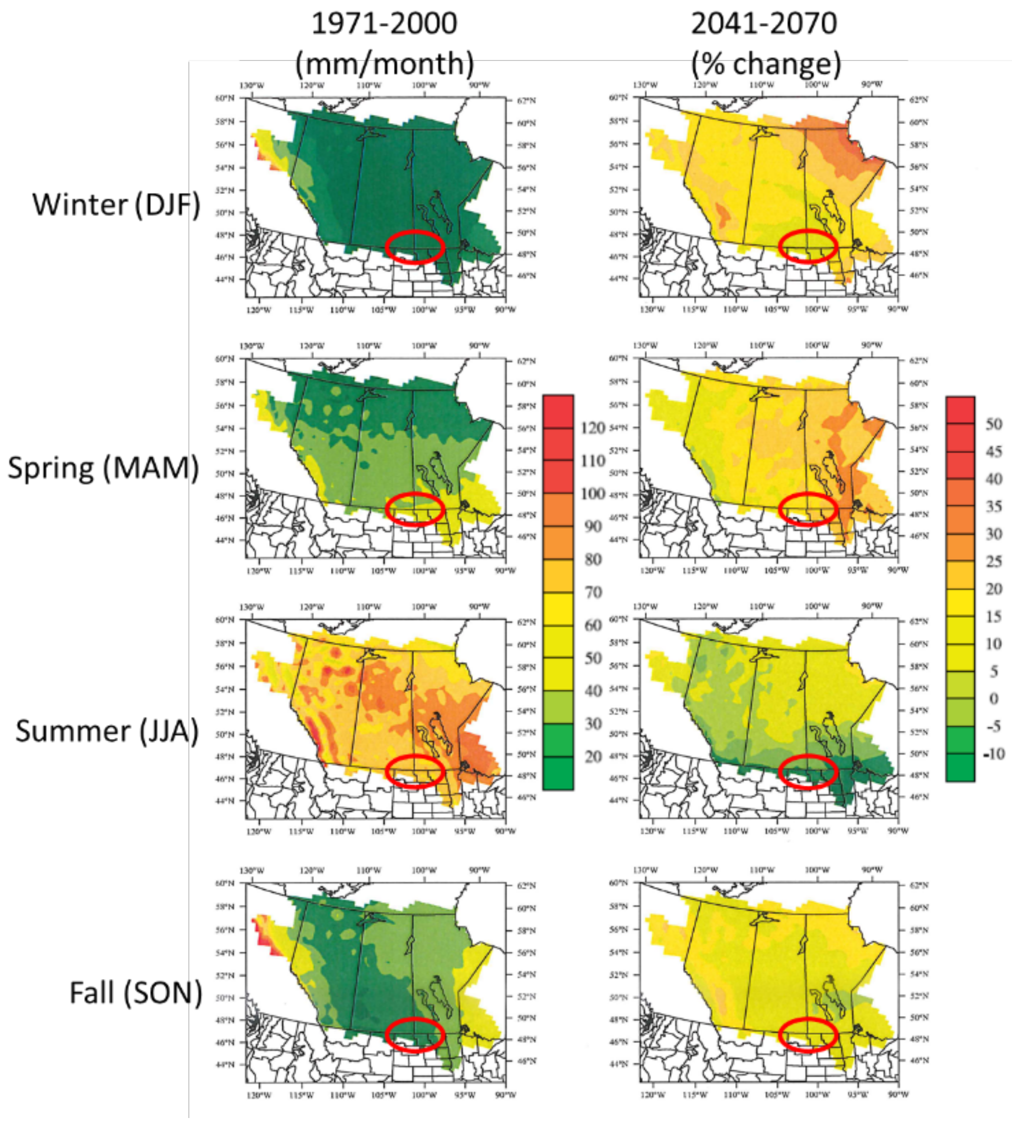


**Figure 23 Average seasonal precipitation for the 1971-2000 period and projected changes for the 2041-2070 period using the Canadian Regional Climate Model (modified from PaiMazumder et al. 2013). Red oval is approximate location of Souris River Watershed.**

Projected changes in precipitation-based drought severity, suggest that the southern Canadian Prairies may experience less severe droughts (Chun et al. 2013). However future droughts will also be influenced by increasing temperatures and associated increases in evapotranspiration showing that precipitation alone cannot be the only factor in calculating drought severity (Chun et al. 2013). Other factors include longer warm season, and shorter snow-cover season.

Dry spells can serve as indicators of drought conditions and can be a useful tool when managing water resource systems. Sushama et al. (2010) used the Canadian Regional Climate Model to project changes to dry spell[6] characteristics across Canada for the April to September period. Their

[6] Dry spell is defined as the number of days with consecutive days with precipitation less than 1 mm (Frich et al. 2002).

analysis shows that in the Souris River watershed, the mean number of dry days[7] could increase over the two projection periods compared to 1971-2000 time frame (Figure 24) but the number of dry spells will decrease. By the 2041-2070 period, the number of dry days of 1 mm or less (Figure 24) could increase between 1 and 10 days and the mean number of dry days that receive 2 and 3 mm of precipitation for the April-September period could increase by up to 5 days compared to the 1971-2000 averaging period.

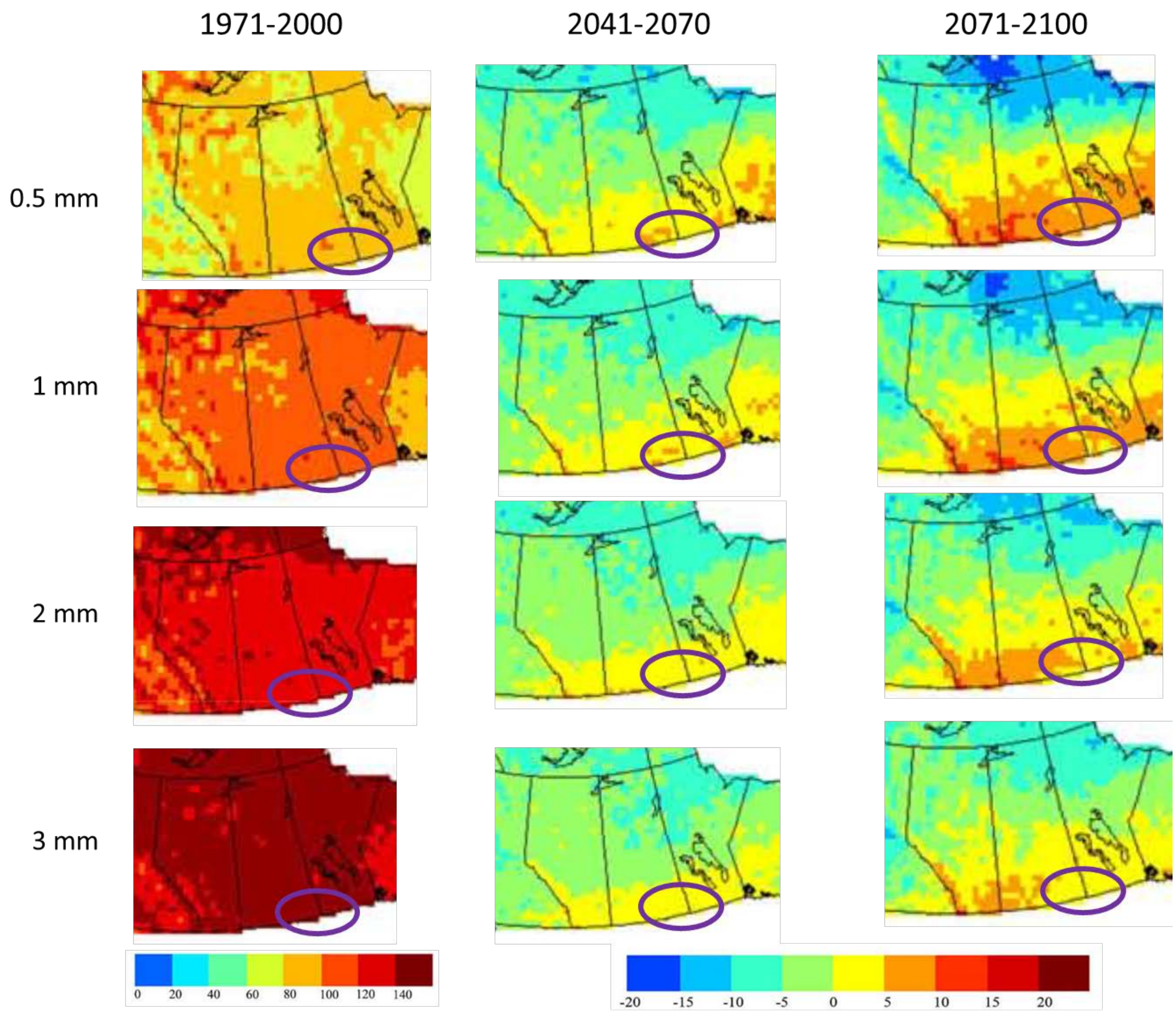


**Figure 24 Mean number of dry days for the April-September period (modified from Sushama et al. 2010) Purple oval is approximate location of Souris River Watershed.**

The CMIP5 RCPs, as presented by Walsh et al. (2014b), indicate the annual number of consecutive dry days in the 2070-2099 period for both RCP 2.6 and RCP 8.5 will increase by 10% in the south western portion of the watershed and decrease by 10% in the more eastern portion compared to the 1971-2000 averaging period (Figure 25). Their definition of consecutive dry days are those days that received less than 1 mm of precipitation.

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[7] A dry day is defined as a day with amount of precipitation less than a pre-defined threshold. Sushama et al. (2010) used precipitation thresholds of 0.5 mm, 1 mm, 2 mm and 3 mm.

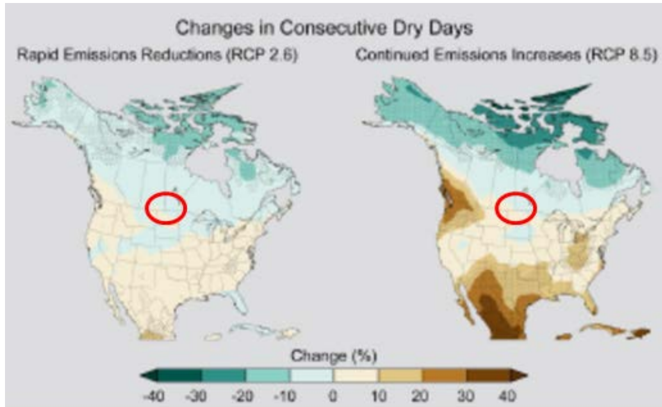


**Figure 25 Projected changes in annual maximum number of consecutive dry days (days receiving less than 1 mm of precipitation) for the 2070-2099 period compared with 1971-2000 (Walsh et al. 2014b). Red oval is approximate location of Souris River Watershed.**

## Future Possible Excessive Moisture

Extreme precipitation events will likely increase to coincide with the seasonal increases in precipitation events (Figure 15 to 17). In looking at the North America, Walsh et al. (2014a) showed that if the observed or measured trends over recent decades continue, more precipitation is expected to fall as heavier precipitation events but this does not necessarily significantly change the overall amount that occurs annually. They examined how the annual maximum precipitation on the wettest day of the year will change across North America (Figure 26) for the 2070-2099 period compared with the 1971-2000 averaging period. Walsh et al. (2014b) found that under the RCP 2.6 annual maximum precipitation for the wettest day would only slightly increase, up to 10%, in the Souris River watershed while the RCP 8.5 model show that the wettest day precipitation increases in the watershed would be between 10 and 20% (Figure 26).

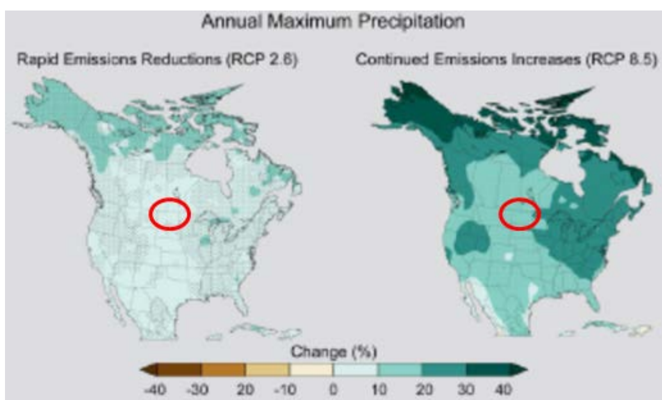


**Figure 26 Changes in average precipitation on wettest day of year for 2070-2099 compared to 1971-2000 (Walsh et al. 2014b). Red oval is approximate location of Souris River Watershed.**

Mladjic et al. (2011) calculated the percentage projected changes in return precipitation extreme periods at a regional level for all of Canada with Figure 27 focusing on the Prairie region. They assessed projected changes in selected return period for the April-September maximum precipitation amounts. They used an ensemble of five 30-year integrations for the 1961-1990 reference period; the Canadian Regional Climate Model (CRCM) corresponding to the A2 Special

Report on Emissions Scenarios (SRES) was used for the 2040-2071 projection period. For the 20-year return period of 1, 3, and 7 day precipitation extremes increases are in the 5-12% range for the Northern Plains region which includes the Souris River watershed. For the 50 and 100 year return levels, the percentage increase is 10% for the 1-day extremes and 8 and 9% for the 3- and 7- day extremes. They hypothesised the expected increases in magnitude of the short and longer term (7-day) extreme precipitation events will have implications for various water management activities including flood control networks.

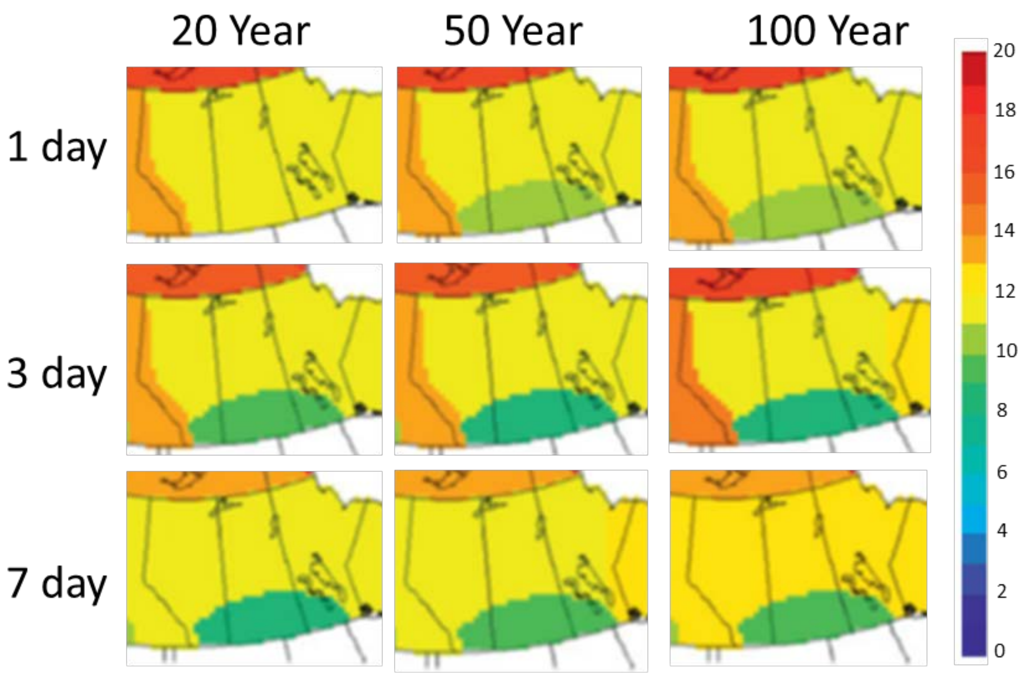


**Figure 27 Projected changes (percentage) in regional return periods (years) and precipitation extremes (length in days) for 2041-2070 with respect to the 1961-1990 reference period (modified from Mladjic et al. 2011).**

Snow cover on the prairies is very important for water storage. The amount of snow is anticipated to decrease in response to a warming climate (Brown and Mote 2009). It is complicated however, because of the projected increase in winter precipitation at higher latitudes may be sufficient to offset reductions in the length of snow cover accumulation season (Brown and Mote 2009) but with higher temperatures, this winter precipitation could be in the form of rain and thus potentially lesser amounts of snow.

More research needs to be done in this area to further determine the level of extreme climatic events. For example, the author became aware of updated climate scenario data sets such as climate moisture indices and standardized precipitation and evapotranspiration indices. Due to time and financial constraints, it was not possible to incorporate these but is a recommendation for future incorporation into the analysis.

In summary, the climate of the 2050s will in general have higher minimum temperatures, and summers will likely be drier. These will be interspersed with intense rainfall events similar to climatic conditions of 2010-2015 but with higher temperatures resulting in the likelihood of extended droughts increasing. So as Wheaton et al. (2013) state: "*wet times become wetter and dry* *times drier*" remains valid. The projected increases in both wet and dry events are indicators of potential increases in vulnerability for the energy sector.

## Motivators of Change

The motivators of change in the energy sector when dealing with a changing climate can come from many areas. For example, as shown previously, winters are projected to become warmer and summer low temperatures higher plus an increase in the number of summer hot days. While annual precipitation is projected to be in general higher, it will be highly variable with the summer likely drier than it has been in the recent past. In addition, precipitation projections have large uncertainty compared to temperature.

Figure 28 and Table 2 show some of the potential climate change issues and their accompanying implications for the oil and gas and the electric power generation sectors. An example for the oil and gas sector is with the likelihood of an increase in the intensity of severe storm events, which could translate into a higher probability of damage to infrastructure, such as rail lines and roads, which will make it more challenging to get the product off-site. An example for the electric power generation is that while winter heating is currently provided by liquid and gas fuels as well as electricity, cooling is provided almost exclusively by electricity (Wilbanks 2015). The result is different timings of energy demand with potentially lesser requirements for electricity in the winter but more in the summer, which may result in challenges for future energy production in the future (Wilbanks 2015). In addition, seasonal and possibly chronic water supply constraints, both excessive water and drought, could pose threats to reliable energy supplies in some regions (Wilbanks 2015).

Figure 28 and Table 2 also show how intricate, intertwined and complicated the energy supply structure is. When only one climatic parameter is changed, it can have an effect on the rest of the system. For example, temperature increases can have an influence on water quantity and quality and can also expose the various facilities to severe weather events, such as cooling capacity of a plant decreasing, causing a domino effect on other parts of the industry.

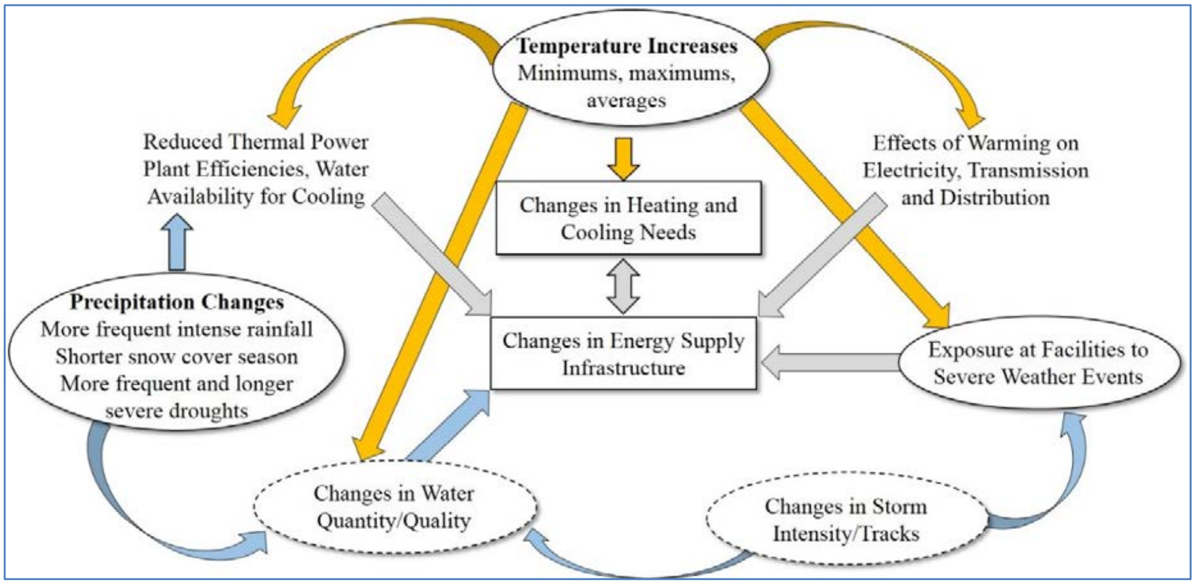


**Figure 28 Potential Climate Change effects on Energy Supply Infrastructure (modified from Wilbanks 2015)**

**Table 2 Energy Supply - Challenges and Opportunities (Dell et al. 2014; Zamuda et al. 2013)**

| | Oil & Gas Extraction and Production | Oil & Gas Distribution Transport | Thermal Power Generation | | Electricity Distribution | |
|---|---|---|---|---|---|---|
| **Physical Impacts** | Increased ambient temperature of air and water | | Increased ambient temperature of air and water | Increased extremes in water availability | | Increasing summer temperatures |
| | Decreased water availability | | | Decreased water availability | | |
| | Increased intensity of storm events | Increasing intensity and frequency of flooding | | Increased intensity of storm events | Increased intensity and frequency of flooding | Increasing intensity of storm events |
| **Implications** | Decreased production and refining capacity (drought event) | Damage to facilities | Reduced plant efficiency and cooling capacity | Interruptions to cooling systems | | Reduced capacity / damage to lines |
| | Potential damage to infrastructure (flood event) | Disruption in rail and road transport (flood event) | Increased risk of exceeding thermal discharge limits | Potential impact on coal supply chain (flood event) | | |
| | | No disruption in rail or road transport (drought event) | | No disruption on coal supply chain (drought event) | | |

## Oil and Gas

The historic excessive moisture conditions and projected changes to both temperature and precipitation resulted in several risks to the oil and gas industry. Extreme and changing climatic elements such as increasing temperatures leads to compressed time available to conduct field operations and develop and build infrastructure due to changes in winter freeze/spring melt timing (Wiensczyk 2014). In addition, events such as high precipitation events result in flooding that affects access to structures (Wiensczyk 2014, David Gardiner & Associates. circa 2011). Increasing temperatures, highly variable precipitation and sporadic extreme events can lead to water scarcity (Sauchyn and Kulshreshtha 2008). Water is required for drilling and other operations at well sites and water scarcity may lead to water conflicts in the region.

The flooding that occurred in the 2010 to 2015 period resulted in negative impacts to access, development and transportation to and from the rigs and equipment (e.g., Figures 29 and 30). These events also posed risks to the workforce and potential public health and safety concerns (Terton and Parry 2016). These impacts will likely occur again in the future when these extreme rainfall events again take place (PRI Project – Sustainable Development. 2009, David Gardiner & Associates. circa 2011). The extreme rainfall event could reduce the amount of energy generated for a time and, if that turns into an extended period of time, may result in an impact on energy supplied and financial implications (Table 3).

**Figure 29 Oil Pump Jack and high surface water in Southeastern Saskatchewan (28 May 2015) (Photo: Radchenko, SRC)**

**Figure 30 Pipeline equipment impacted by extreme rainfall event in southwestern Manitoba (29 June 2014) (Photo: Winters)**

Higher temperatures and decreased seasonal precipitation can have multiple impacts on the oil and gas sector (Table 3). For example, higher temperatures, especially for extended time periods time, can result in heat strain on equipment and supply vehicles. The benefit of warmer temperatures is the reduction in extreme-cold related damage to equipment and vehicles. These temperatures changes may also have an influence on workers' health and well-being as well with potentially less likelihood of harm to workers health due to extreme cold temperatures but also the possibility of greater harm with increased number of hot days. Currently, the greatest climate risk to workers are extended cold periods (Terton and Parry 2016).

When the sites are undergoing decommissioning and rehabilitation the climate will have changed from when they were established. For example, with the sites being in production until about mid-21$^{st}$ century, the higher temperatures will likely lead to changes in vegetation that may affect current site rehabilitation plans (Table 3).

In terms of extended drought situations, the resulting water scarcity may result in water conflicts with communities and other users and possibly damage corporate reputation (David Gardiner & Associates. circa 2011). With the oil and gas sector using water from small sources such as dugouts, this water is not a reliable during drought events and other water sources will be required in order to continue operation. Drought conditions, if not occurring over extended periods, can be beneficial to the oil and gas industry because infrastructure access to rigs is not impeded.

### Table 3 Potential impacts on Oil and Gas Industry (ICF Marbek 2012; Ebinger and Vergara 2011; Huang 2005; Terton and Parry 2016)

| Climate Indicator | Impact | |
|---|---|---|
| Higher temperature | Exploration, extraction & production | • Heat strain on equipment and vehicles<br>• Potential savings from reduction in frost-related damage to equipment and vehicles<br>• Altered snowmelt season leading to changing in stream flow and altered siltation<br>• Increased number of hot days may negatively affect workers' health and safety and overall productivity<br>• Decreased number of extreme cold days may positively affect worker's health and safety and overall productivity<br>• Extreme temperatures can cause malfunctioning of above ground facilities<br>• Freeze-thaw cycle can result in soil instability from freeze-thaw cycles resulting in potential breaches in underground facilities.<br>• Increased fire hazards (grass fires) |
| | Decommissioning & rehabilitation | • Higher soil temperature may affect contaminant pathways<br>• Changes in vegetation may affect rehabilitation plans and may need to be revised |
| | Transport of Product | • Changes in road ban season due to higher winter and spring temperatures resulting in disruption of road transport of equipment and product. |
| Increased seasonal precipitation & earlier and more rapid snowmelt | Exploration, extraction & production | • Increased cost of managing on-site drainage and runoff<br>• Risk of disruption due to flooding resulting in limitation of access to drill site<br>• High snow amounts limit access to facilities, cause delays in repairs and maintenance and increase cost of snow management |
| | Decommissioning & rehabilitation | • Changes in groundwater flow patterns which could result in sub-surface contaminant flow resulting in re-examination of decommissioning and rehabilitation plans |
| | Transport of product | • Risk of disruption and downtime due to damage to transportation and distribution systems e.g., road, rail, pipeline |
| Decreased seasonal precipitation, shifts in precipitation type and changes to soil moisture | Exploration, extraction & production | • Already limited water resources will further reduce water supply and availability and have implications on efficiency and cost<br>• Already limited water resources may result in water allocations being capped or otherwise limited thus constraining the ability to extract the resource<br>• Less precipitation as snow could reduce summer stream flow resulting in implications for extraction and production processes that require surface water<br>• Low surface water flow could result in competition for available water among multiple users |
| | Decommissioning & rehabilitation | • Seasonal water scarcity can lead to changes in-site water balances. Influences vegetation suitability on site rehabilitation plans |
| Possible increased storm intensity and severity of high winds | Exploration, extraction & production | • Potential increased risks to workforce and public health and safety<br>• Disruption in field access<br>• Reduced energy generated and increased production uncertainty<br>• Equipment damage due to tornado event or equivalent extreme wind storm |

| | | |
|---|---|---|
| | Transportation of product | • Disruption to production<br>• Physical damage to transport assets |
| Cascading impacts | Exploration, extraction & production | • Damage to company reputation<br>• Decreased investor confidence<br>• Increased vulnerability and uncertainty in production<br>• Growing multi-user demand for limited water supply may result in conflict |
| | Decommissioning & rehabilitation | • Potential underestimation of decommissioning costs |
| | Transport of product | • Challenges in design and maintenance of transportation assets<br>• Compound transportation issues when assessing multiple assets<br>• Challenges in company and community partnerships e.g., road systems |

## Thermal Power

Changes in precipitation patterns and temperature regimes and the associated droughts and floods may have impacts on the operating conditions of the generation facilities (WECC 2015) (Table 4). The electrical industry will need to be aware of the possibility of water scarcity and overall variability in water supply and precipitation patterns (David Gardiner & Associates. circa 2011) resulting in challenges for cooling thermal power plants and other generation plant operations when there are water shortages (WECC 2015). Increasing flooding can result in increasing sediment loads. These increased sediment loads result in reduced amount of water storage available and changes to operating decisions (Kumar et al. 2011). SaskPower's electrical supply is vulnerable to an extended drought because alternative cooling systems such as groundwater and/or dry cooling are either not sustainable or cost prohibitive (Halliday 2013). The extended drought of the 1980s resulted in too little surface water to supply the needs of the power generation stations in the Souris River watershed and other water sources needed to be utilized (Arthur and Chorney 1992). These challenges may increase costs for water and possibly competition for the limited water resources in the region (WECC 2015). Extended wet periods likely have little direct effect on SaskPower's electrical generation capability (Hovdebo, p. comm. 30 Sept 2015). Wet periods do have an impact on other facts of electrical production through the supply chain. For example, higher than projected infrastructure failure (poles) lead to increased maintenance requirements and flooding would impact site accessibility (Table 4). These electrical generating stations are powered by coal. It was beyond the scope of this research to also examine how changing climate will influence how coal mining is affected and processed therefore is a recommendation for future investigation.

Another issue is coal-fired electrical generation generates large quantities of waste heat that is dispersed using cooling water supplied by local water sources. If the cooling water is degraded, due to, for example, dissolved solids, engineering problems can result with the water either needing to be treated before it is used or a scale-removal process needs to be in place to prevent unwanted scale build-up (Sauchyn and Kulshreshtha 2008). During drought situations and when both air temperatures and water temperatures are already high, low surface water flow results in limits to cooling water for the plants, resulting in a decrease in power generation from that site, potentially resulting in financial losses (Sauchyn and Kulshreshtha 2008). Cooling water that is used in the electrical generation process can only be returned to the source watershed at temperatures that are suitable to not result in damage to aquatic ecosystems (Sauchyn and Kulshreshtha 2008). Net impacts depend on regulatory requirements and goals. The Boundary Dam coal plant raises water temperature and keeps the surface open on part of the reservoir in the winter. This increases fish populations and creates a suitable habitat for largemouth bass which is not a native species to Saskatchewan (Hanly p. comm. 19 Jan 2016).

These changing climatic patterns, and the potential increase in extreme weather events such as heat waves, storms and flooding, will however likely impact patterns of consumer energy demand (David Gardiner & Associates. circa 2011) (Table 4). For example, the patterns may shift to increased summer demand and decreased winter demand (PRI Project – Sustainable Development 2009, Dell et al. 2014, WECC 2015). Extreme weather events such as heat waves, storms and flooding will result in changes in consumer energy demand (David Gardiner & Associates. circa 2011).

Changes in extreme events can result in implications to the electrical infrastructure (Table 4), such as transmission lines are vulnerable to extreme events such as flooding and ice storm and wind storms including tornados (PRI Project – Sustainable Development 2009, Terton and Parry 2016). Increased temperatures will also impact the operations of the generating plants and transmission lines (WECC 2015). The distribution network may also be affected by storm frequency, intensity and type of event (RSI 2012). The potential increase frequency and intensity of severe storms may lead to higher levels of damage to electric generation and transmission assets due to site specific flooding and increased lightning strikes (WECC 2015). The resources that are required in power generation, such as access to coal supply and personnel not being able to get to work, may also be impacted by these extreme weather events and may impact electrical production (WECC 2015).

**Table 4 Potential Climate Change Impacts on the Electrical Sector (WECC 2015; ICF Marbek 2012; Ebinger and Vergara 2011; Hanly p. comm. 2015; Zizzo et al. 2014; Terton and Parry 2016)**

| Climate Indicator | Impact |
|---|---|
| Higher temperatures | • Accelerated equipment and infrastructure deterioration<br>• Increased operation and maintenance needs and costs<br>• Increased line losses in electrical flow<br>• Reduced water flow through cooling efficiency<br>• Decreased efficiency of dry-cooled thermal generation stations especially during peak-load<br>• Higher water temperatures resulting in limiting generating capacity and restricting cooling water discharge<br>• Warm water affects water quality through algal growth which can create bottlenecks in water treatment that limit water for cooling and boiler make-up<br>• Increased summer energy demand<br>• Decreased winter energy demand<br>• Longer construction/maintenance season<br>• Increased number of hot days may negatively affect workers' health and safety and overall productivity<br>• Decreased number of extreme cold days may positively affect worker's health and safety and overall productivity |
| Changes in Precipitation Patterns | • Increased rate of decay or corrosion processes<br>• Possibility of dam safety being compromised<br>• Higher operation costs of managing on-site drainage and runoff<br>• Changes in seasonal surface water discharge<br>• Lower water levels and scarcity of cooling water<br>• Potential utilization of groundwater due to low surface water availability<br>• Changes to slope stability, erosion and siltation levels |
| More frequent extreme weather events (wind, drought, ice, rain, flood, heat) | • Infrastructure failure (e.g., line collapse due to icing, strong wind events (galloping lines))<br>• Increased maintenance requirements<br>• Increased and changes in timing of seasonal peak demand<br>• Weather conditions could prevent vehicle movement |
| Changes in freeze/thaw cycles | • Damage to concrete (e.g, moisture expansion / contraction)<br>• Increased maintenance requirements |
| Cascading impacts | • Negative environmental performance<br>• Growing demand for water may result in potential conflict |

WECC (2015) developed a matrix for assessing climate risk analysis compared to electrical generation assets in general (Figure 31). They found that the highest probability of occurrence and highest likelihood of electrical production impacts will be from increasing droughts, changes in river runoff, changes in timing and type of precipitation, higher temperatures impacting peak capacity demand, and higher temperatures impacting cooling water (both intake and outflow).

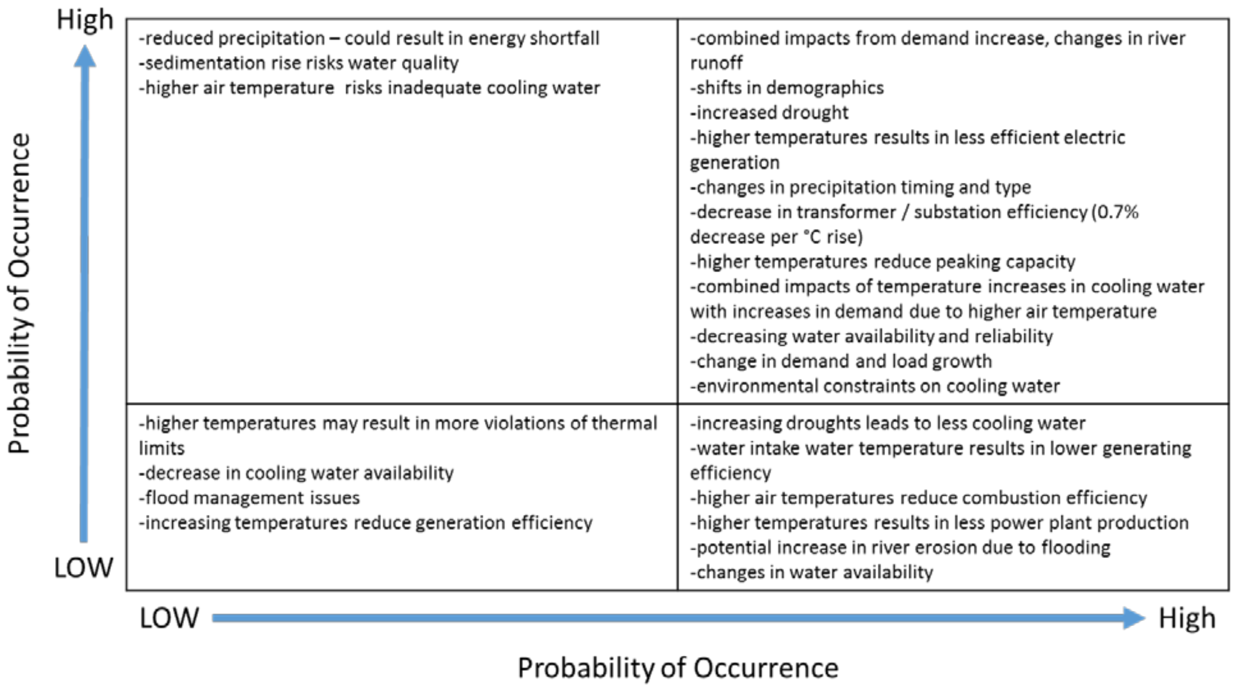


**Figure 31 Electrical Generation Assets / Climate Risk Analysis Matrix (WECC 2015)**

## Common Risks for both Oil and Gas and Electrical Power Generation Industries

The oil and gas and the electrical generation industries have several common risks with a changing climate. For example, water is a commodity that is used by a wide variety of users. With both oil and gas production and thermal power generation are considered to be consumptive water users[8] and the Souris River watershed is susceptible to water shortages such as in 1988 and 1961 (Figure 4). It is therefore important to examine water demands at present and in the future. Kulshreshtha et al. (2012a) calculated the present and future water demand for most of the Saskatchewan River basins including the Saskatchewan side of the Souris River watershed. The two thermal power plants in the Souris River watershed had water demand of 23,164 dam$^3$ and the oil and gas sector demand in the Souris watershed was estimated at 5,215 dam$^3$ in 2010 (Kulshreshtha et al. 2012a). Water usage in the Bakken formation is considered to be substantially less than what occurs in conventional oil extraction and other areas where hydraulic fracturing occurs (e.g. Eagle Ford Oil in southern Texas) likely due to geologic differences (Scanlon et al. 2014). The water to oil ratio for the Bakken ratio is 0.42 while for conventional oil production the ratio ranges from 0.1 to 5 indicating that oil production in the Bakken is in general less water intensive than conventional oil production (Scanlon et al. 2014).

No major changes in total water demand are apparent when either the climate change scenario or water conservation scenarios were utilized. Power generation demand for water would decrease under the Conservation Scenario calculated by Kulshreshtha et al. (2012a) as opposed to increasing when the Climate Change Scenario is used (Tables 5 and 6). Higher temperatures in the future will require greater amounts of water for cooling. Shifts to newer technologies such as water recycling

[8] Consumptive water user is a user where all or some of the water used is lost or not returned to the original source (Kulshreshtha et al.2012a)

could reduce water demand and assist with offsetting the effect of climate change (Kulshreshtha et al. 2012b). It is not known if work similar to Kulshreshtha's et al. (2012a) is available in Manitoba and should be further investigated.

**Table 5 Water Demand in the Saskatchewan portion of the Souris River Watershed (Climate Change Scenario) (Kulshreshtha et al. 2012a)**

| Activity | Water Demand ($dam^3$) | | |
|---|---|---|---|
| | 2010 | 2020 | 2040 |
| Oil and Gas | 5,215 | 7,002 | 4,201 |
| Power Generation | 23,164 | 23,164 | 23,628 |

**Table 6 Water Demand in the Saskatchewan Portion of the Souris River Watershed (Conservation Scenario) (Kulshreshtha et al. 2012a)**

| Activity | Water Demand ($dam^3$) | | |
|---|---|---|---|
| | 2010 | 2020 | 2040 |
| Oil and Gas | 5,215 | 5,952 | 3,571 |
| Power Generation | 23,164 | 22,006 | 20,848 |

Another commonality is infrastructure and how extreme climatic events such as flooding can have a tremendous influence on all facets of life. When infrastructure is disrupted, a domino effect takes place with multiple sectors impacted (Figure 32). For example, when electrical power is disrupted by an extreme event, there is a strong interdependency on most of the other sectors, whereas when the oil and gas sector gets damaged or a disruption occurs due to an extreme event, the cascade is not quite so interdependent upon other sectors, at least in the short term.

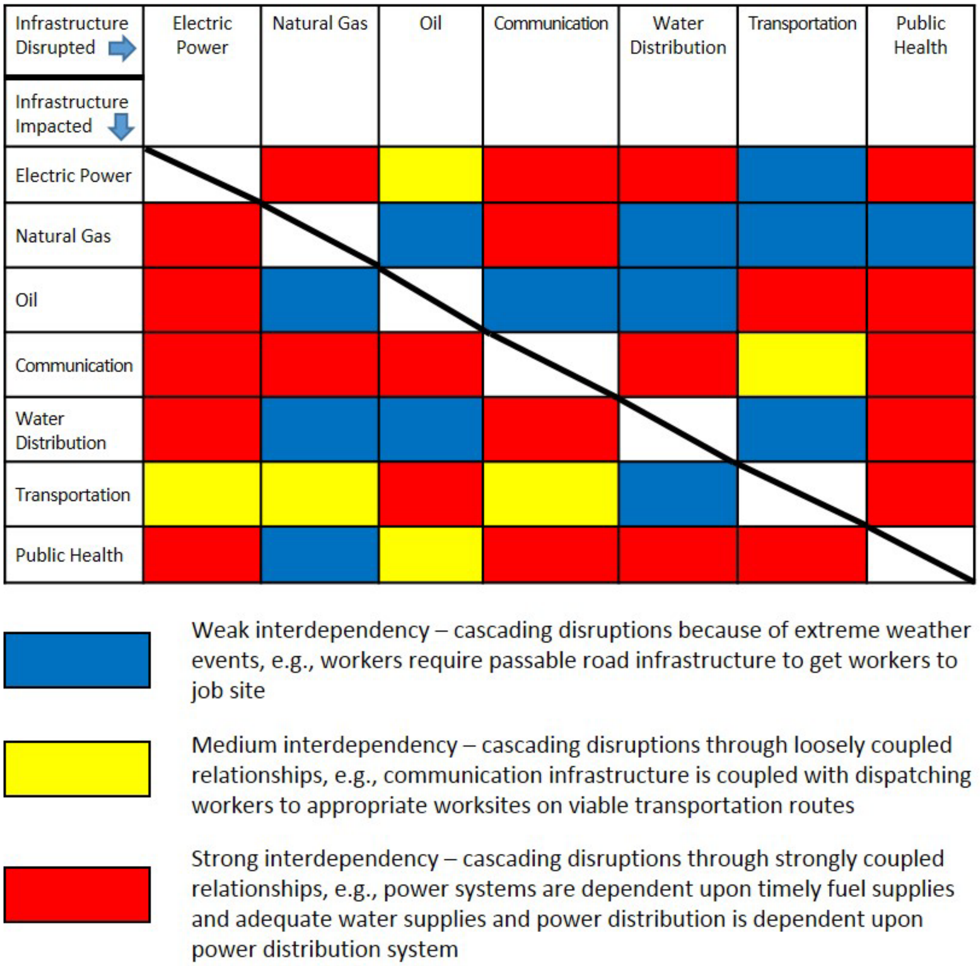


**Figure 32 Infrastructure impacted and disrupted by extreme weather events and their interdependencies (modified from Wilbanks and Fernandez 2012)**

## Risk Management in a Changing Climate

Sectors that face significant climate change risks are those with long-term planning and investment horizons, are sensitive to weather conditions and are dependent on extensive infrastructure and international supply (PRI Project – Sustainable Development 2009). As such it is important to determine the level of resilience and ultimately risk management strategies to a changing climate. With many of the oil and gas wells located in the Souris River watershed likely being in operation for the next 30 to 40 years and the coal-fired electric generation stations operating for an estimated fifteen to 30 more years, considering the climate risks associated with the changing climate is important. The major risk for both demand and supply in the energy sector comes from disruptions related to extreme and episodic weather events and implications of changes in temperature and precipitation (Wilbanks et al. 2012, Wilbanks 2015). In the US, extreme weather events and water shortages are already interrupting energy supplies (Dell et al. 2014). These events affect energy production and delivery facilities, resulting in supply disruptions of various time spans and magnitudes and affect other infrastructure depending on that energy supply (Dell et al. 2014). They also pose economic costs to both energy suppliers and users (Wilbanks et al. 2012). Although extreme weather events are difficult to predict over the long term period for a specific location and time, there is some evidence that frequencies, intensities and locations of these events over the past few decades are different from the long term historical pattern (Melilo et al. 2014).

The energy sector has many interdependencies with other sectors and the variable and changing climate has a multitude of impacts associated with these interdependencies (Figure 33). The likelihood and consequences of any particular impact vary by sector, company and location, as do appropriate strategies for adapting to those impacts (David Gardiner & Associates. circa 2011). Physical risks brought on by changing climatic conditions are business risks to the energy sector (David Gardiner & Associates. circa 2011). Business planning, such as enterprise risk management, business continuity planning and other approaches used to assess and manage a variety of risks can assist companies to identify climatic risks associated with both extreme weather events and incremental climatic changes (David Gardiner & Associates. circa 2011).

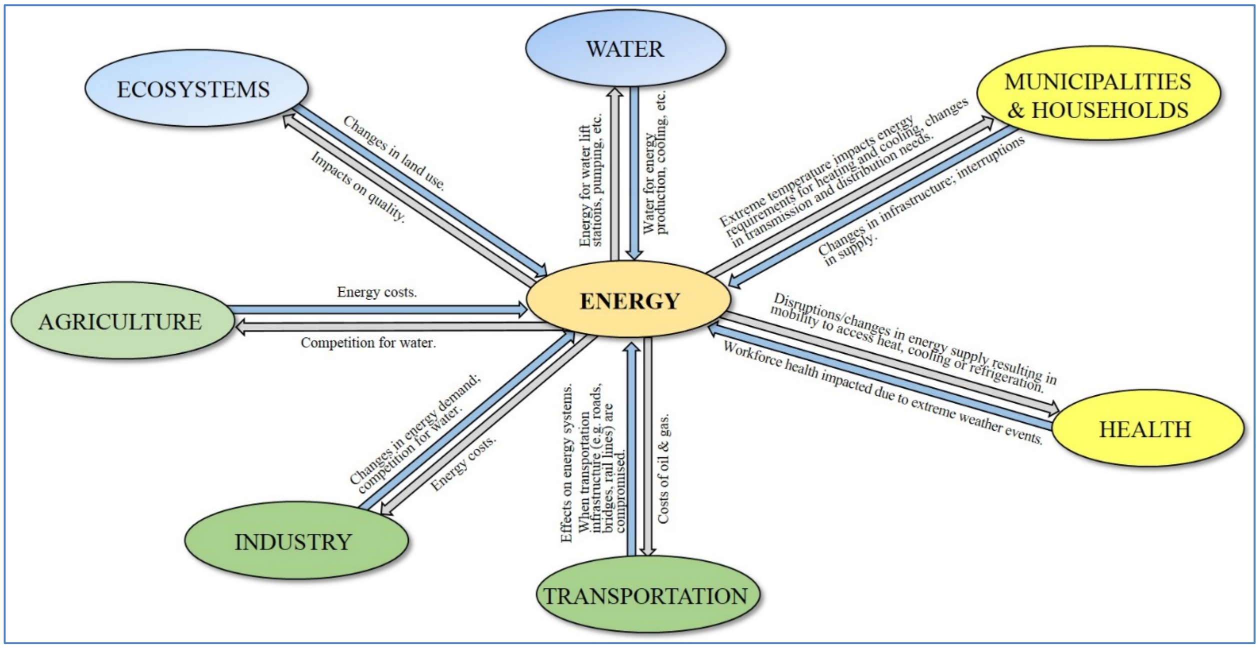


**Figure 33 Energy and other sectors interdependencies (modified from Wilbanks and Fernandez 2012)**

The level of climate change impacts interact with and are affected by regulatory environments (Wilbanks et al. 2012) and government programs (Terton and Parry 2016).

## Oil and Gas Sector

The oil and gas sector requires several risk management strategies in place for its various stages of exploration and production including physical, technical, political, policy and market risks (PRI Project – Sustainable Development 2009). Climate change magnifies these risks and adds complexity and usually higher capital and operating costs (PRI Project – Sustainable Development 2009). The oil and gas sector in the Souris River watershed generally believed they responded to the recent flood events (2010-2014) effectively even though they have lost revenue, had to abandon some wells, deal with potential environmental risks and deal with risks to personnel (Terton and Parry 2016). It is not known if there are risk management strategies in place for the decommissioning of the wells. Water resource management, including water reuse, will be critical to the success and social license of oil extraction methods (ICF Marbek 2012).

The interdependencies between the various sectors became apparent when the oil and gas sector assisted the local governments when flooding impacted the local infrastructure. Oil and gas companies loaned equipment to local government to help with the repair process of the infrastructure (Terton and Parry 2016).

### Thermal Power Generation Sector

Long-term risk management for thermal electric power generation is similar to the oil and gas sector but potentially on a longer time frame. In the USA, it is hypothesized that temperature increases will likely contribute to the necessity to construct up to 95 gigawatts of new power generating capacity in the next five to 25 years resulting in increasing costs to rate payers (Gordon 2014).

SaskPower has several strategies in place for coping with climatic variability. For example, when calculating demand forecasting, SaskPower uses a most recent 30-year climate average in its models for peak demand due to temperature as per industry standard. Other jurisdictions are contemplating using a 10-year climate normal to give more weight to recent weather and may better reflect the trends of the changing climate (Hanly p. comm. 2015). Climate change is expected to lower the average winter peak and raise the average summer peak electrical demand (Hanly p. comm. 2015). Since SaskPower's highest peak electrical demand is currently in winter, a warmer climate may lower the average yearly peak demand (Hanly p. comm. 2015). SaskPower's planning and operational decisions include reducing the expected capacity of thermal units in different seasons relative to the capacity in January. As temperatures increase the capability of thermal units such as gas turbines can decline by 10% to 20% from winter to summer capacity. The capacity of steam turbines are not impacted or only slightly impacted by changes in seasons unless there are shortages of cooling water at appropriate temperatures for cooling purposes (Hanly p. comm. 2015). SaskPower's planning for generation capacity currently has a significant reserve margin above the projected peak demand resulting in considerable flexibility in order to respond to higher than expected demand (Hanly p. comm. 2016). During low water period, SaskPower's cooling process can be adjusted where necessary to reduce water demand including accessing ground water to supplement surface water if needed (Hanly p.comm. 2016).

Manitoba Hydro projected for 2050 that the average annual temperature would be 2.5°C greater than the existing climate normal. This increased temperature would lead to winter electricity use decreasing by 756 GWh and peak declines by 176 MW (current peak is 4600 MW) and summer electricity use increasing by 486 GWh and peak summer demand rising by 300 MW (current peak is 3400 MW) (Hanly p. comm. 2015). The Manitoba example shows that winter will remain the highest electrical demand period but summer becomes a more important generation time.

## Moving Forward

The energy sector through the course of the historic extreme climatic events have put into place some strategies they have learned to deal with the future climate. Many of the adaptation responses to recent extreme events are mostly reactive (Terton and Parry 2016). This section examines what lessons were learned based on the previous extreme events and what procedures the energy sector has in place to move forward into a continually changing climate. Adaptation can be classified into two categories: operational (non-structural) and physical (structural) (PRI Project – Sustainable Development 2009). This section examines both categories.

## Oil and Gas

As indicated in the motivators of change section, a main risk to the oil and gas exploration, extraction and production sector is currently viewed as flooding. While the recent flood did disrupt their operations, the oil and gas sector found that it responded effectively within their existing policies and procedures and also met all provincial regulations (Terton and Parry 2016). They did however find areas of improvement were needed including being able to access sites. It is important that companies ensure adequate storm water drainage and construction of certain facilities above the flood plain where possible (Wiensczyk 2014). Terton and Parry (2016) also point this out as a lessoned learned on where future oil rigs will be located. The flood plain will be taken into consideration when locating future development. The oil and gas sector also indicate that undertaking due diligence in monitoring current infrastructure such as culverts is important to maintain viable access roads (Terton and Parry 2016).

The excessive moisture years resulted in the Saskatchewan Ministry of the Economy issuing a Minister's Order to well owners that had wells deemed inaccessible by surface location for a period greater than 12 months due to surface flooding conditions. The owners (licensees) of the wells were to do an inventory, risk assessment and notification of the Ministry of any wells that fell into this criteria (SK Ministry of the Economy 27 April 2015). This order impacted about 100 wells out of the 18,000 in the Weyburn / Stoughton region and the risk of leakage or spills was considered low as none of the wells were indicating signs of spills or other environmental disasters (Garney 23 June 2015).

The aspect of droughts that will potentially affect the oil and gas sector in the Souris River watershed is the potential lack of water for drilling purposes. While water demand for the oil and gas sector is currently around 5,000 $dam^3$ on the Saskatchewan side of the Souris River watershed, demand is projected to increase to around 7,000 $dam^3$ when using the climate change scenario (Table 6 and 7) (Kulshreshtha et al. 2012a). This water usage may become a problem if there is an extended drought in the region with multiple sectors including communities and agriculture wanting to utilize the same water sources as the oil and gas industry. The author does not know if this potential has been taken into account by the industry in their risk management planning.

The author found that the decommissioning of the sites was rarely mentioned. This is an area that will need to be investigated as to how extreme events will impact that process.

## Thermal Power

A long-term planning window is required for electricity reliability (WECC 2015). Many possible adaptation actions exist to assist the power industry with changing climate when disruptions occur due to extreme events, changes in peak load requirements or dealing with water constraints (Table 7). Some of these adaptations can take years to implement, for example, changes to the grid because the grid's lifespan is usually decades in length (WECC 2015). In addition, adaptation can be classified into two categories: operational (non-structural) and physical (structural) (PRI Project – Sustainable Development 2009). Non-structural adaptation options could include modifications to operating rules, improve hydrological/flow forecasting tools, develop improved technologies to evaluate performance and identify ways of operating systems under modified climate conditions (PRI Project – Sustainable Development 2009). Structural modifications may include diverting water courses from upstream tributaries; movement of water between sub-basins; modification of the characteristics of electrical components (generators, transformers, transmission line etc) (PRI Project – Sustainable Development 2009).

**Table 7 Possible Adaptation Actions and Climate Resilience Strategies for the Electric Power Energy Sector (Dell et al. 2014; Ebinger and Vergara 2011; Hanly 2016 p.comm).**

| | Possible Challenges | | |
|---|---|---|---|
| Possible Actions | Extreme Weather Events | Increase in Peak Energy Loads | Water Constraints on Energy Production |
| *Supply: System and Operational Planning* | | | |
| Diversify supply chains | X | X | X |
| Improve security of existing fuel sources through storage and operational planning | X | X | |
| Strengthen and coordinate emergency response plans | X | X | X |
| Prepare for supply interruption such as back-up systems for road/rail damage | X | X | X |
| Provide protected emergency-response coordination centers | X | | |
| Develop flood-management plans and improve stormwater management; manage on-site drainage and runoff | X | | |
| Develop drought management plans for reduced cooling flows | | | X |
| Model flood risk for siting new facilities | X | | |
| | | | |
| *Supply: Existing Equipment Modifications* | | | |
| Hard/build redundancy into facilities | X | X | |
| Elevate water-sensitive equipment or redesign elevation of intake structures | X | | |
| Build dikes or barriers | X | | |
| Improve reliability of grid systems through back-up power supply, intelligent controls, and distributed generation | X | | X |
| Insulate equipment for temperature extremes | X | | |
| Implement dry (air-cooled) or low-water hybrid (recirculating) cooling systems for power plants | | | X |
| Add systems to pre-cool water discharges | | | X |
| Inspect facilities for damage by weather related events and repair | X | | |
| | | | |
| *Supply: New Equipment* | | | |
| Add peak generation, power storage capacity and distributed generation | X | X | X |
| Add back-up power supply for grid interruptions | X | X | X |
| Increase transmission capacity within and between regions | X | X | X |
| Bury power grid lines where feasible; expand redundancy in electricity transmission capacity and fuel storage capacity | X | X | |
| | | | |
| *Use: Reduce Energy Demand* | | | |
| Improve building energy, cooling-system and manufacturing efficiencies as well as demand-response capabilities (e.g., smart grid) | X | X | |

The electric power industry has some plans in place for future drought events. For example, the1987-1988 drought resulted in the power plants having to use large amounts of groundwater for cooling. Since that time, a process was put into place where surface water can be moved from one reservoir to another to assist with low water levels (Hovedebo, J. p. comm. 30 Sept 2015). An adequate water supply is needed to meet regulatory requirements that include a variety of human, ecological and transboundary uses (Canada NRTEE 2010). Upgrades were recently completed to assist with high flow events. An upgrade to the Boundary Dam spillway was performed 2008-2010 because of insufficient spillway capacity and deficiencies with the condition of the existing spillway (McPhail et al. 2010) with the spillway chute section being designed for the Potential Maximum Flood (Hanly p. comm. 7 Oct 2015). It performed as designed during the 2010-2015 high water years (Hanly p. comm. 7 Oct 2015, Terton and Parry 2016).

In the USA, the Scenario Planning Steering Group (SPSG) proposed a future scenario that identifies the impacts of a changed environment on the electric system and a method to correlate the impacts associated with electric reliability risks that could result with an average global temperature increase of 1.67°C (3°F) by 2034 from the 1960 to 1979 average. Air temperature increase results in changes in water availability, ambient air temperature, weather-related impacts and other factors (WECC 2015). WECC (2015) hypothesises that by using this specified temperature increase, it will assist planners and other stakeholders with a 20-year planning window (WECC 2015). As noted previously, the seasonal differences for the Souris River watershed have average temperature increases ranging from two to four degrees Celsius in the winter to between zero and three degrees Celsius for the other three seasons resulting in the WECC temperature being on the lower low end so while WECC (2015) is a good example, the Souris River watershed area would need to use the local projected temperature increases for planning purposes.

## Conclusions and Recommendations

The electric and oil and gas sectors are an important component of the Saskatchewan and Canadian economy but the overall impact of extreme climate changes to these industries is not well understood or documented. The purpose of this report is to determine what possible future adaptation actions the energy sector can do both locally and nationally to capitalize on the potential opportunities and reduce their risks for a changing climate.

The Canadian side of Souris River watershed was chosen to be the case study region because it contains both of these industries and has had numerous climatic extremes in the past. While past events assist with determining what possible impacts will occur in the industries, developing adaptation actions based on historic climatic and hydrologic averages does not necessarily equate to what will occur in the future. This is due to the climates' uncertainty and variability as well as the industries requirement for long-term assets and planning.

This reports utilizes previously published literature to examine future climate and projected extremes. In the Souris River watershed, on average, the region will be warmer for all seasons with more precipitation. In terms of projected extremes, the number of hot days, those with temperatures greater than 30°C, will increase. On the precipitation side, the number of 1, 3 and 7-day precipitation extremes will also increase. It should be noted that climate change models and value-added data keep evolving and it is imperative that the most up-to-date information is utilized, when possible.

The historic weather and climate events tended to be the motivators of change in both industries. For example, the flooding that occurred in the 2010 to 2015 period resulted in negative impacts to the oil rigs and equipment. This posed potential risks to the workforce and potential public health and safety concerns, and resulted in the oil companies examining alternative procedures and making modifications to their risk management plans.

An example of a lesson learned by SaskPower relates to the drought event in the 1980s when the adaptation strategy implemented was to utilize large amounts of groundwater for cooling due to limited amount of surface water. Water can now be moved from one reservoir to another if needed as well as still having the option of using groundwater.

In general, the oil and gas industry believe they are fairly well situated to adapt to the changing climate with some modifications to their future development such as developing future oil rigs outside the flood prone region. SaskPower generally believes it is able to deal with future climatic issues at the power plants. The main source of concern is the infrastructure to supply power to the costumers after the power has been generated.

In examining the risks, motivators and adaptions to changing climate as they relate to the energy sector in the Souris River watershed, several gaps were identified resulting in the following recommendations:

1) The flood events resulted in various forms of infrastructure including roads and bridges being negatively impacted. These floods also resulted in several oil rigs having surface water surrounding them making them unreachable. The regions flood prone areas are not well documented and therefore it is recommended that more areas be assessed for flood hazards and flood prone regions using detailed digital elevation information as well as information on the location on transportation infrastructure and associated drainage structures such as culverts.
2) The coal industry in the Souris River watershed is the energy source for the power stations. The coal industry was not part of this projects assessment and it is recommended that the impact the changing climate has on the coal mining and supply chain to the power stations be examined.

## Acknowledgements

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# Appendix 1 Seasonal precipitation (maps and graphs)

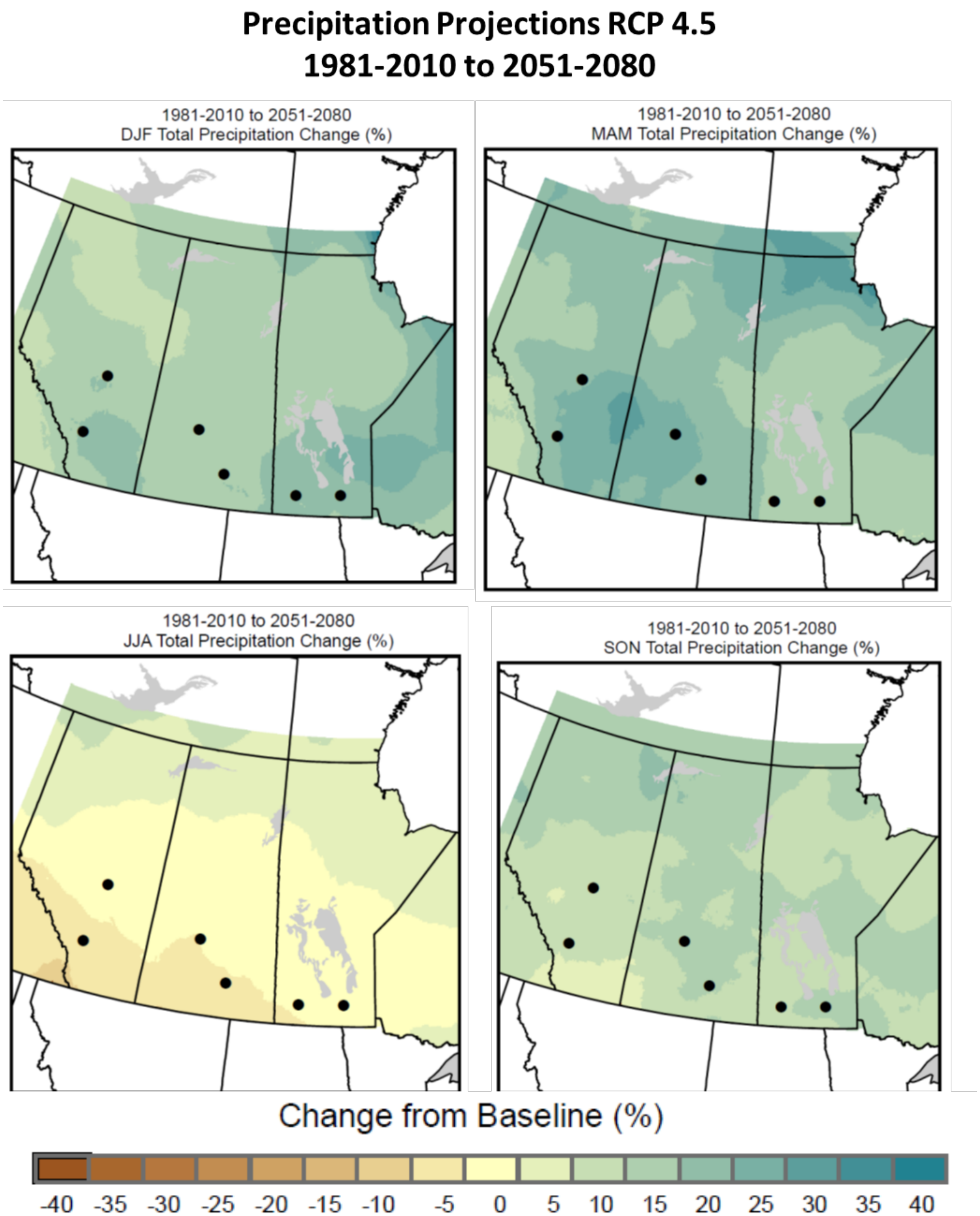


**Figure 34 1981-2010 (Baseline) to 2041-2070 (RCP 4.5 Ensemble) Precipitation Change (expressed as percent change from Baseline period) (Blair and Smith 2015)**

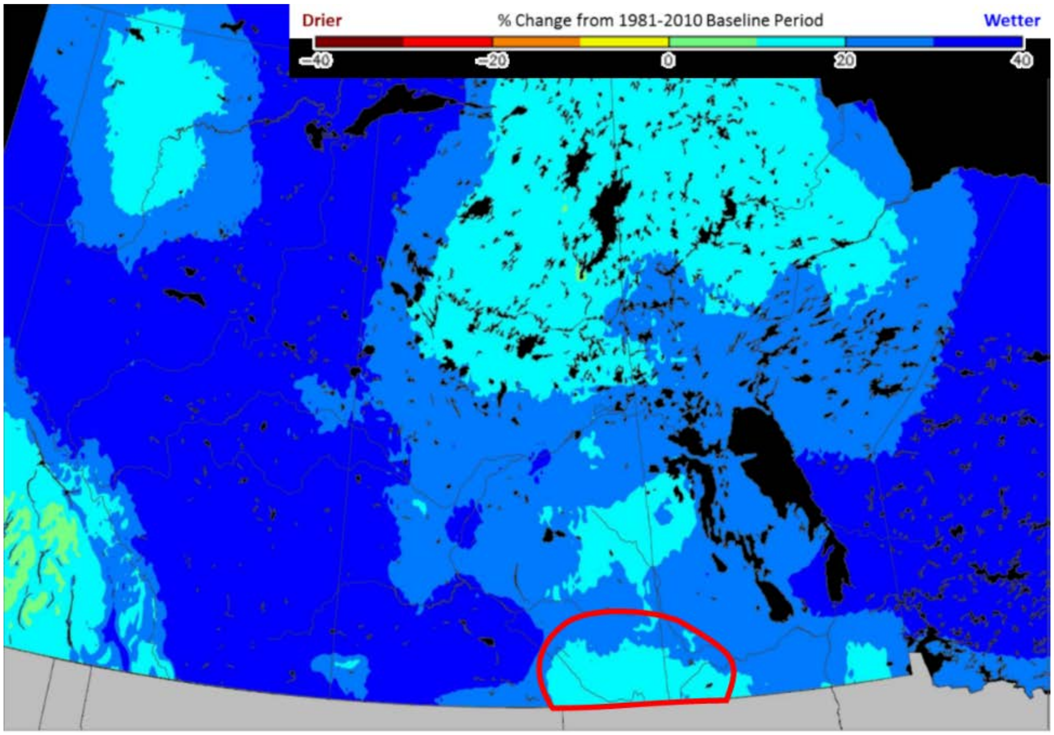


**Figure 35 1981-2010 (Baseline) to 2041-2070 (RCP 8.5 Ensemble) Winter (DJF) Precipitation Change (expressed as percent change from Baseline period) (Smith and Blair 2015DRAFT) Red oval approximately denotes location of Souris River Watershed**

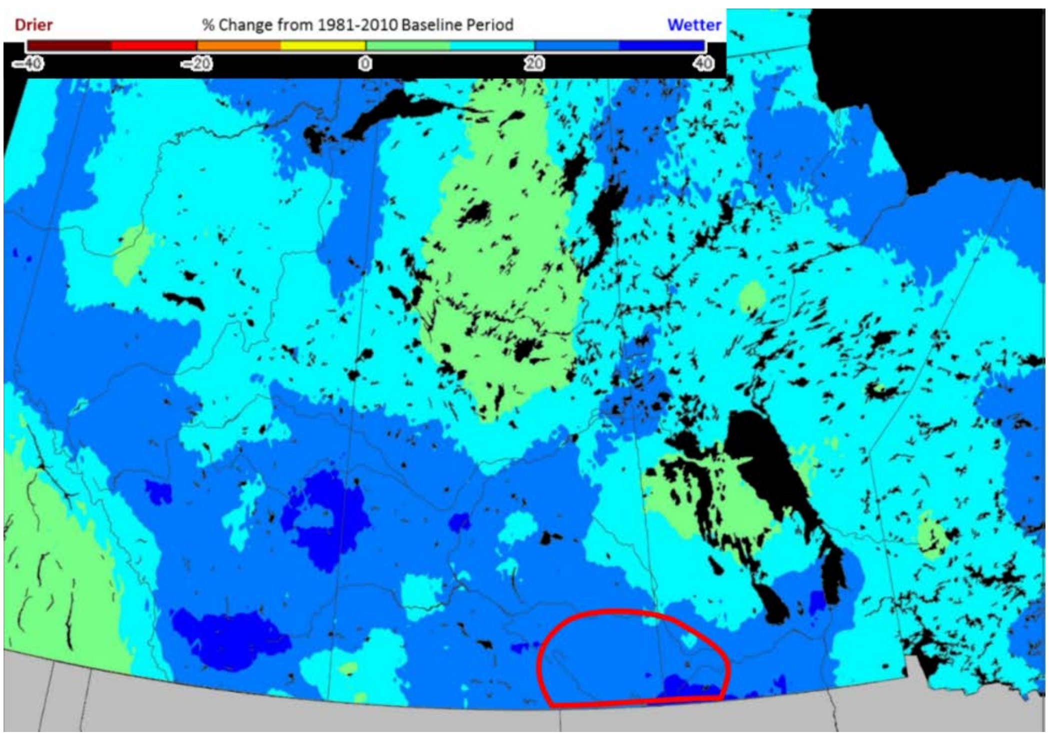


**Figure 36 1981-2010 (Baseline) to 2041-2070 (RCP 8.5 Ensemble) Spring (MAM) Precipitation Change (expressed as percent change from Baseline period) (Smith and Blair 2015DRAFT) Red oval approximately denotes location of Souris River Watershed**

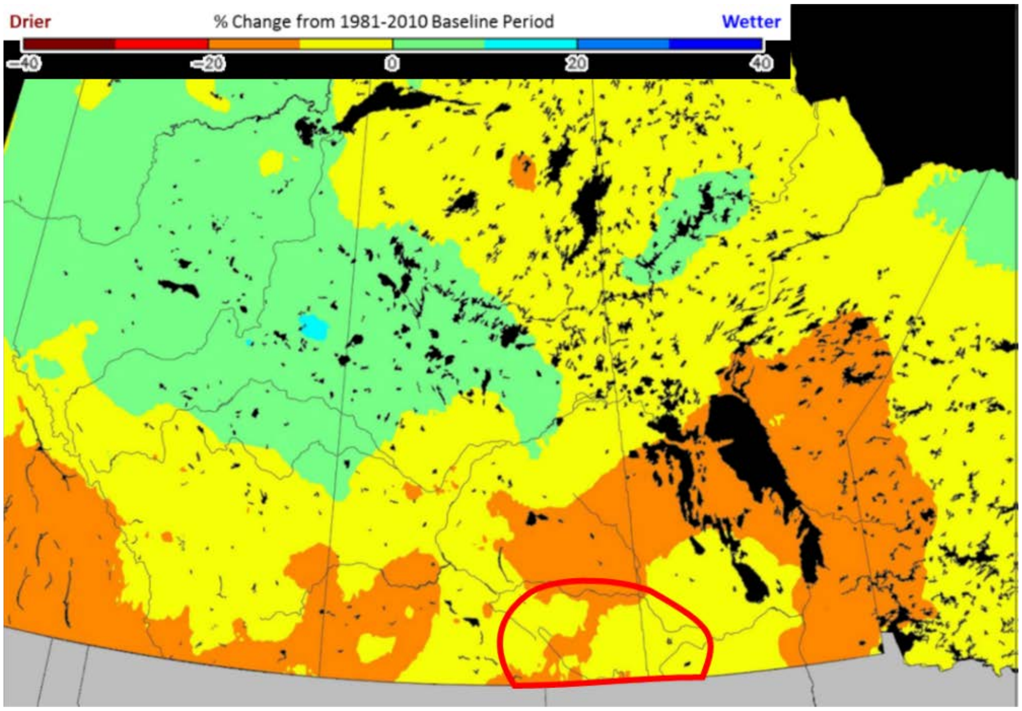


**Figure 37 1981-2010 (Baseline) to 2041-2070 (RCP 8.5 Ensemble) Summer (JJA) Precipitation Change (expressed as percent change from Baseline period) (Smith and Blair 2015DRAFT) Red oval approximately denotes location of Souris River Watershed**

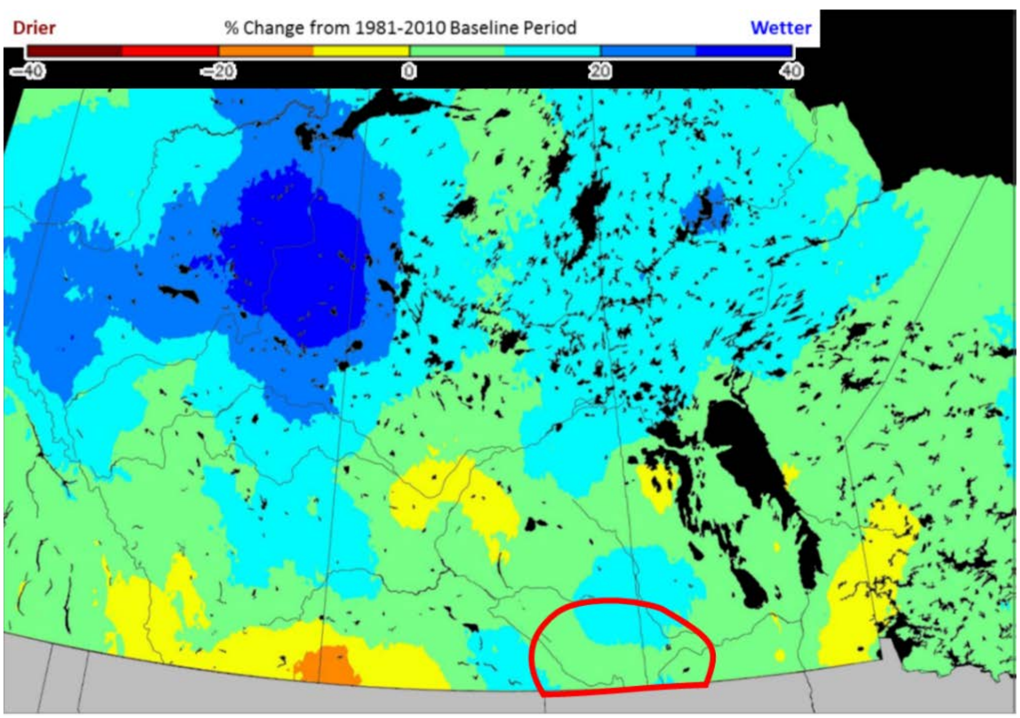


**Figure 38 1981-2010 (Baseline) to 2041-2070 (RCP 8.5 Ensemble) Fall (SON) Precipitation Change (expressed as percent change from Baseline period) (Smith and Blair 2015DRAFT) Red oval approximately denotes location of Souris River Watershed**

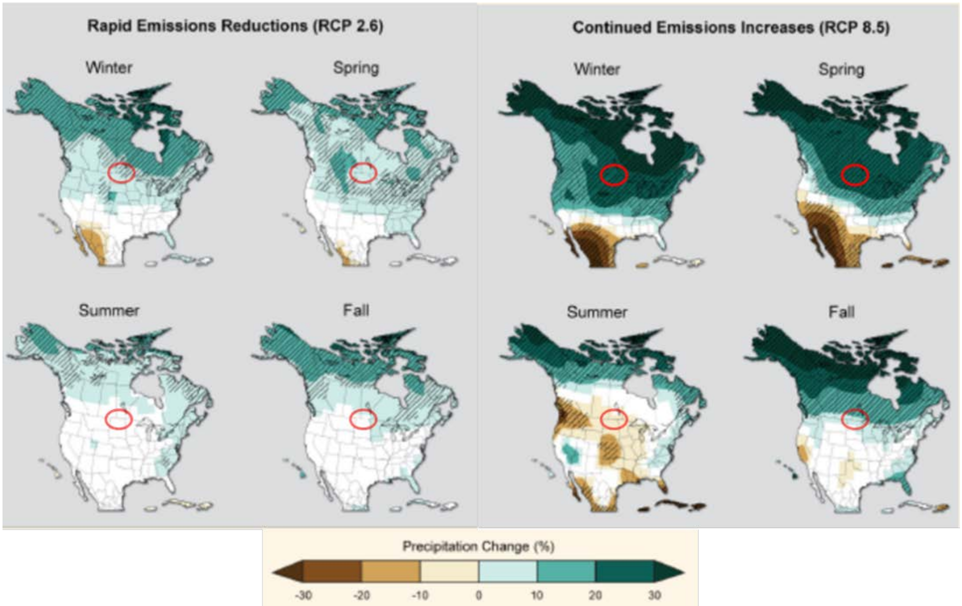


**Figure 39 Seasonal Precipitation Change for 2071-2099 compared with the 1970 to 1999 averaging period. Seasonal maps under RCP 2.6 assume rapid emissions reductions. RCP 8.5 seasonal maps assumee continued increases in emissions. Hatched areas indicate projected changes are significant and consistent among models. White areas indicate precipitation changes are not projected to be larger than expected from natural variability. Simulations are from CMIP5 models (Walsh et al. 2014). Red oval is approximate location of Souris River Watershed.**

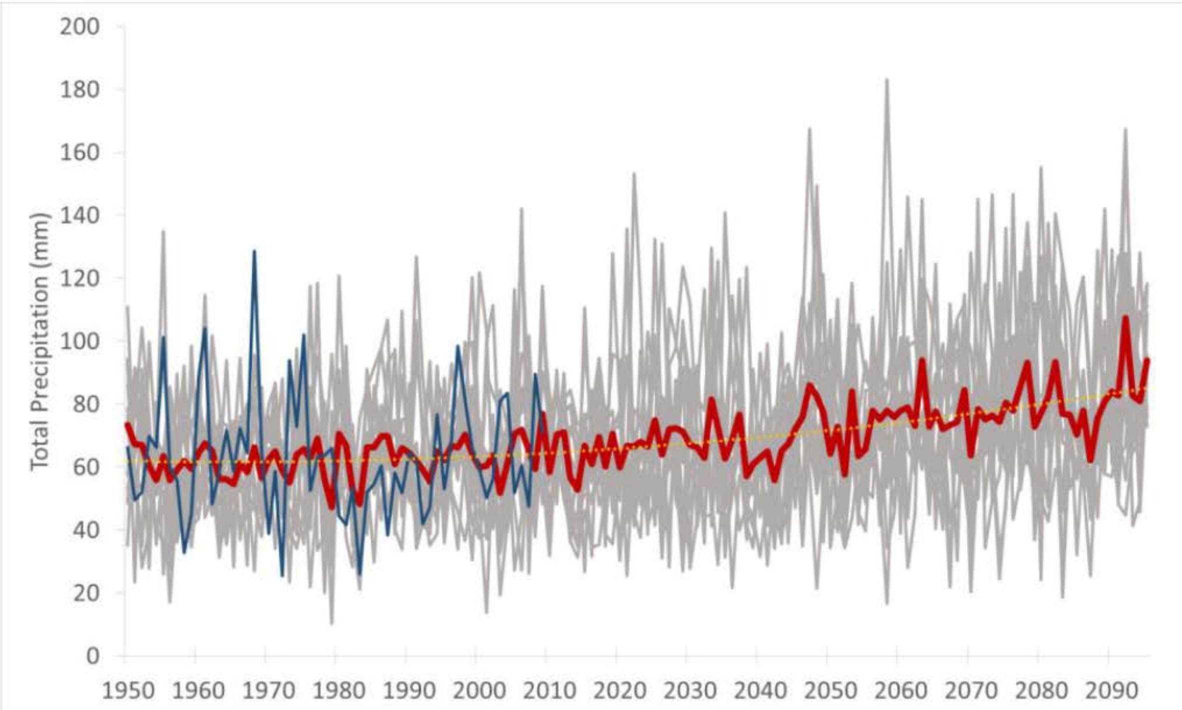


**Figure 40 1950-2095 Observed and Modelled Historic and Future Winter (DJF) Precipitation in Brandon RCP 8.5 Models (gray lines), the Ensemble (red line), and observed data (dark blue line) (Smith and Blair 2015 DRAFT)**

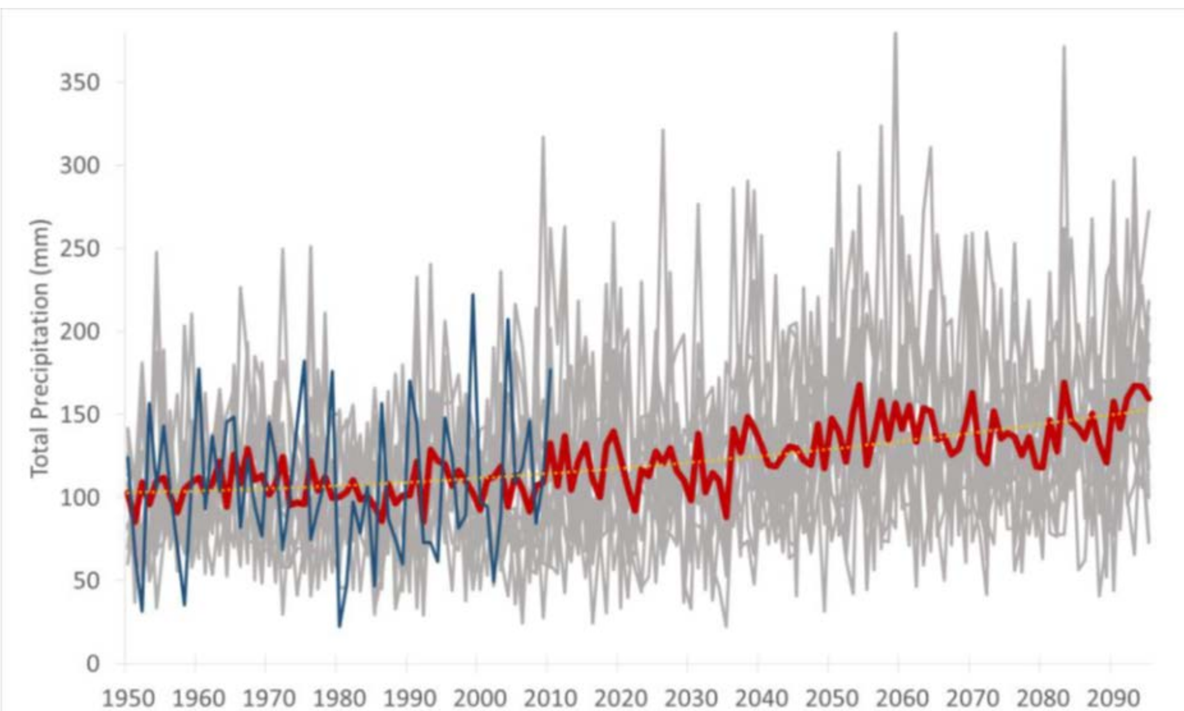


**Figure 41 1950-2095 Observed and Modelled Historic and Future Spring (MAM) Precipitation in Brandon RCP 8.5 Models (gray lines), the Ensemble (red line), and observed data (dark blue line) (Smith and Blair 2015DRAFT)**

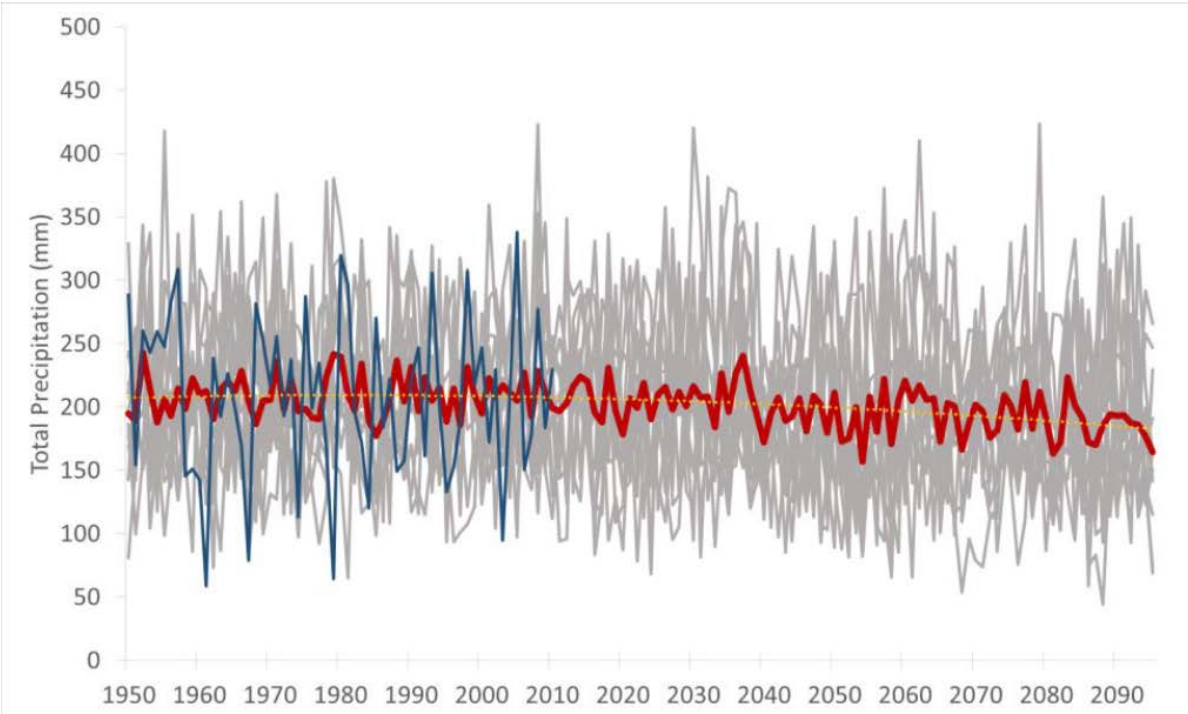


**Figure 42 1950-2095 Observed and Modelled Historic and Future Summer (JJA) Precipitation in Brandon RCP 8.5 Models (gray lines), the Ensemble (red line), and observed data (dark blue line) (Smith and Blair 2015DRAFT)**

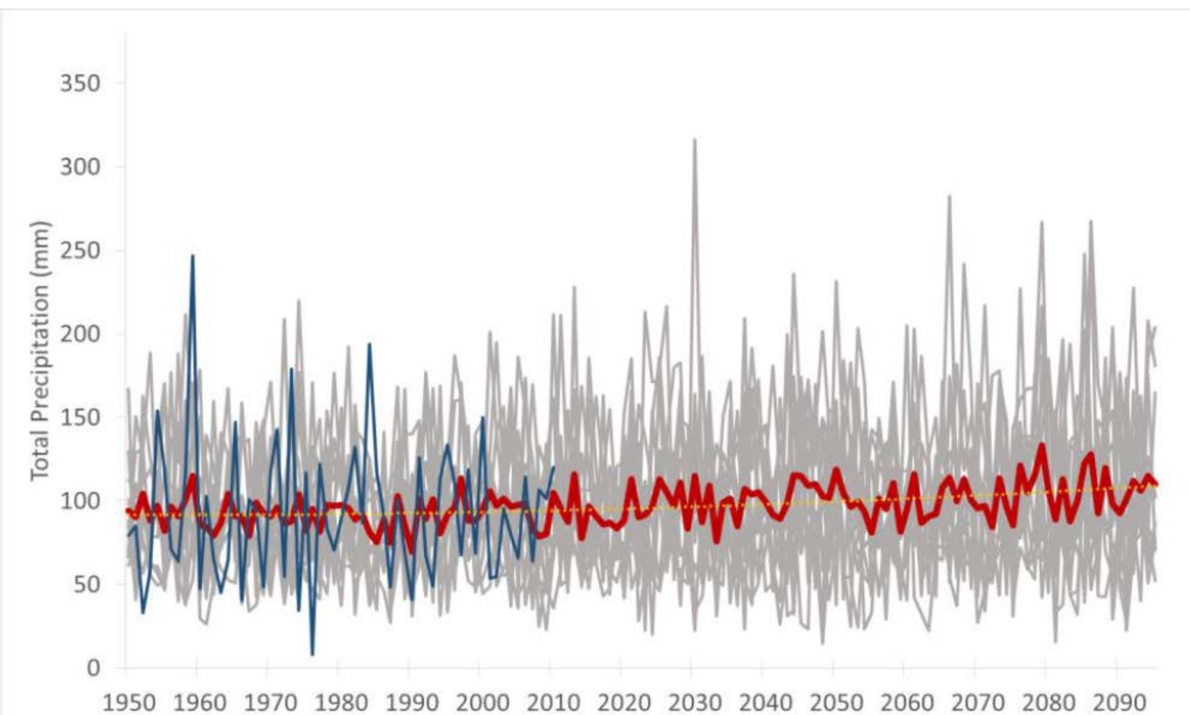


**Figure 43 1950-2095 Observed and Modelled Historic and Future Fall (SON) Precipitation in Brandon RCP 8.5 Models (gray lines), the Ensemble (red line), and observed data (dark blue line) (Smith and Blair 2015DRAFT)**

# Appendix 2 Major Reservoirs along the Souris River in Canada comparing extreme flood year 2011 to typical and historic extreme volume

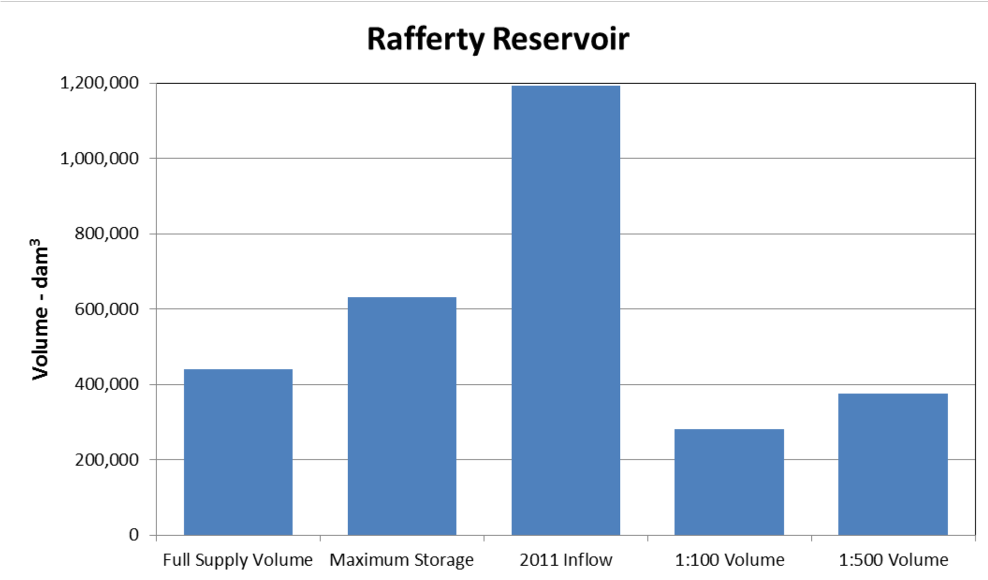


**Figure 44 Rafferty Reservoir 2011 Inflow Volume compared with Storage and Historical Extreme Volumes**

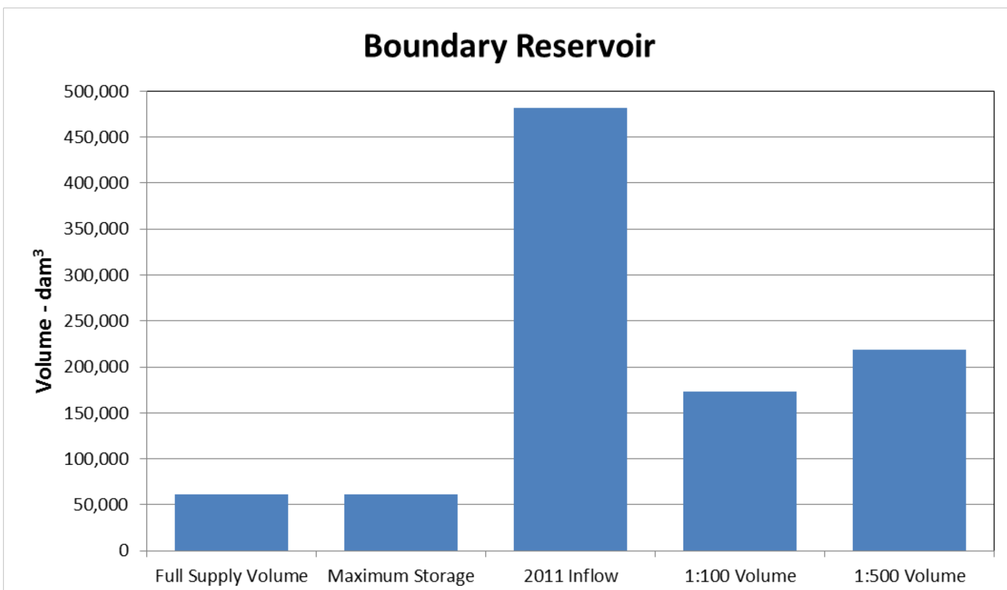


**Figure 45 Boundary Reservoir 2011 Inflow Volume compared with Storage and Historic Extreme Volumes**

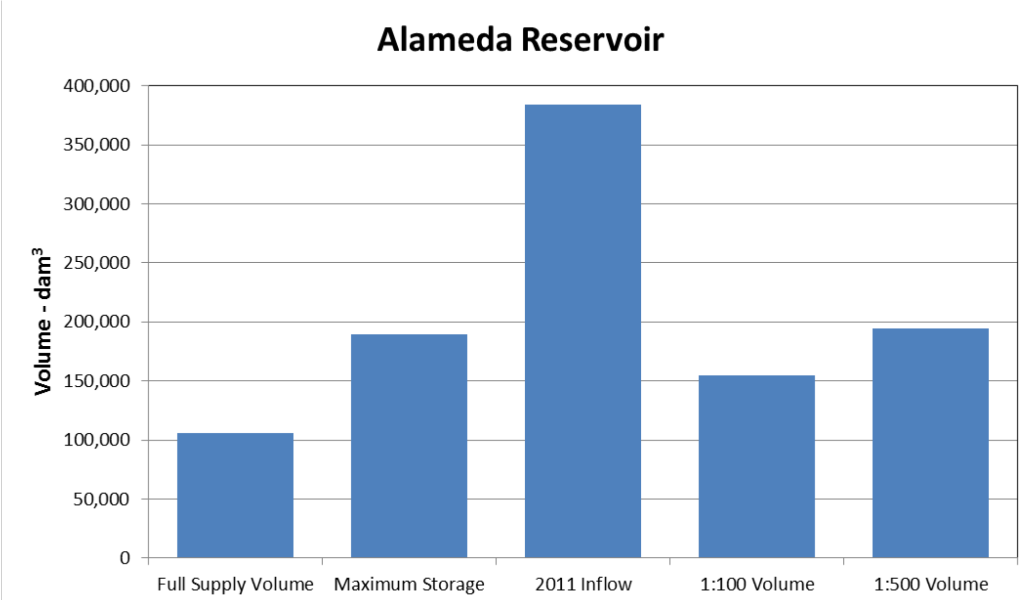


**Figure 46 Alameda Reservoir 2011 Inflow Volume compared with Storage and Historic Extreme Volumes**

# Appendix 3 Roche Percee & Estevan and High Water Conditions

Figure 47 Roche Percee May 3, 2009 (SGIC Imagery) (Hallborg 2012)

Figure 48 Roche Percee - May 14, 2011 dykes holding (Photo: WSA) (Hallborg 2012)


Figure 49 Roche Percee - June 23, 2011 (Photo: WSA) (C. Hallborg 2012)

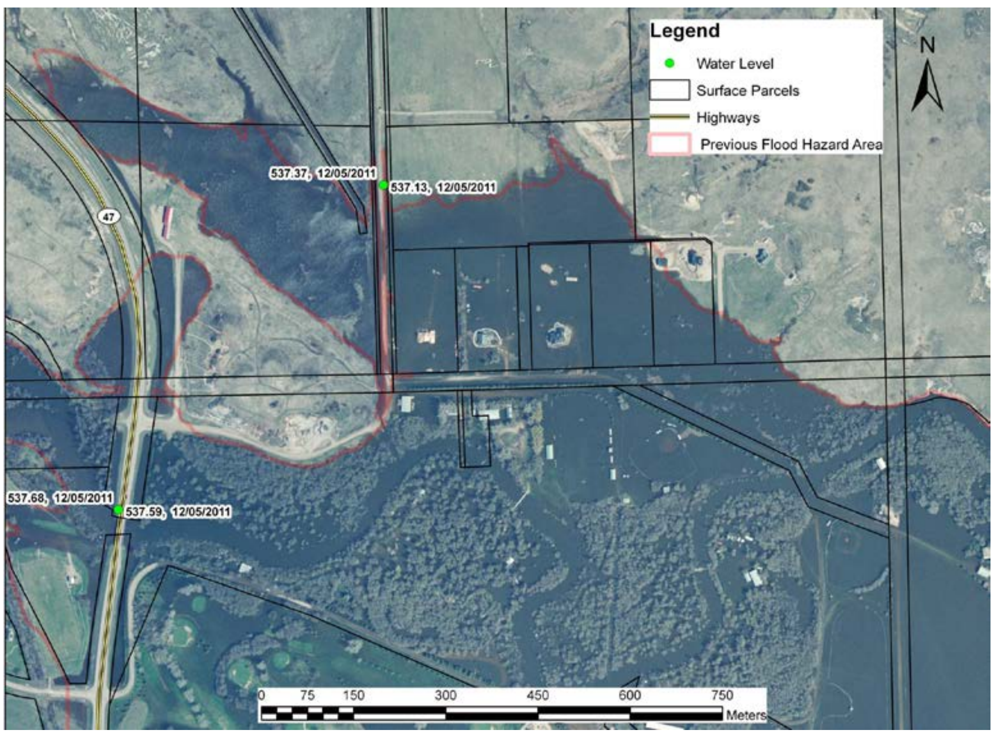

Figure 50 Estevan May 14, 2011 (Photo: WSA) (Hallborg 2012)